PRODUCTIVITY OF RUBBER-TIRED SKIDDERS IN SOUTHERN PINE FORESTS

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ABSTRACT

Sixteen stands were harvested at intensities (proportion of basal area removed) ranging from 0.27 to 1.00. Logging contractors used one or two rubber-tired cable and/or grapple skidders. Harvested sites were similar in slope, tree size, and stand composition. Thirteen of the stands had even-aged structures while the other three were uneven-aged. Skidding time per cycle was directly related to skidder type, distance, and number of stems hauled, and inversely related to harvest intensity. Skidding productivity (grapple skidder, per productive hour) was sensitive to distance, stem size, number of stems in a load, and harvest intensity. Productivity was more sensitive to tree size than harvesting intensity.

Forest engineers, procurement foresters and harvesting contractors are concerned with designing and managing harvesting systems that will extract timber from the forest at low unit costs. This report, the second in a three-part series, centers on the efficiency of ground-based skidding machinery in a wide range of harvesting strategies. The first report (6) focused on felling productivity. These first two reports identify the major components that impact harvesting time and productivity. The third will deal with unit cost and operational profitability.

Harvesting equipment must be kept operating efficiently in order to achieve an acceptable return on the capital investment. Skidding machinery represents the greatest single capital investment for many independent contractors. When this is the case, skidders need to be as productive as possible. Efficiency of skidding operations is dependent on having a skilled operator, a mechanically sound piece of equipment, and a sufficient volume of logs to be skidded, which is influenced by the stand conditions and the harvest prescription. The influences that pre-harvest stand conditions and harvesting prescription have over skidding efficiency are the focus of this paper.

Peters (8) investigated the productivity relationship between number of stems and log size skidded, and Garland (2) identified the general factors that influence the productivity of skidding operations. Greene (3) noted that grapple skidders are generally highly productive components of a harvesting operation. However, most published studies generally addressed only a single harvest method (4,7) and, to date, no one has modeled productivity of skidders working on a variety of harvest prescriptions. There has been a need for studies that cover a wide range of silviculture treatments and contain a large enough data set to identify trends common to harvesting operations (5). An analysis of more than 1,050 individual skidding cycles, on 16 harvesting operations, conducted over 4 years is presented here.

METHODS

STAND TREATMENTS

The harvesting prescriptions in the study ranged from clearcutting to single-tree selection. Proportion of basal area removed was used as an index of harvesting intensity because it was sensitive to both number of trees removed from the stand and average tree size. Stands were located in western Arkansas: 13 on the Ouachita National Forest and 3 on privately owned industry land. The stands were composed primarily of shortleaf pine (*Pinus echinata* Mill.) and loblolly pine (*Pinus taeda* L.). There was a small hardwood component in all stands. The 3 privately owned stands harvested had an

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TABLE 1. — Summary of skidding data variables used in the total skidding time regression equation.

Variable	Cable (alone)			Cable (with Grapple)			Grapple		
	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
Proportion of BA removed	0.27	0.32	0.45	1.00	0.74	0.31	0.27	0.61	1.00
Load volume (ft.^{3})	18.7	77.6	169.3	13.6	71.8	180.6	3.3	88.0	189.0
Stems per load	1	2.7	5	1	3.7	7	1	4.2	14
Horsepower	72	79	98	91	116	120	100	118	130
Skidding distance (ft.)	252	1,131	2,500	292	1,387	3,415	228	1,349	3,444

uneven-aged structure; the other 13 were even-aged.

All stands were cruised before and after harvest to determine the harvest intensities. Diameter distributions from pre-harvest cruises were compared using a Kolmogorov-Smirnov distribution test (9) to insure that all stands could be grouped into a single data set for later analysis.

Trees were manually felled with a chain saw, but directional felling to optimize skidding was not practiced. Trees were processed into tree-length stems by the sawyer immediately after felling. Felling and skidding operations worked in concert in the same general area of the stands at the same time.

Skidding

A complete skidding cycle consisted of travel empty, bunch building, travel loaded, and deck-time. Components of the skidding cycle were timed separately. Distances traveled while empty, building a bunch, and loaded, were measured for each cycle. After the skidder deposited and piled the stems at the deck, the diameter at breast height (DBH) and length of each stem were measured. A random sample of skidding cycles was observed on each stand. Stem DBH and length measurements were used to calculate the average DBH in the load and the total volume of the load. The load volume was the sum of stem volumes, which were calculated[1] using DBH and merchantable length (1).

Total skidding cycle time was estimated separately for each skidder-operation type: grapple skidders, cable skidders operating in concert with grapple skidders, and cable skidders operating alone. Independent variables considered in the analysis included total travel distance, number of stems in the load, average DBH of the stems in the load, volume of the load, harvest intensity, skidder type, and manufacture's advertised draw bar horsepower. A nonlinear equation (*Total time* $= a \times X^b \times Y^c \times Z^d$) was developed for each skidder-operation type using only independent variables that were significant at the 0.01 level.

Nonlinear models for estimating skidding productivity were also developed. These models combined the total skidding cycle time equation with an equation that estimated load volume based on average DBH and number of stems of the load. The load volume equations used the form: $VOLUME = a \times DBH^b \times STEMS^c$. Variation in load volume estimation precluded modeling productivity directly.

Results

The pre-harvest diameter distributions of samples taken compared to the stand distributions using a Kolmogorov-Smirnov distribution test showed that the 16 stands were equivalent and could be grouped into a single data set for analysis. The diameter distributions for the three uneven-aged stands harvested in 1994, while not statistically different from the other stands, displayed more of a "reverse-j" distribution, indicative of uneven-aged stands. The average harvested stem DBH was larger in these stands. This was a function of the uneven-aged selection harvest prescription where the harvested trees were concentrated in the larger DBH classes.

Three operating groups were apparent, based on the skidder type and operation organization. The cable skidders fell into two groups depending on whether or not there was a grapple skidder operating in conjunction with the cable skidder. The presence of a grapple skidder in the operation influenced how the cable skidders were operated and allowed them to be used more efficiently and aggressively. The presence of a cable skidder did not significantly alter the performance of the grapple skidders on the same operation, so all grapple skidder observations were grouped together. Each of the three groups showed different relationships with the independent variables. In the case of cable skidders operating alone, a different set of independent variables was significant.

The independent variables found to be statistically significant at the 0.01 level in estimating total skidding time were: total distance traveled (TDIST in 100-ft. stations), number of stems in the load (STEMS), harvest intensity (INTENSITY), and skidder horsepower (HP). However, INTENSITY was not significant for the cable skidders operating without grapple skidders. Additionally, HP was significant for only this group. **Table 1** gives the range of values observed for the significant independent variables. The cable skidders operating solo had a relatively high volume per load for the average number of stems per load because they were observed on three uneven-aged stands and the average harvested stem DBH was significantly larger on these stands.

The equations listed below estimate total cycle time (TT) in minutes for each of the three groups.

All Grapple Skidders

$$TT = 1.418 \times TDIST^{0.574} \times STEMS^{0.100} \times INTENSITY^{-0.113}$$
$$r^2 = 0.50 \qquad n = 542 \qquad [1]$$

Cable Skidders Operating With Grapple Skidders

$$TT = 2.140 \times TDIST^{0.399} \times STEMS^{0.190} \times INTENSITY^{-0.325}$$
$$r^2 = 0.61 \qquad n = 315 \qquad [2]$$

Cable Skidders Operating Solo

$$TT = 83.626 \times TDIST^{0.453} \times STEMS^{0.295} \times HP^{-0.758}$$
$$r^2 = 0.64 \qquad n = 240 \qquad [3]$$

[1] The individual stem volume equation used on the deck for volume estimation was: Cubic feet = $0.0017\ (DBH^2)^{0.916}\ (\text{Merch. Ht.})^{0.894}$. Based on Clark and Saucier (1).

where:

TT = total cycle time
$TDIST$ = skidding distance in 100-foot stations
$STEMS$ = number of stems in load
$INTENSITY$ = proportion BA removed

The first two equations (grapple skidders and cable skidders operating with grapple skidders) are illustrated in **Figure 1**, where all independent variables except for harvest intensity are held at their mean value. Cable skidders were typically slower than grapple skidders. This was especially true at low harvest intensities. **Figure 2** shows the influence that horsepower had on total cycle time for cable skidders operating without the presence of grapple skidders.

The equations estimating productivity were a combination of the skidder cycle time model and a derived load volume equation. The load volume equation was based on the average DBH of the load and the number of stems within the load.[2] Thus, the combined equations include DBH and a coefficient for STEMS. The r^2 value was not reported because the equation is a combination of two derived equations.

Figures 3 and **4** show productivity surfaces for grapple skidders and for cable skidders operating with a grapple skidder. In these figures, STEMS and TDIST are held at their mean values. The influence of DBH and INTENSITY on productivity is, thus, isolated. Of all the variables in the skidding model, stem size had the greatest impact on productivity across the entire range of diameters observed. The productivity estimating equation indicates that the increased volume in the larger stems (DBH) more than compensated for the additional distance traveled (TDIST) in gathering them. Cable skidders working with a grapple skidder were more sensitive to harvest intensity than grapple skidders. This was due to the fact that, if the stems were widely scattered, the cable skidder operator would not be able to hook up more than one stem each time he got off the machine.

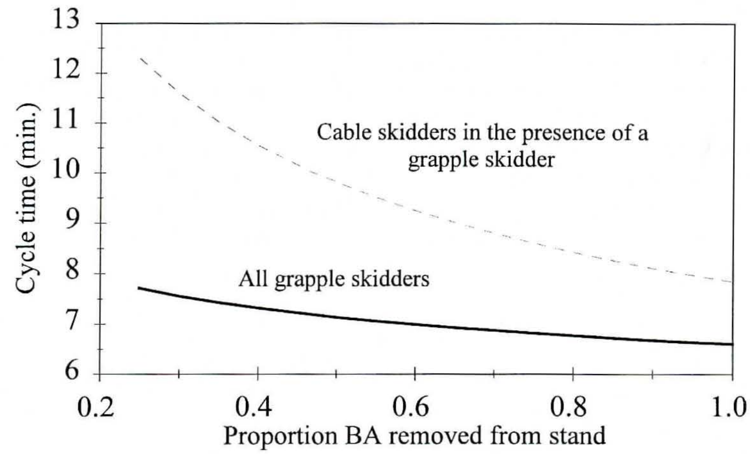

Figure 1. — Total cycle time by harvest intensity for grapple skidders and cable skidders working with grapple skidders.

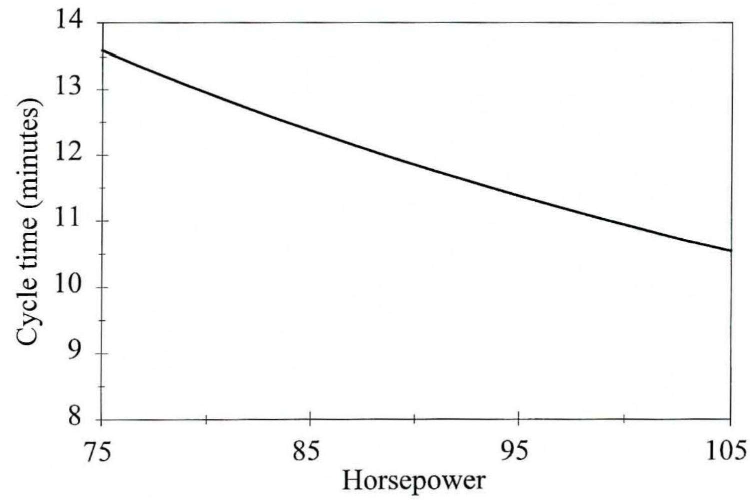

Figure 2. — Total cycle time by horsepower for cable skidders operating independently.

All Grapple Skidders

$$\frac{CCF}{HR} = 0.077 \times TDIST^{-0.574} \times DBH^{2.002} \times STEMS^{0.865} \times INTENSITY^{0.113} \quad [4]$$

Cable Skidders Operating With Grapple Skidders

$$\frac{CCF}{HR} = 0.046 \times TDIST^{-0.399} \times DBH^{2.041} \times STEMS^{0.766} \times INTENSITY^{0.325} \quad [5]$$

Cable Skidders Operating Solo

$$\frac{CCF}{HR} = 0.002 \times TDIST^{-0.453} \times DBH^{1.814} \times STEMS^{0.477} \times HP^{0.758} \quad [6]$$

where:

$\frac{CCF}{HR}$ = productivity in hundreds of cubic feet per hour
$TDIST$ = skidding distance in 100-foot stations
DBH = diameter at breast high of skidded stems
$STEMS$ = number of stems in load
$INTENSITY$ = proportion of BA removed
HP = skidder horsepower

Skidding productivity followed the same general pattern found for felling (first paper of this series). Productivity was highest when large trees were harvested at high intensities, and was more sensitive to DBH than to harvest intensity.

[2] Load volume equations were as follows. All grapple skidders: CCF = 0.181 $DBH^{2.002}$ $Stems^{0.965}$; Cable skidders operating with grapple skidders: CCF = 0.165 $DBH^{2.041}$ $Stems^{0.956}$; Cable skidders operating solo: CCF = 0.289 $DBH^{1.814}$ $Stems^{0.772}$.

The regions identified in **Figures 3** and **4** show where different harvesting prescriptions would fall on the productivity surface. If the stand pre-harvest average stem diameter was 12 inches, the average harvested stem diameter would vary under differing harvest strategies. A clearcut (CC) would have the same average DBH for the pre-harvest stand and the harvested stems (**Fig. 3**); productivity for a grapple skidder hauling 12-inch trees on a clearcut would be 8.79 CCF/hr. For a shelterwood harvest (SH) (60% BA removal), however, the average harvested DBH would be smaller (10 in. DBH) than the average DBH of the pre-harvest stand due to the number of large trees left standing and productivity would be lower (5.76 CCF/hr.). Single-tree selection when used as an uneven-aged management harvesting prescription concentrates harvest on the larger diameter classes even when applied to an even-aged stand. On an even-aged stand, a single-tree selection cut (SE) (40% BA removed) would have a slightly larger average harvested DBH (14 in. DBH), and on an uneven-aged stand (SU) (35% BA removal) it would be much larger (22 in. DBH) than the average pre-harvest stem diameter (12 in. DBH). Estimated productivity for these prescriptions would be 10.79 CCF/hr. and 26.3 CCF/hr., respectively.

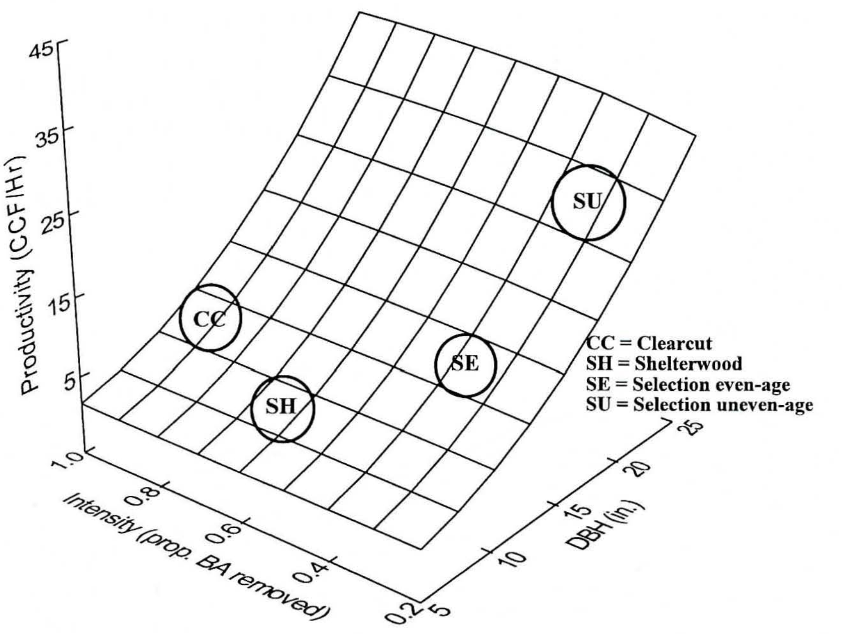

Figure 3. — Productivity (CCF/hr.) by DBH and harvest intensity for grapple skidders.

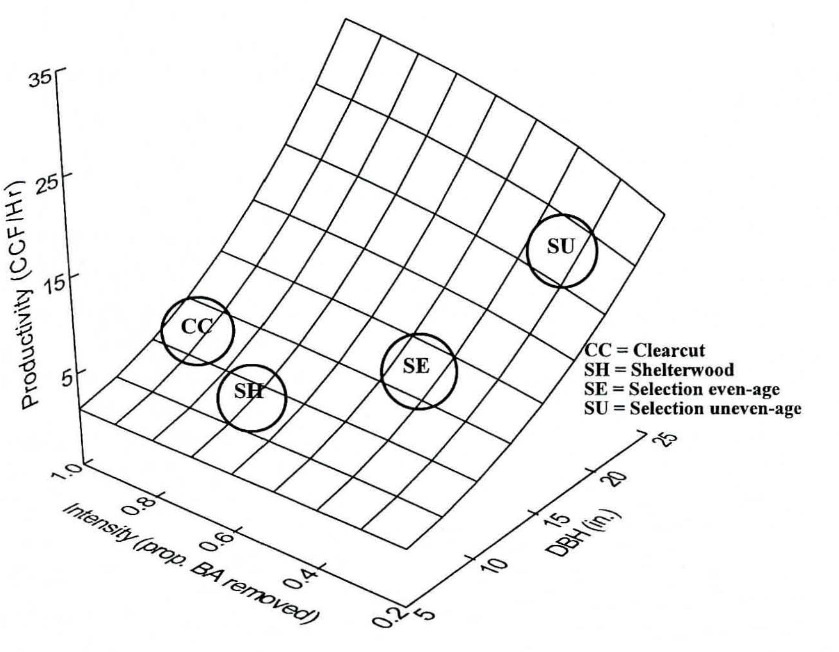

Figure 4. — Productivity (CCF/hr.) by DBH and harvest intensity for cable skidders operating with grapple skidders.

In this study, cable skidders operating solo were not greatly affected by harvest intensity. On these operations, horsepower proved to be a limiting factor. The machines in this type of operation were on the average, smaller and older than those in the other two groups. There were also typically fewer crew members on these operations. There was no grapple skidder present on these operations to motivate the cable skidder operator to try to "keep up" with the grapple skidder. Operations that used only a single cable skidder were more prone to run the skidder less than fully loaded and tended to be less productive than cable skidders working with a grapple skidder.

Productivity for cable skidders operating solo is depicted in **Figure 5** with TDIST and HP held at their observed mean value for this type of operation (**Table 1**). In this graph, the importance of filling all the chokers is shown by the rise in productivity as more stems are included in the load. The figure also emphasizes that it is unreasonable to expect a skidder to pull many large stems in a single load. The overall productivity for cable skidders operating solo was dramatically less than the other two operation types.

Discussion

Grapple skidders

Grapple skidders were consistently faster and more productive than cable skidders on the stands observed in this study. The use of cable skidders did not alter the performance of the grapple skidders in any predictable way. The grapple skidders observed in this study tended to be somewhat larger than the cable skidders, but horsepower did not prove to be a limiting factor on the operations observed.

Cycle time for the grapple skidders was influenced by the harvesting intensity, but varying intensity from 0.3 to 1.0 proportion of basal area removed, only reduced the cycle time by about 1 minute from 7.56 to 6.60 minutes (all other factors being equal). This was due, in part, to the fact that the grapple skidders had to approach every stem individually, so there was not a large difference operationally between closely spaced and widely scattered stems. The difference that did show up was captured by the total skidding distance measure.

The one factor that had the greatest influence on skidding productivity was stem size. This was true for all of the operation types observed. The extra volume of the larger stems increased productivity dramatically across all harvest intensities. The time required to pull large stems was significantly longer than the time required to pull small stems. In fact, total cycle time tended to be less when working with large trees than with small trees because the operator was able to fully load the skidder with fewer stems.

Skidding distance and the number of stems per load, while being greatly influenced by stand characteristics, may be controlled through thorough planing by skilled operators. Locating primary skid roads and landings wisely can dramatically reduce average cycle time. Directional felling (something that was not done on these stands) can also help the skidder be more efficient. The results of this study underscore the desirability of pre-bunching for a grapple skidder.

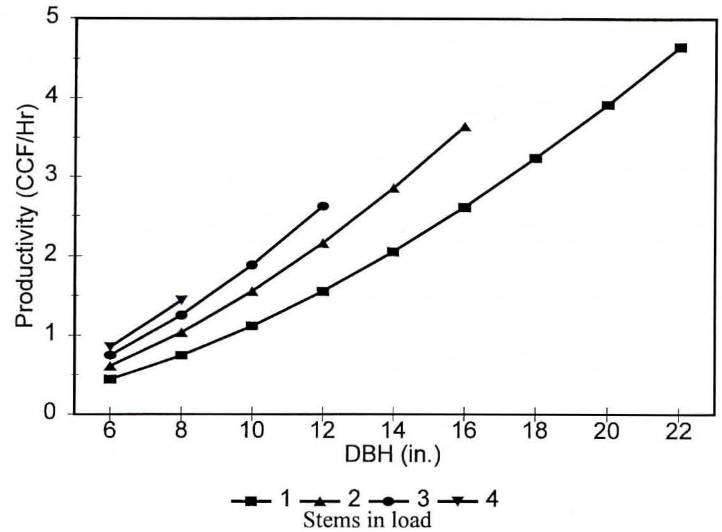

Figure 5. — Productivity (CCF/hr.) by DBH and number of stems in a load for cable skidders operating independently.

Cable skidders operating with grapple skidders

When cable skidders were used in concert with a grapple skidder, the cable skidders were more productive than when operating solo. Areas of the stand where maneuvering around residual trees was difficult could be left for the grapple skidder and the cable skidder could operate where it functioned better. It was observed that the presence of another skidder on the stand also fostered some competition between operators and motivated them to a higher level of productivity.

Harvest intensity had a larger influence on skidder productivity for these machines than for the grapple skidders. This was especially true for stems over 18 inches. When the logs were close together, the operator could choke multiple stems each time he stopped the skidder. If the logs were widely scattered, he had to stop and get off the skidder to hook each stem rather than hooking multiple stems at a stop. Maneuvering in a stand and building a bunch with a large number of residual trees was more time consuming for cable skidders than for grapple skidders. The grapple skidders' ability to control its load while backing up and the option of temporarily dropping a stem in the bunch-building process made grapple skidders more efficient when working around residual trees than the cable skidders.

Gathering multiple stems slowed this skidder type down more than the grapple skidders. The effect of the extra volume in the additional stems was not as high for the cable skidder as that for the grapple skidder (lower coefficient).

Cable skidders operating solo

Two main differences set operations using a single cable skidder solo apart from the other operations. First, harvest intensity was not significant in the final analysis, and second, horsepower was a significant factor. Overall, these operations were the slowest and least productive of the three and were characterized by fewer crew members and smaller machines. It should be stated, however, that the slope of the stands observed in this study were not limiting to the grapple skidders. Stands with steep slopes could be more difficult if not impossible to log using a grapple skidder. Since slope was not a limiting factor for the grapple skidders on any of the operations, the singular advantage of employing a winch line to retrieve stems on steep slopes or across ravines was not an issue. Thus, the comparison here was across gentle to moderately sloping terrain, well within the production limits of the grapple skidders.

The rate at which these operations moved through the stand was slow enough that there was no identifiable benefit to having stems close together. The number of residual trees did not make the operation significantly slower.

Machine size (HP) was a significant factor for this type of operation. In the first two operation types, other factors were more limiting, so horsepower was not significant. The smaller machines, typical to the cable-only operations, were pushed to their limits and a little more power increased the productivity markedly.

Harvesting in even-aged versus uneven-aged stands

Regions on the productivity surfaces in **Figures 3** and **4** identified how stand structure and harvesting prescription can influence operation productivity. The trees removed from an even-aged stand will vary depending on the harvesting prescription, but the magnitude of this variation is limited by the fact that most of the trees in the stand are similar to one another. An uneven-aged stand has a much broader range of stem sizes, so a single-tree selection harvesting prescription can greatly increase skidding productivity by harvesting just the larger diameter classes. This can occur in spite of the lower harvesting intensities.

Harvests designed to begin a conversion process from an even-aged stand to an uneven-aged stand will typically be less productive than an even-aged harvesting method (i.e., clearcutting). This is due to the low harvest intensities associated with selection harvests and the lack of large-diameter trees available to improve productivity.

Conclusion

Skidding efficiency is influenced by many factors. Some of these factors can be controlled by the operator, but many are outside of the operator's control. The better the operator understands how different factors influence the skidding operation, the better he will be at planning and organizing his operation.

Stem size was the most important factor in determining skidder productivity. Harvest intensity also played a role when the skidders were running as efficiently as possible. Average skid distance and number of stems per load (two factors that can be partially controlled by the operator) also determined skidding productivity. In operations where the crews used smaller machines by themselves, skidder horsepower was a limiting factor. The interactive nature of these factors is emphasized in the structural form of the regression format that was found to best fit the data.

The next step in this analysis will be to combine information learned about skidding operations and felling operations together with cost and value information to determine total harvesting costs. The next research question is to explain how the factors that impact harvesting productivity affect harvest profitability. This is the focus of the final paper of this series.

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