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ECONOMIC COMPARISONS OF HAUL ROAD CONSTRUCTION VERSUS FORWARDING VERSUS LONGER SKID DISTANCES

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SUMMARY:

There currently exists no set of basic guidelines for Appalachian loggers to use in the decision making process for selecting the best way to harvest a tract of timber. Specifically, guidelines are needed for deciding between the alternatives of constructing truck haul roads to access an area or other alternatives such as skidding or forwarding timber longer distances, thereby limiting road construction costs. The results of this study indicate that several interrelated factors influence the choice of system to be used. These factors include road building costs, harvest volumes, skid distances, and machine operation costs.

KEYWORDS:

Timber harvesting, Economics, Skidders, Forest roads, Forwarders

The final step in the stump to landing extraction process is to transport the felled timber from the felling location to the landing. The transporting of felled timber is most often carried out by rubber-tired skidders which are by far the most commonly utilized machines. Although alternative means of transporting felled timber exist, including cable yarding systems, tracked skidders, grapple skidders, and forwarders, the rubber-tired cable skidder in the medium to large size class is still king and dominates this part of the operation in the Appalachian region.

Although the typical logging operation begins with the construction of haul roads for log truck access, this may not always be the most economically sound beginning to a harvest operation. In the Appalachian region, haul road construction can often times be a time consuming and costly undertaking. Because of the mountainous and often rocky terrain in conjunction with deep narrow drainages, forest road construction costs can often run into the thousands and even tens of thousands of dollars per mile depending on road standards and terrain characteristics. In a study involving cost estimators for the construction of forest roads in the central Appalachians, it was found that construction costs per mile averaged $11,104 for roads constructed with equipment on an hourly rental basis, and $68,385 per mile for roads constructed on a total job bid basis on National Forest lands in West Virginia (Layton et al. 1992). Kochenderfer et al. 1984, found that costs to construct "minimum-standard" truck roads in the same general area averaged $8,119 per mile. Surfacing roads with 4 inches of gravel will commonly add an additional $10,000 per mile.

Although roads are costly to build, forest managers for the most part agree that access is necessary before forest lands can be managed. In Appalachia, road-building costs often are high relative to timber values. Often times tract volume or value is too low to allow a commercial harvest usying traditional harvesting techniques. Under these conditions it is difficult to build truck roads that provide efficient access at an acceptable cost without creating situations which lend themselves to harming other resources in the forest environment (Kochenderfer and Helvey 1987).

One possible alternative which may be used where road construction costs may limit the feasibility of a harvest operation is the alternative of either forwarding the felled timber with a forwarder, or simply skidding the timber a longer distance to landings located further away from the harvest unit, thereby reducing the amount of haul road which must be constructed. Although road construction costs will be reduced by using such an approach, there are tradeoffs in that forwarding or skidding costs will increase due to the longer distances and longer cycle times from stump to landing. Information is lacking on just how these two alternatives react in the form of system productivity and costs. It is thought that at some given road construction cost level that an equal dollar amount of skidding or forwarding could be performed without changing the overall stump to landing cost. It is also believed that if harvest volumes are low and road costs are high, skidding or forwarding a longer distance may well be the most effective way to approach the operation. At some point when harvest volumes become high enough, the savings attributed to reduced road construction costs may no longer offset the increases in skidding or forwarding costs due to the number of trips and associated cost of skidding or forwarding the longer distance. The remaining question and the focus of this study, is under what combination of road costs and forwarding or skidding productivity levels is it best to build roads or skid longer distances.

STUDY OBJECTIVES

There currently exists no set of basic guidelines for Appalachian loggers to assist them in the decision-making process for selecting the best alternative for harvesting a particular tract of timber. Specifically, guidelines are needed for deciding between the alternatives of constructing truck haul roads to access an area, and other alternatives such as either skidding or forwarding timber longer distances to reduce the length of haul road which must be constructed. In certain situations the best alternative may very well be to forego bidding on a given tract due to economic and other constraints which preclude a site from being economically or otherwise harvested.

This study seeks to begin the development process of a first-level model which is easy-to-understand and use by timber operators for assessing the most effective and economical way to harvest a particular tract of timber. Three methods of timber extraction, including constructing truck haul roads, skidding longer distances, and forwarding timber were examined. The results of this investigation along with other research can then be refined, over time, to reflect a more comprehensive set of variables, conditions, and constraints from which to base further guidelines and recommendations on the most efficient and cost effective harvesting technique to utilize.

METHODS

Data compiled for the investigation was collected from a number of loggers and or road contractors conducting commercial logging operations or building haul roads for harvest operations in north central West Virginia and southwestern Pennsylvania. All operations were in Appalachian hardwood timber stands under terrain, soil, and stand conditions typical to the central Appalachian region. Since the underlying question in this investigation is to determine and compare productivity and costs with respect to different techniques of getting harvested timber from the stump to a landing, data for four primary functions needed to be collected: road-building, skidding, forwarding, and skid trail construction costs.

ROAD CONSTRUCTION

One of two situations are typically encountered when constructing haul roads. The first is where the road construction activities are contracted out to a firm or individual where their sole function is to construct the road and does not involve any other harvesting activities. Road construction costs under this scenario are generally charged by applying an hourly rate for the equipment and operator for the time spent constructing the road. The second situation is where a logging contractor uses his or her own equipment and labor force to perform the road-building activities. Under this scenario it is not uncommon for the same piece of equipment used in building the road to be used concurrently for other activities during the construction phase. The equipment is often used to assist with harvesting right-of-way timber, and can often times be less productive in constructing the road due to delays associated with other activities taking place at the same time and place as the construction process itself.

For the purposes of this study, time and motion study techniques were used during the construction phase for four truck haul roads constructed under conditions typical to the region.

Two roads were constructed by road building contractors at an hourly rate, while the remaining two roads were built by the logger using his own equipment. Throughout the road construction process for each of the four roads, complete continuous time and motion data was collected for the equipment used for building the road. The data included both productive and delay time elements. From the recorded data the actual number of productive and scheduled machine hours which were required to construct the roads were calculated. In order to keep the cost calculations standardized for both the contracted and total job based roads, a machine rate procedure was used to calculate construction costs for both classes based on the equipment used (Miyata and Steinhilb 1981). The cost calculation includes only the cost of equipment (fixed and operating) and labor, and does not allow for any profit which may have been built into the hourly rate charged under the contractor roads.

In addition to the time study data, measurements were also taken on the road itself in order to describe the site and finished road characteristics. These measurements included such things as road length, grade, cut and fill amounts, side slopes, number of dips and culverts installed. Figure 1, includes a description of each road along with the calculated construction cost.

	Road 1	Road 2	Road 3	Road 4
Dozer type	Cat D6	JD 750	Cat D7	JD 750, JD 455
Road length (ft)	0.86	0.47	0.68	0.42
Avg. width (ft)	15.4	15.3	20.4	17.6
Avg. grade (%)	8.9	11.4	6.8	4.2
Avg. cut height (ft)	4.0	3.3	5.0	3.6
Avg. side slope (%)	27	29	28	25
No. culverts	1	2	0	4
No. broad based dips	3	0	13	0
soil cut/fill (yds)	4186	1642	4777	1841
Cost per mile ($) [a]	2362	2769	3408	4974

a Based on machine rate cost approach.

Figure 1. Characteristics and costs of truck haul roads.

SKIDDING and FORWARDING

Skidding and forwarding activities include those operations associated with transporting felled timber from the stump to the landing where it can then be loaded onto trucks and delivered to a mill. Skidding activities include four primary productive elements along with any number of delay elements. The primary productive elements include: travel unloaded from the landing to the hooking site, the hooking phase of setting chokers and winching logs to the skidder, skidding the hooked timber from the hooking site to the landing, and unhooking and decking skidded timber in the landing. Forwarding activities are similar to skidding and include those operations associated with transporting felled timber from the stump to the landing. Forwarding activities also include four primary productive elements along with any number of delay elements. The primary productive elements include: travel unloaded from the landing to the loading site, loading the bunk of the forwarder with felled and bucked logs, travel loaded from the loading site to the landing, and unloading timber from the forwarder bunk in the landing.

It has been assumed that the approach to skidding and forwarding does not differ with respect to skid distance. That is, regardless of the distance, the operator always attempts to maximize turn volume and productivity. Skidding and forwarding will be the only component of the harvest operation to be affected by additional haul road construction. Distance will have no effect on felling productivity or costs. Neither will additional haul roads have an effect on felling productivity or costs. Also, we have assumed that once the trees are transported to the landing, the effect of longer skidding or forwarding distance versus longer haul road construction is irrelevant.

Skidding data was obtained from two logging jobs. Both jobs were operating under similar conditions, and both used John Deere 640D machines to skid the felled timber. A total of 760 skidding cycles were included in this study, 45 from one operation and 715 from the other. Again, complete continuous time and motion data was collected for the skidding cycles used in the study and included both productive and delay time elements, as well as other turn cycle parameters including skid distance, number of stems skidded, turn volume, and other important variables. From the skidding time study data regression analysis was performed to develop a model which could be used in the analysis of productivity and costs of skidding at different distances from stump to landing.

Similar time study data was collected from 4 logging jobs running forwarders to transport felled timber from the stump to the landing. Data from two different forwarders were included in the study. The forwarder used on site 1 was a Timberjack 230, 8-ton forwarder, while the forwarders used on the other 3 sites were Blondin 750 mod. 600 FD machines. A total of 31 forwarder cycles is included in the analysis. Again, regression analysis was run on the data to develop a model from which to predict forwarding productivity levels and costs at different distances from stump to landing.

SKID TRAIL CONSTRUCTION

In order for skidding and forwarding equipment to operate safely and effectively in the often steep and rocky terrain of the central Appalachians, skid trails are often constructed. The construction of skid trails generally involves blading a path with a dozer down to mineral soil which is relatively level with respect to the contour of the ground. If haul road construction is minimized then additional skid roads must be pushed in to make up for the distance to the landing not covered by haul roads. The cost of pushing in additional skid roads to the landing was determined based on time study data collected of the construction of 17 variable length skid trails. From this data an average construction rate and corresponding cost was calculated for roads pushed in with a JD 750 dozer. Based on the data from the 17 skid roads, skid road construction costs averaged $5.33 per 100 feet of length.

RESULTS

SKIDDING AND FORWARDING

Skidding productivity levels and associated costs were determined from the data collected from the two skidding operations. Figure 2 shows the breakdown of total skidding cycle time for both sites as well as the pooled skidding data with mean values shown for each of the individual time elements. Figure 3 shows the average percent of total cycle time each of the individual elements occupies based on the pooled data of 760 skid cycles. From the graph we can see that on average 20%, 31%, 19%, and 14%, of total cycle time is taken up by the outrun, hooking, inrun, and landing elements, respectively. In addition to these four productive elements, 17 percent of total cycle time is consumed by some sort of delay element. Table 1 further summarizes the skidding activities and shows that for the pooled data skidding productivity was 541 cubic feet of wood skidded per productive machine hour.

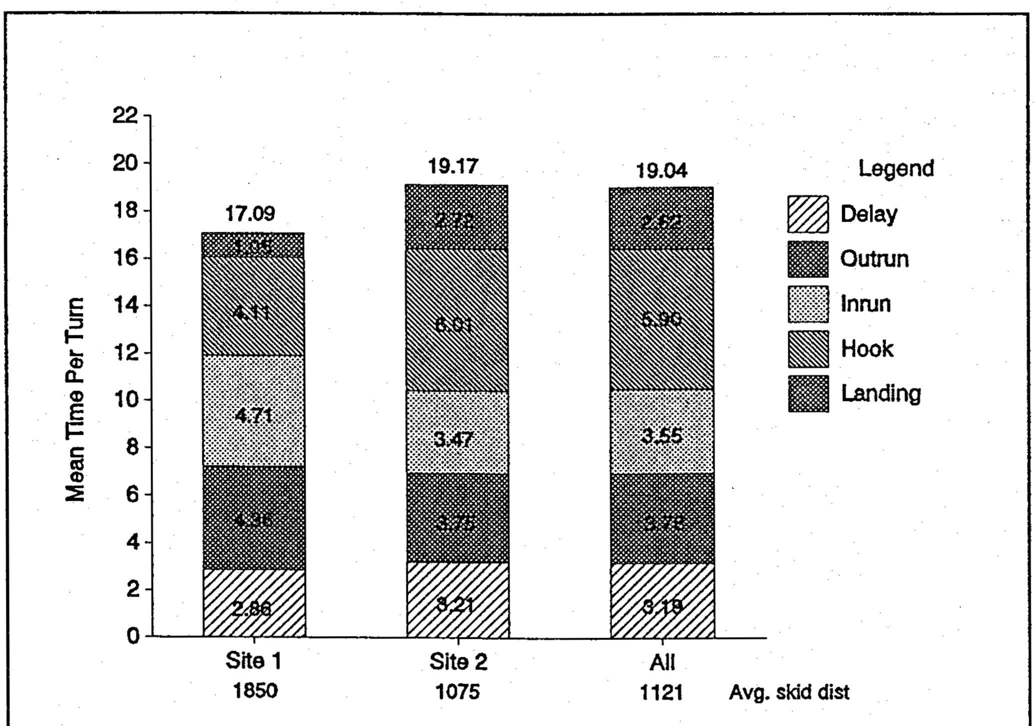

Figure 2. Skidding cycle time breakdown by element class.

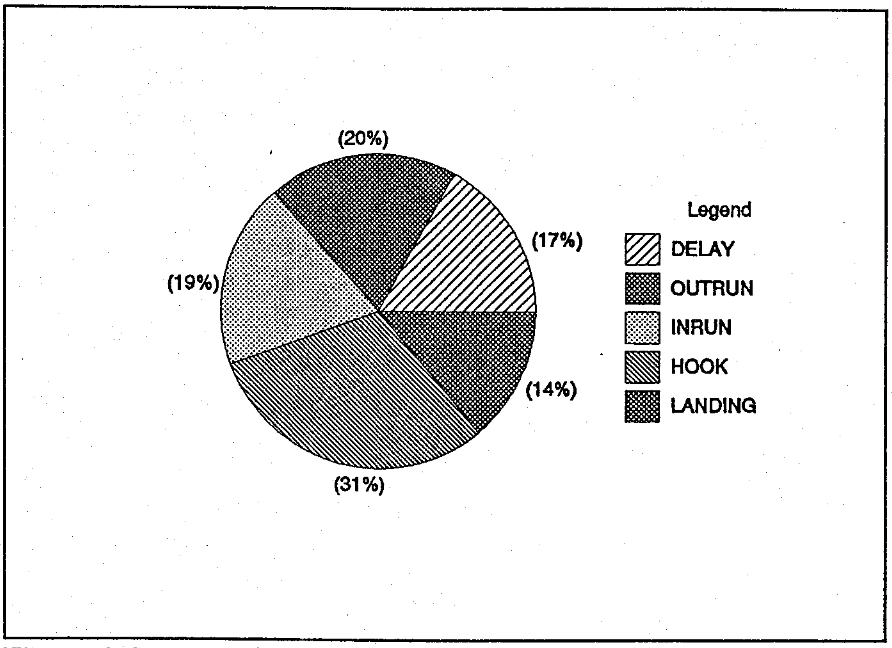

Figure 3. Percent of total cycle time by skidding element class.

Table 1. Performance summary for skidding.

	Site 1	Site 2	All
No. Trips Observed	45	715	760
Avg. 1-way distance (ft)	1850	1075	1121
Range (ft)	823-3568	200-2187	200-3568
Avg. travel speed empty (ft/min)[a]	371	304	308
Range (ft/min)	178-594	27-900	27-900
Avg. travel speed loaded (ft/min)	404	321	326
Range (ft/min)	236-558	68-875	68-875
Avg. volume per trip (ft^3)	131.6	143.8	143.1
Range (ft^3)	51-265	22-391	22-391
Avg. no. logs per trip	3.6	4.4	4.4
Range	2-5	1-9	1-9
Machine utilization (%)	83.3	83.2	83.2
Productivity (ft^3/PMH)	555.1	540.6	541.4

[a] Includes machine turnaround and positioning time.

Forwarding productivity levels and costs were also determined from the time study data collected. Figure 4 shows total forwarding cycle time for each site, as well as the pooled data by element class. Figure 5 shows the average percent of total cycle time for each of the individual elements, based on the pooled data of 31 cycles. From the graph we can see that the percent of total cycle time occupied by each element is very similar to that of skidding with 20%, 33%, 15%, and 13% of total cycle time taken up by the outrun, loading, inrun, and unloading elements, respectively. In addition to the four productive elements, 25 percent of total cycle time was consumed by delay activities. Table 2, further summarizes the forwarding function and shows that on average for the pooled data productivity is 375.7 cubic feet of wood forwarded per productive machine hour.

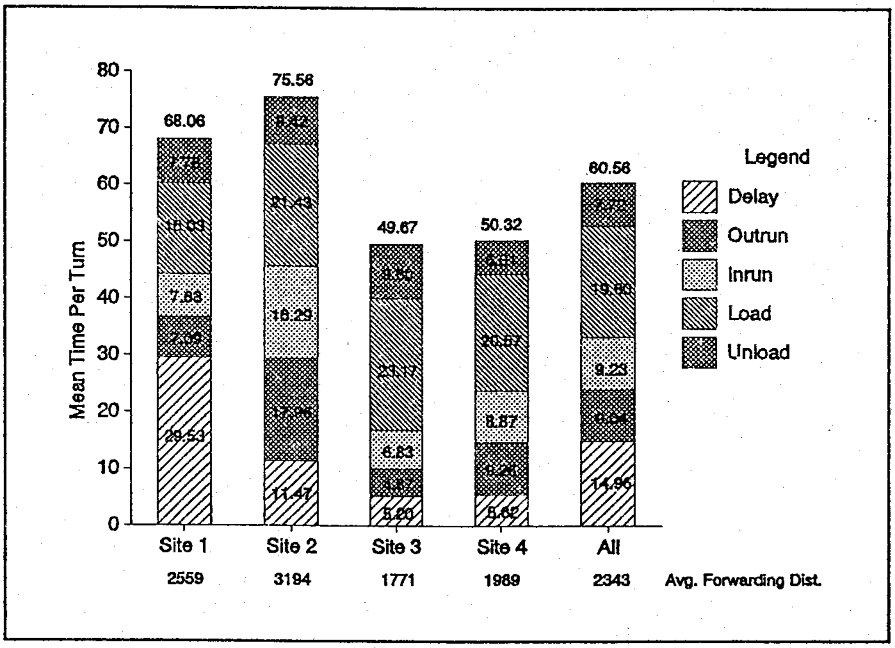

Figure 4. Forwarding cycle time breakdown by element class.

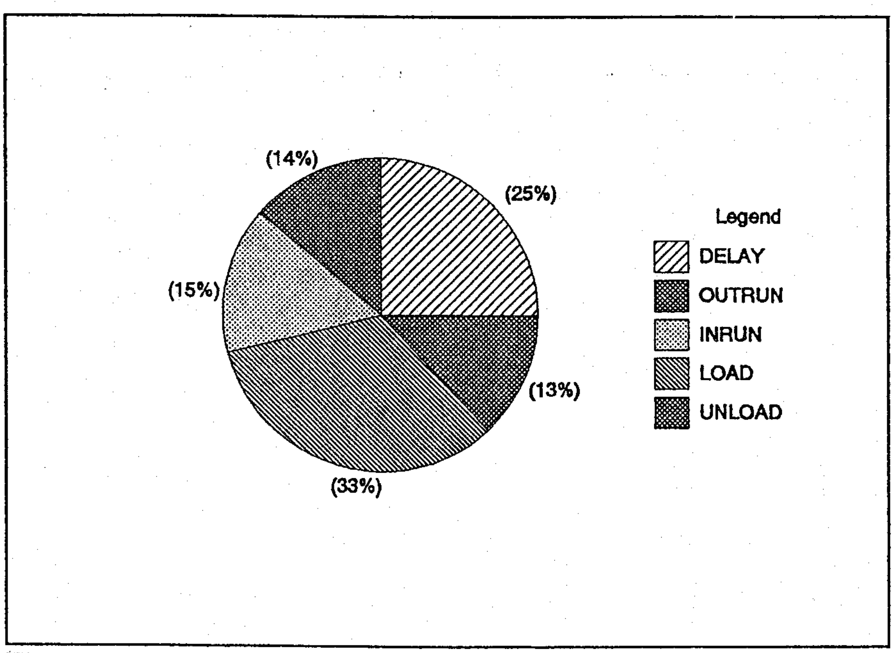

Figure 5. Percent of total cycle time by forwarding element class.

Table 2. Performance summary for forwarding.

	Site 1	Site 2	Site 3	Site 4	All
No. Trips Observed	11	5	6	9	31
Avg. 1-way distance	2559	3194	1771	1989	2343
Range (ft)	2164-2889	2888-3512	1650-2010	1464-2516	1464-3512
Avg. travel speed empty[a]	438	182	338	212	312
Range (ft/min)	414-458	132-213	271-364	131-268	130-458
Avg. travel speed loaded	396	178	257	212	281
Range (ft/min)	358-427	165-188	230-277	142-263	141-427
Avg. volume per trip	285.5	225.0	354.5	321.8	299.6
Range (ft^3)	228-353	128-297	256-393	320-336	128-393
Avg. no. logs per trip	22.5	21.8	24.7	40.1	27.9
Range (ft^3)	14-32	14-28	22-27	24-66	14-66
Machine utilization (%)	56.6	84.8	89.5	88.8	75.3
Productivity (ft^3/PMH)	444.6	210.6	478.3	431.8	375.7

[a] Includes machine turnaround and positioning time.

Multiple regression techniques were used to develop models to predict skidding and forwarding cycle times from which predictions could be made for different distances from stump to landing. For both the skidding and forwarding, the resulting productive cycle time models were based on the pooled data. Although two different forwarders were used on the harvesting jobs, machine differences did not significantly influence the regression. Therefore, all forwarding data was pooled before modeling the system. Both equations used the same set of independent variables which included maximum 1-way skid or forwarding distance, turn volume, average log volume, and a bunching dummy variable. Average log volume for skidding was the average volume of tree length material skidded, while average log volume for forwarding was the average volume of the bucked logs loaded onto the bunk of the machine. The bunching dummy variable was included since cycle times were significantly reduced when materials were prebunched in the woods for both the skidding and forwarding operations. The resulting regression models are as follows:

Skidding DFCT = 10.5 - 3.08*X1 + 0.00431*X2 + 0.0119*X3 - 0.0240*X4

Forwarding DFCT = 29.6 - 14.3*X1 + 0.0110*X2 + 0.0045*X3 - 0.435*X4

where:

DFCT = Delay free cycle time
X1 = Bunching dummy variable (0=no, 1=yes)
X2 = Maximum 1-way distance
X3 = Turn volume (cuft)
X4 = Average log volume

Figure 6 was created using the above regressions and changing the distance variable in 500 foot increments while maintaining the other independent variables at their mean values from the respective data sets. The graph shows that as distance is increased the resulting delay free cycle time also increases with the slope of the forwarding model steeper than that of the skidding model. This indicates that as distance increases so does cycle time and in turn cost to skid or forward material to the landing. By changing only the distance variable and maintaining the others at their mean values, the sensitivity of the equations with respect to this single parameter can easily be seen.

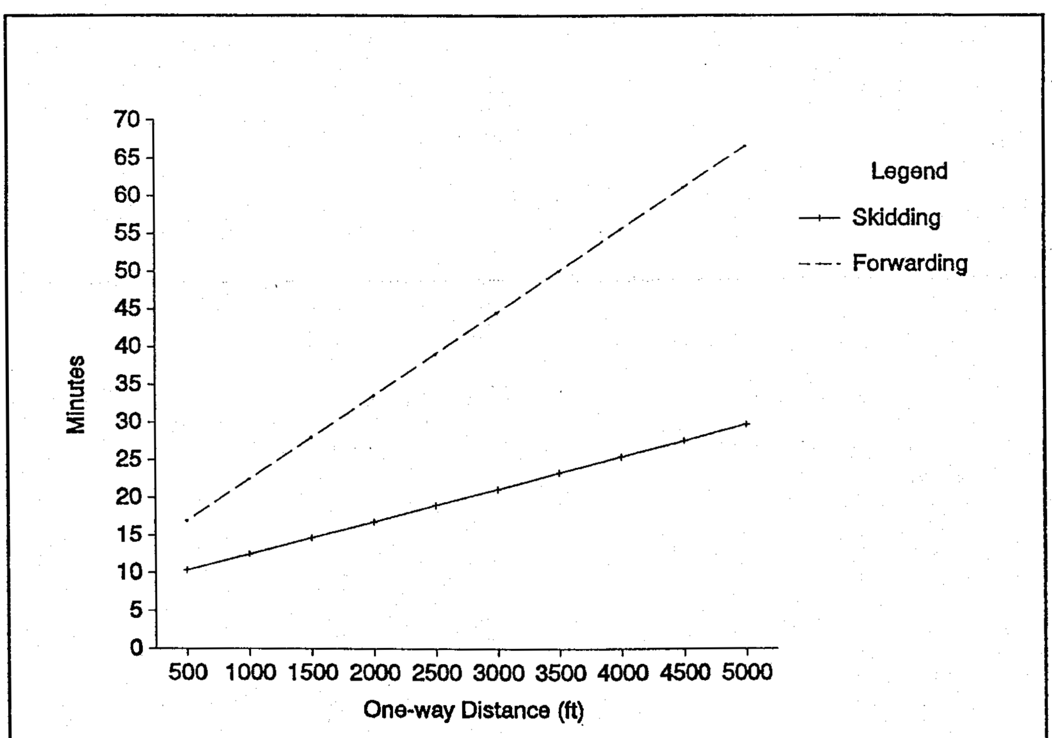

Figure 6. Delay free cycle time based on regression models.

ROAD CONSTRUCTION

The construction of forest truck haul roads can add considerable expense to timber harvesting operations. Road construction costs are difficult to predict and estimate due to the number of variables involved, and because these variables differ from site to site and from operation to operation. Factors such as terrain, soils, weather, and equipment, all play a significant role in the costs associated with constructing a forest road.

Because road costs are hard to predict due to the number of variables which must be considered, costs used in the study are simply averages from the four roads identified earlier. Costs per mile ranged from a low of $2,362 for road 1 to a high of $4,974 for road 4. The average cost to construct these roads was $3,378 per mile. In order to test the influence of other road cost rates, a second construction cost rate of $6,363 was used. This cost rate was arrived at by modifying the average cost per mile as presented in Kochenderfer et al. 1984, to reflect the same costing procedure as was used here. The two rates, $3,378 and $6,363 will be used in the following discussion to show the sensitivity of system costs as they are affected by haul road construction costs. A graphical representation of the costs associated with the construction of haul roads at these two cost rates over a range of road lengths is included in Figure 7. The graph also includes a line representing skid road construction costs which would be necessary to build if haul roads were not built. It should be understood that these two rates are only assumed construction rates for purposes of discussion, and that road costs can vary significantly depending on site conditions.

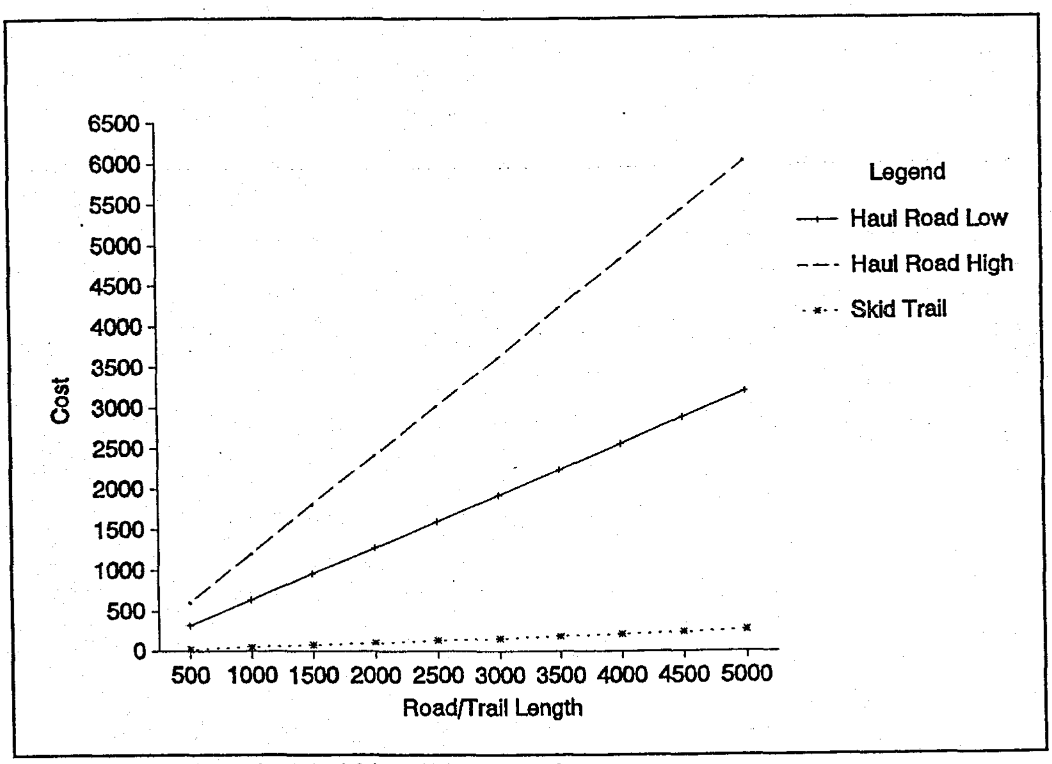

Figure 7. Haul road and skid trail construction costs.

DISCUSSION

For purposes of discussion an illustration will be used to show how the results of this study can be used to aid in the decision making process of whether to build haul roads or to forward or skid harvested timber longer distances.

The illustration will assume a 100 acre harvest unit under two levels of road construction costs, a low cost of $3,378/mile and a high cost of $6.363/mile; two haul road lengths, no road and 4000 feet of road; and the estimated skidding and forwarding costs based on the regression models and appropriate machine rate costs for equipment used. The appropriate length of skid road needed to service the system along with its associated cost will be added based on whether or not the haul road was built. In addition to these factors two levels of harvest will be assumed, one being a low volume harvest of approximately 231 cubic feet per acre, the second a high volume harvest of approximately 615 cubic feet per acre. It will also be assumed that under all combinations of the above factors that the felled timber was prebunched in the woods for both the skidding and forwarding systems. By assuming the bunching condition, no additional costs are incurred for one system over the other for the bunching operation.

Because the approach to skidding and forwarding remains unaffected regardless of whether or not haul roads are constructed, the volume per trip will remain constant, with only distance changing under the road or no road conditions. Throughout the illustration mean values, as observed in the time study, will be used for each of the independent variables in the regression models with the exception of maximum 1-way distance which will be altered to reflect the road and no road conditions. If the 4000 feet of truck road is constructed the skidding and forwarding distance used in the model will be 1000 feet, which will reflect the average stump to landing distance. If the truck road is not constructed, the average distance used in the models will be the same 1000 feet plus the additional 4000 feet needed to get to the landing when the haul road is not constructed.

The results for each of the above defined conditions will be presented in the form of stump to landing cost for skidding, forwarding with the Blondin forwarder, or forwarding with the Timberjack forwarder. Costs include skidding or forwarding costs as well as any skid road or truck road costs as is relevant to the system in question.

Low Volume Scenario

Under the low harvest volume scenario three alternatives apply. The first alternative is to build 4000 feet of haul road at the high road construction rate and skid or forward the short distance. Under these conditions the haul road construction costs total $4,820. With the road construction costs added to the skidding or forwarding costs, the total system cost is $6,344, $6,391, and $6,074 for the JD 640 skidder, the Blondin forwarder, and the Timberjack forwarder, respectively. Under these conditions there is very little difference in total stump to landing costs for the three machine options Figure 8.

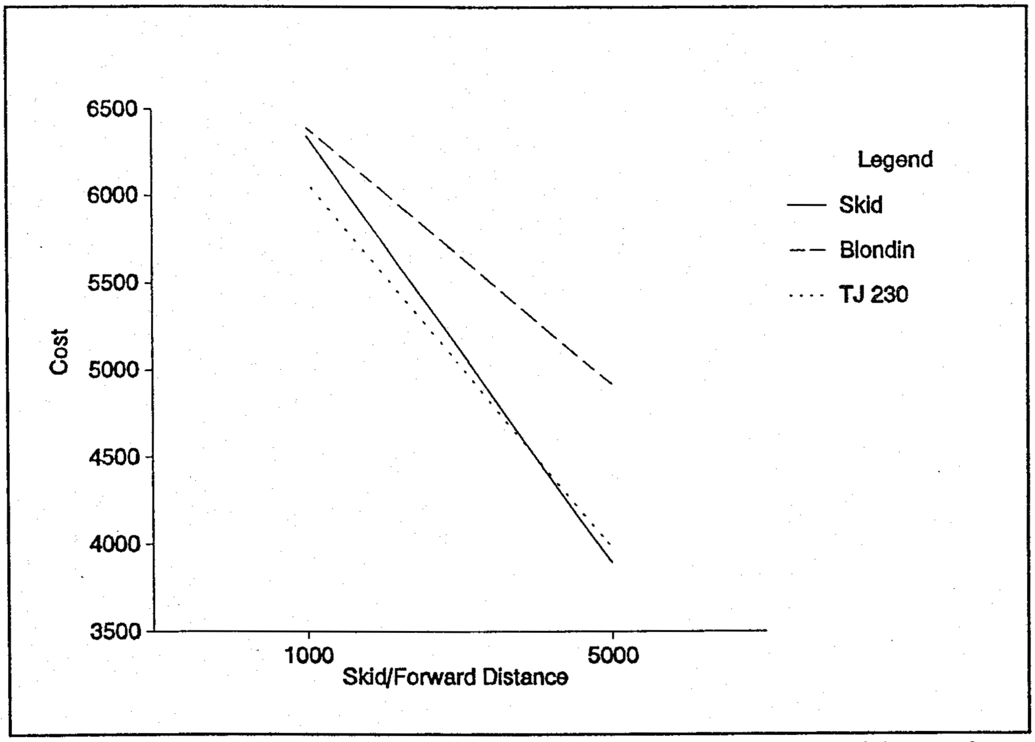

Figure 8. Skidding and forwarding system costs, high road cost and low volume harvest.

The second condition under the low harvest volume scenario is to build 4000 feet of haul road at the low road construction rate and skid or forward the short distance. Under these conditions the haul road construction costs now total only $2,559. With the road construction costs added to the skidding or forwarding costs, the total system cost is $4,083, $4,131, and $3,813 for the JD 640 skidder, the Blondin forwarder, and the Timberjack forwarder, respectively. Again, under these conditions there is very little difference in total stump to landing costs for the three machine options Figure 9.

The third condition under the low harvest volume scenario is to forgo building the 4000 feet of haul road and skid or forward the timber the longer distance (5000 feet). Under these conditions the haul road construction costs are eliminated, but there is a skid road construction cost of $267. With the skid road construction costs added to the skidding or forwarding costs, the total system cost is $3,893, $4,923, and $3984 for the JD 640 skidder, the Blondin forwarder, and the Timberjack forwarder, respectively. Under this set of conditions very little difference in total stump to landing costs exist between the skidder or the Timberjack forwarder, while the cost of running the Blondin machine is substantially higher. The reason for the difference in costs to operate the two forwarders is primarily a function of the slower travel speeds (see Table 3) of the Blondin machine as compared to the Timberjack over the now 5000 foot distance from stump to landing, Figures 8 and 9.

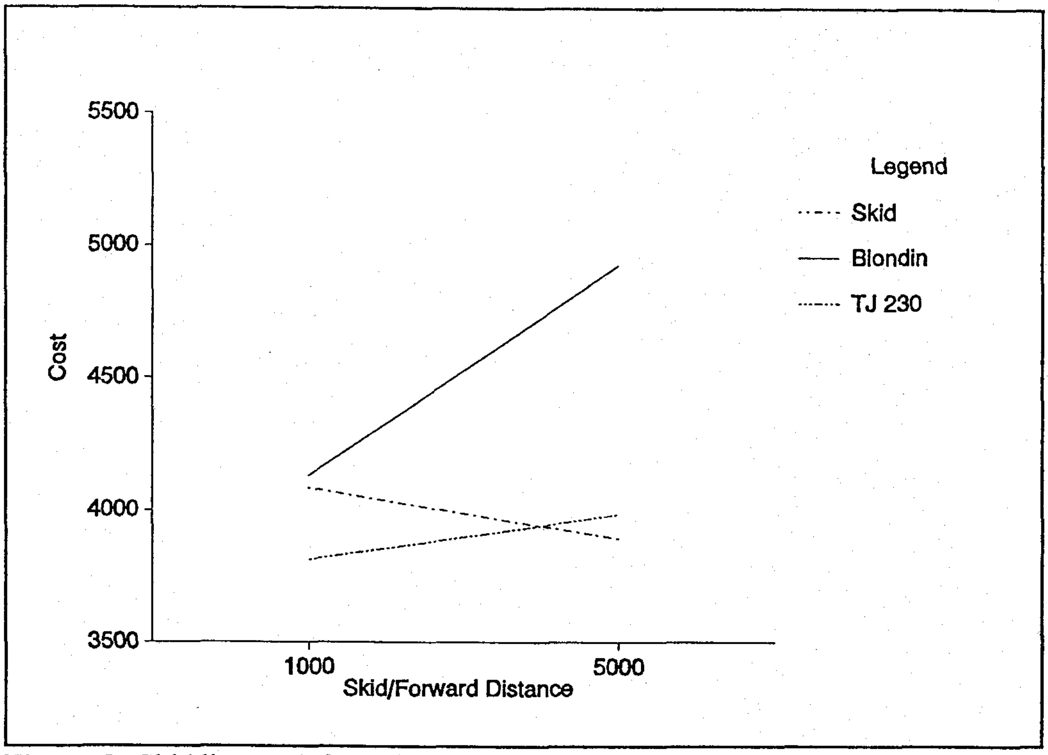

Figure 9. Skidding and forwarding system costs, low road cost and low volume harvest.

High Volume Scenario

Under the high harvest volume scenario three similar alternatives apply. The first alternative is to build 4000 feet of haul road at the high road construction rate and skid or forward the short distance. Under these conditions the haul road construction costs again total $4,820. With the road construction costs added to the skidding or forwarding costs, the total system cost is $8,890, $9,004, and $8,160 for the JD 640 skidder, the Blondin forwarder, and the Timberjack forwarder, respectively. Under this option the Timberjack forwarder has a definite advantage over the Blondin or JD 640 skidder in total stump to landing costs for the three machine options Figure 10.

The second condition under the high harvest volume scenario is to build 4000 feet of haul road at the low road construction rate and skid or forward the short distance. Under these conditions the haul road construction costs now total only $2,559. With the road construction costs added to the skidding or forwarding costs, the total system cost is $6,629, $6,743 and $5,899 for the JD 640 skidder, the Blondin forwarder, and the Timberjack forwarder, respectively. Again, under these conditions the TJ 230 forwarder provides the lowest system costs, while there is very little difference in total stump to landing costs for the other two machine options Figure 11.

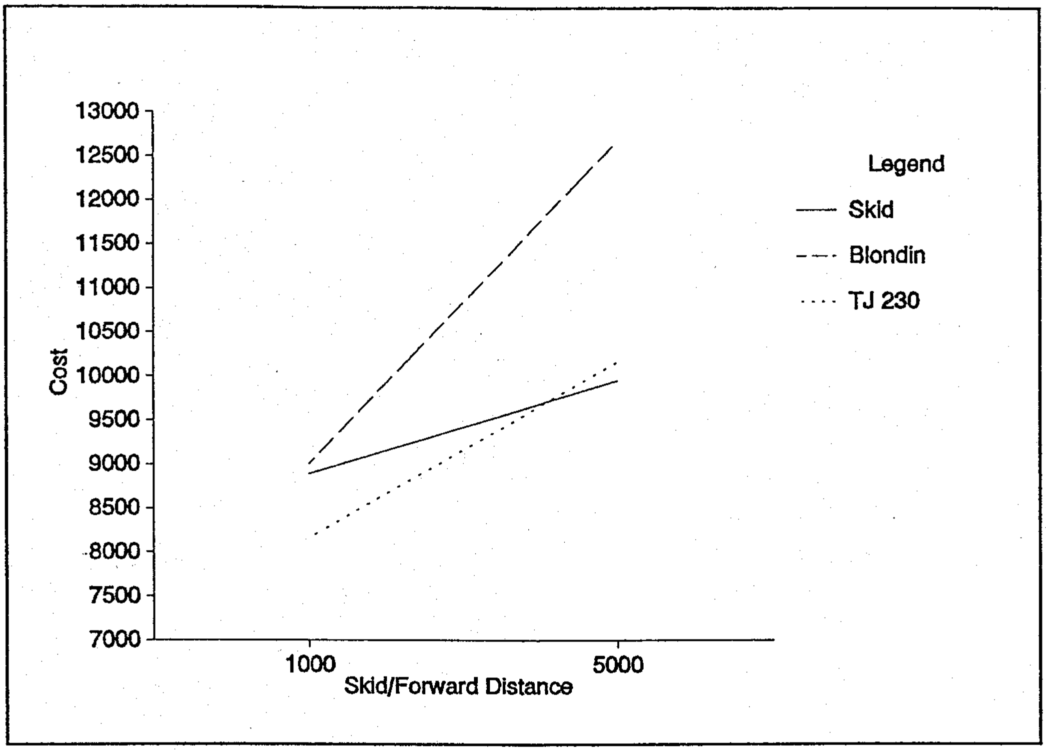

Figure 10. Skidding and forwarding system costs, high road costs and high volume harvest.

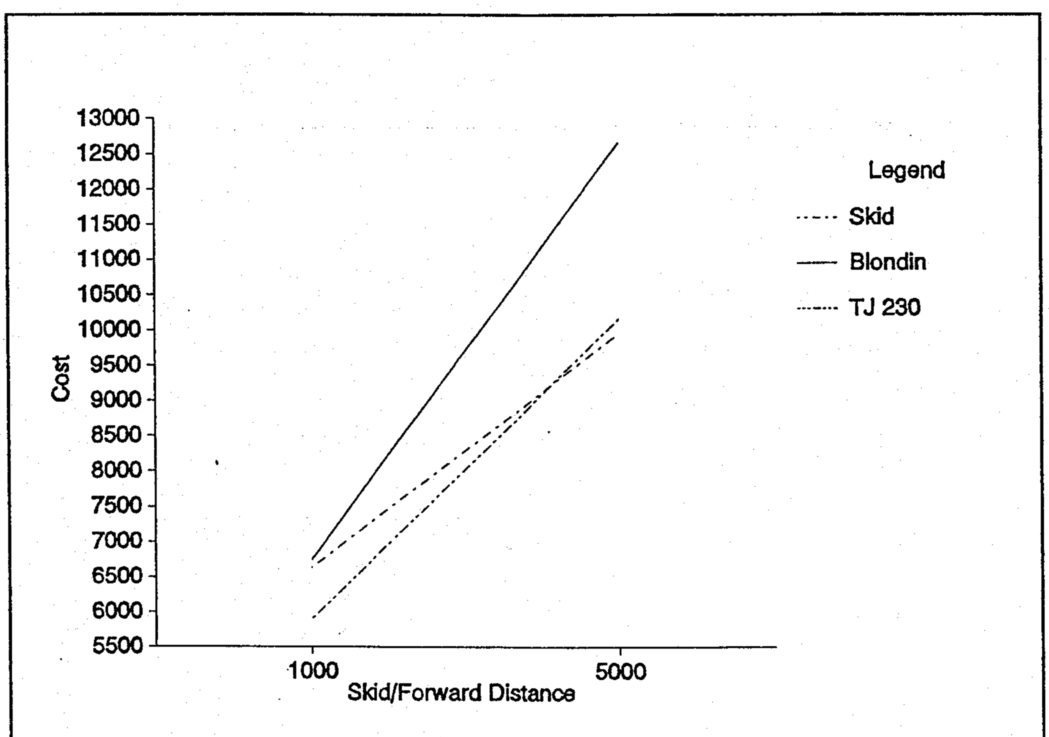

Figure 11. Skidding and forwarding system costs, low road costs and high volume harvests.

The remaining condition under the high harvest volume scenario is to forgo building the 4000 feet of haul road and skid or forward the timber the longer distance (5000 feet). Under these conditions the haul road construction costs are eliminated, but there is a skid road construction cost of $267. With the skid road construction costs added to the skidding or forwarding costs, the total system cost is $9,953, $12,664, and $10,163 for the JD 640 skidder, the Blondin forwarder, and the Timberjack forwarder, respectively. Under this set of conditions very little difference in total stump to landing costs exist between the skidder and the Timberjack forwarder, while the cost of running the Blondin machine is substantially higher. Again as we saw before, the reason for the difference in costs to operate the two forwarders is primarily a function of the slower travel speeds of the Blondin machine as compared to the Timberjack over the now 5000 foot distance from stump to landing (Figures 10 and 11).

CONCLUSION

The results of this preliminary study evaluating the economic ramifications of alternative methods of harvesting timber from stump to landing suggest that no single harvesting system design is optimal under all circumstances. The findings of the illustration suggest that under any given set of conditions there exist several possible alternatives as to how to log a tract of timber.

Generally speaking, when timber volumes to be harvested are low and road construction costs are low, there is very little difference in the stump to landing costs associated with either building haul roads or opting to skid or forward timber longer distances. As road construction costs increase while the timber volume remains constant, there is an increase in the marginal savings attributed to transporting the timber longer distances to a landing. On the other hand, when timber volumes are high additional haul road construction will pay for itself by reducing the skidding or forwarding distances and resulting costs which become excessive due to the number of trips required to land the increased volume. This situation will hold true until such a point is reached where road-building costs become high enough to again justify the added time and expense of landing timber from a further distance.

It must be kept in mind that this study is only the beginning of a much larger investigation looking not only at the three systems presented here, but also at systems employing a wider range of equipment, as well as finding optimal solutions over a range of terrain, site, timber, equipment, and cost parameters. The numbers, productivity levels, and costs should not be assumed to apply to all operations, but instead should be looked at as representative of the systems as a whole and can serve as a framework for other operations operating under similar conditions. In the analysis many parameters were assumed and changing any one of these may alter the results significantly. For example, something as basic as the equipment operators skill and efficiency level can have a major influence on overall system costs as was identified by Erickson et al. 1992. Also, consideration was not given to major advantages and cost saving features associated with the use of a forwarder. One advantage a forwarder has over a skidder is the fact that the forwarder itself could be used to load trucks, eliminating the need for and cost of a truck mounted or stationary loader on the landing. This type of savings could be of major importance, especially to the small timber operators common to Appalachia.

Although these results were arrived at by a straight forward dollars and cents approach, consideration must also be given to a number of other factors before a decision is made. These factors include such things as: how does the system fit into an individuals harvest operation and is the appropriate equipment mix available to execute the option selected; would a haul road have sufficient residual value for future harvests or other uses which may justify higher stump to landing costs; do terrain, soil, drainage or other environmental constraints preclude the construction of haul roads thereby mandating skidding or forwarding longer distances; and could a combination of approaches be used to reduce costs while meeting other harvest objectives.

LITERATURE CITED

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