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Log Measuring Accuracy of Harvesters and Processors

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ABSTRACT - FERIC examined the measuring accuracy of common harvesters and processors operating in British Columbia and Alberta. The results showed large variation in length and diameter performance of the machines, which partly was attributed to differences in the emphasis placed on measuring accuracy at the harvesting site. Other factors included variation in tree characteristics, lack of properly calibrated measuring systems, and wrong target lengths programmed in the measuring system's computer. Based on the findings, FERIC suggested actions that could be taken to improve measuring performance.

INTRODUCTION

Manufacturing of stems into company-specified log lengths, be it cut-to-length (CTL) logs or long-logs (LL), prior to mill delivery is a common harvesting practice in western Canada. The machines processing the stems are expected to manufacture logs within company-specified length and diameter tolerances. While these specifications vary among companies, common length accuracy requirements are 95+% of the manufactured logs within ±5 cm in CTL operations and within ±7.5 cm in LL operations. However, information on actual measuring performance has been lacking, which has raised concern that manufacturing logs at the harvesting site will cause substantial revenue losses to the industry. To address this issue, the Forest Engineering Research Institute of Canada (FERIC) conducted studies on several types of measuring systems and processing units on CTL and LL harvesters and processors between October 1996 and September 1999 on active logging operations throughout British Columbia and Alberta (Table 1). FERIC recorded the measuring accuracy under different stand and operating conditions; quantified the influence of these conditions on measuring accuracy; and recommended possible solutions to reduce log-measuring errors.

STUDY PROCEDURE

The field data were collected both under controlled and normal harvesting (production-oriented) conditions. In the 'controlled studies', the machine manufactured logs from about 50 pre-selected trees of known characteristics. The logs from each tree were placed in separate piles so that they could be tracked back to their 'original' tree. Where conditions allowed a researcher to be in the cab during processing, FERIC recorded the length and diameter displayed on the computer at the time the cut-off saw was activated.

In the 'production-oriented studies', FERIC collected length data on randomly selected logs that were manufactured under normal harvesting conditions. To minimize the risk of including random-length logs, FERIC excluded logs with top diameters near company-specified minimums, and logs with lengths that might have been affected by a stem defect.

Table 1. Summary of equipment studied

Log measuring system	Type of processors
Dasa 280	Woodking 650
Denharco MD II	Denharco T3500
Entek TY 5000	Ultimate 4500, 5300
Lim-mit COMS	Lim-mit 2000, 2100, 2200
Lokomatic 90	Timberjack 762B
Motomit	Lako 550
Optilog	Denharco 550
Rolly (Risley)	Rolly II
Scanmet 512	Keto 500, 1000
System 90	Rottne Snoken, EGS 85
Timberjack 3000	Timberjack 762B, 763C
Toshiba (Target)	Target, Hornet 825
Valmet VMM 1000 /1100	Valmet 960, 965
Waratah AS593 / 595	Waratah (Pierce) HTH-20

RESULTS

Length measuring performance

As there are no standard definitions for 'measuring accuracy', FERIC presented the length measuring results in several different ways. Two of these are presented here. However, regardless of what yardstick was used to measure the length accuracy, the measuring performance of the machines studied varied greatly.

Company-accepted logs. The percentage of Company-accepted logs among the CTL machines ranged from 37% to 100%, and averaged 85%, while among the LL machines it ranged from 36% to 95% and averaged 74%. Based on the common log manufacturing standards, 28% and 10% of the machines in the CTL and LL operations, respectively, fulfilled the company requirements for length measuring accuracy (Figure 1).

Distribution of length measuring errors. FERIC also examined the distribution of length error of individual logs in 1-cm error classes. To capture the essence of the distribution, FERIC adopted the approach used in Sweden to quantify length measuring accuracy (Berglund and Sondell 1985). Best-5 and Best-10 quantify the frequency of logs (as percentages) within the five and the ten adjacent error classes with the highest number of logs, respectively (Figure 2). These percentages for the Best-5 and Best-10 represent the machine's ability to produce logs within length variations of ±2.5 cm and ±5 cm, respectively.

The Best-5 and Best-10 for the CTL machines ranged from 26 to 92% and from 45 to 100%, respectively (Figure 3). The corresponding numbers for LL machines were from 23 to 67% and from 41 to 91%, respectively (Figure 4).

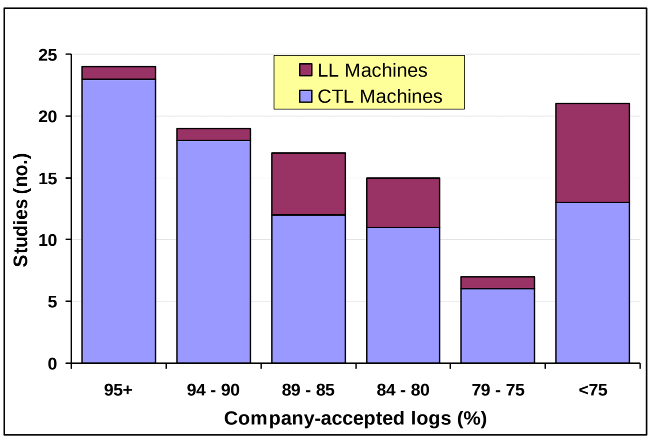

Figure 1. Company-accepted logs.

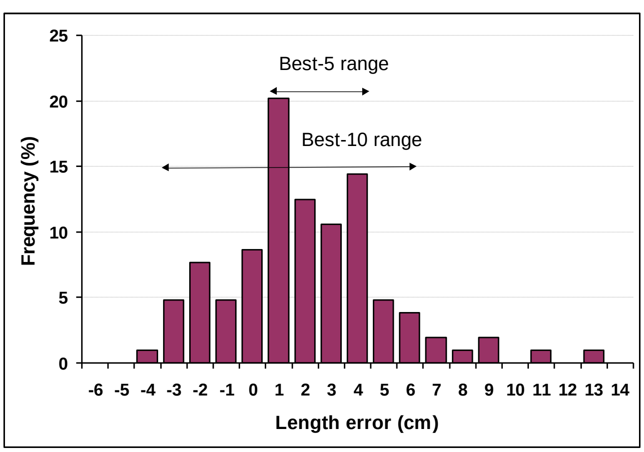

Figure 2. Example of a distribution of length deviation.

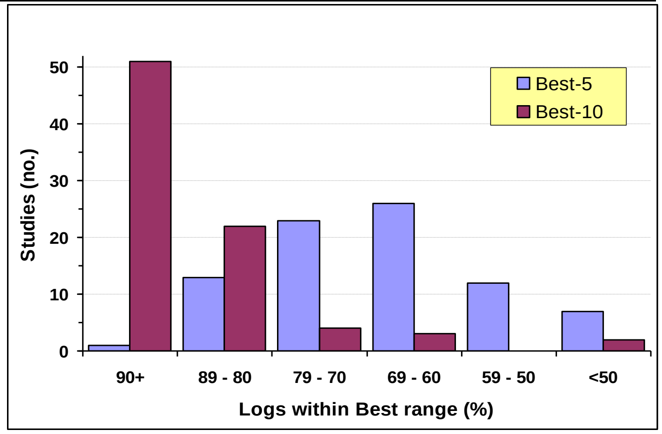

Figure 3. Best-5 and Best-10 distributions of CTL machines.

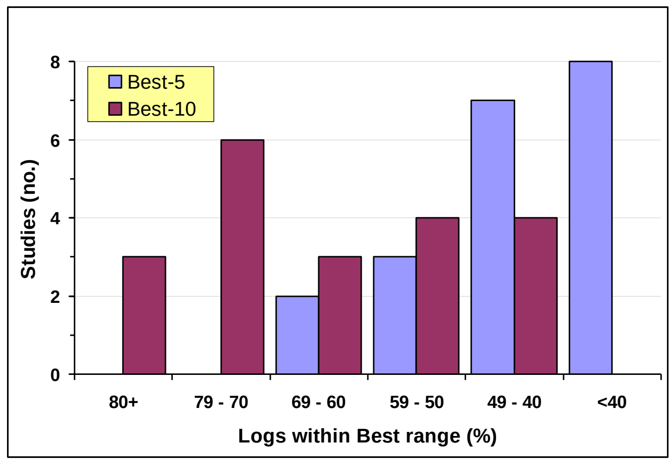

Figure 4. Best-5 and Best-10 distributions of LL machines.

Diameter measuring performance

Most of the CTL machines examined for diameter measuring accuracy were not required to use this measuring function to any great extent for bucking decisions. Often its use was limited to finding the appropriate topping diameter (around 10 cm) of the stems. This lack of required measuring accuracy over much of the systems' measuring range (typically 5 to 55 cm) undoubtedly influenced the results.

Overall, 34% and 57% of the logs per study were within a measuring error of ±4 mm, and ±8 mm, respectively. However, the results of individual studies varied considerably. For example, logs within ±4 mm ranged among the studies from 1 to 69% (Figure 5).

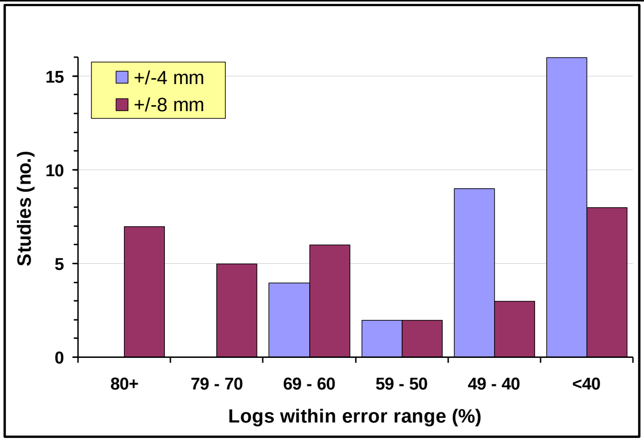

Figure 5. Diameter measuring accuracy from 31 CTL studies.

Factors influencing measuring performance.

The variation in the measuring performance among the machines was attributed to several factors. The logger had no control over some of the factors, such as the design limitations of the equipment, stand and tree characteristics, and climatic conditions. Others were controllable factors, such as calibration of the measuring system, computer target settings, and level of quality control. Although the analyses were done primarily for length measuring accuracy, they are also applicable to diameter measuring accuracy.

The length measuring performance of the machines operating in CTL operations was, in absolute terms (measuring error per log), better than for the machines in LL operations. However, if the measuring errors were expressed in proportion to the length of the manufactured logs (i.e., cm/m), the difference in measuring accuracy was not significant. FERIC found no difference in the measuring accuracy between stroker-type processors and single-grip processors in LL operations.

There was no difference in the length measuring performance between single-grip machines operating either as harvesters or as processors in CTL operations, nor was there a difference between processors working at roadside or at the stump area. However, the double-grip processors were generally more consistent at length measuring than the single-grip processors.

FERIC attributed much of the variation in the measuring accuracy to differences in the emphasis placed on quality control at the harvesting site. Machines that were regularly checked for length accuracy at the harvesting site performed much better than those machines not regularly checked. Measuring errors attributed to lack of calibration of the measuring system, wrong target setting, and malfunctioning measuring system were rare among machines in the former group but not among machines in the latter group. Correcting for these measuring errors would substantially improve the measuring performance of many of the machines tested.

The analyses of non-controllable factors believed to have affected the measuring accuracy produced conflicting results, i.e., a factor found to influence the measuring performance in some studies appeared not to have done so in other studies. Thus, it is more appropriate to assess a factor's probability of affecting the measuring accuracy than to quantify its impact in absolute terms.

Tree branchiness appeared to be a key factor influencing measuring accuracy. Typically, the more branches or the larger the branches, the larger the variation in length of the manufactured logs. Natural variation in the branch characteristics between the tree species and among trees of the same species would explain why FERIC found some differences in the measuring performance between tree species (e.g., pine and spruce), and between logs manufactured from different parts of the stem (e.g., butt logs and top logs) while in other cases no difference was found.

FERIC found no strong indication that the operating season (winter versus summer) affected the length measuring performance of the machines. However, several machine operators had found that large temperature fluctuations during late-winter days affected the measuring system to such a degree that a mid-day calibration of the measuring system was needed.

The effect of length measuring performance on sawmill operations

The length accuracy of manufactured logs can have a significant impact on subsequent sawmill operations. Logs that are cut too short typically reduce both lumber recovery and mill productivity. Logs that are too long reduce mill productivity as more time is used by the breakdown saw to process the logs and fibre is lost to chips. To illustrate this, FERIC calculated lumber recovery and productivity for a theoretical sawmill using four studies of CTL machines with different length measuring performance. Although the impact on sawmilling is much more complex than shown in Figure 6, the results highlight the essence of the impact.

To guard against manufacturing logs that are too short, companies commonly include a trim allowance in their log specification. The best trim allowance should be such that it minimizes the overall fibre losses from all off-length logs (short and long). Its size depends on how consistent the machine is in length measuring, i.e., its Best-5 percentage (Figure 7).

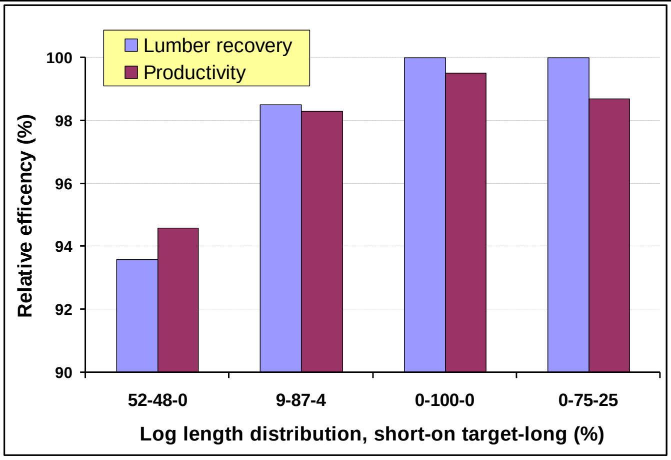

Figure 6. Examples of the impact of length accuracy on lumber recovery and sawmill productivity.

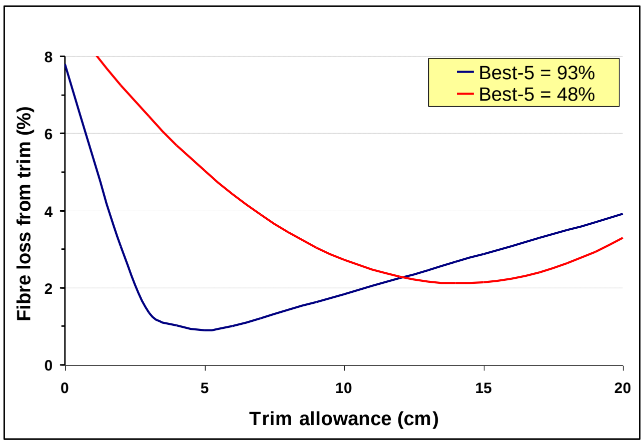

Figure 7. Examples of trim allowance versus fibre loss.

Improving measuring accuracy

While it would be very difficult to completely eliminate measuring errors during log manufacturing, there are some simple and cost effective actions that can be taken to improve the measuring accuracy and thus increase the value of the manufactured logs.

- **Committment**. All parties involved in the harvest operations must be committed to the log accuracy program.
- **Communication.** Information on the log specifications must be current and well understood by operators, machine owners, and company staff.
- **Realistic log specifications**. Targets for length measuring accuracy need to be realistic, and should reflect the value of the manufactured products.
- **Understanding the measuring system**. Machine operators need to know enough about the measuring system to access information programmed in the computer, and to detect when the system is not working properly.
- **Checking logs for accuracy**. Operators should check a few logs, representative of the stand, daily (e.g., 3 to 5 logs, twice per shift). Data from checked logs should be saved and analyzed for trends (e.g., plotting log length vs. length error as in Figure 8) before any adjustments are made to the measuring system.
- **Maintenance**. All components of the measuring system and the processing unit must be maintained in good working condition at all times.
- **Sharing the gain**. Implementing a log accuracy program will decrease machine productivity and add to the operating costs for the logger, while the mill will benefit through increased lumber recovery and mill productivity. Sharing the gain will give the logger the incentive to ensure good log measuring accuracy.

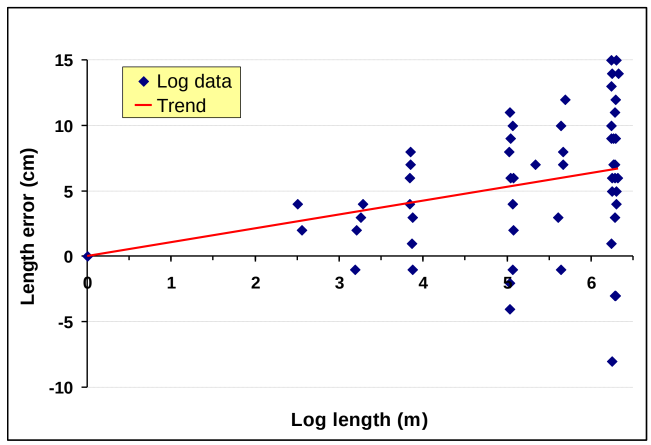

Figure 8. Plotting length errors versus log length

CONCLUSION

Using company log specifications as the standard for length measuring accuracy, FERIC found that between 37% and 100% of the logs processed in 85 CTL operations were accurate, while the corresponding percentages in 23 LL operations were 36% and 95%. Approximately 25% of the machines exceeded the minimum level of company-accepted logs specified by the respective company's log quality program. Other standards used by FERIC to evaluate length measuring accuracy, such as the length measuring consistency in terms of Best-5 and Best-10, also showed a large variation in the length measuring performance.

The diameter measuring accuracy of 31 CTL machines was expressed as percentages of the small-end diameter of the logs measured within errors of ±4 mm and ±8 mm. On average, 34% and 57% of the logs were within these error limits, respectively. These results were not considered representative of the machines' diameter measuring accuracy, as the diameter measuring systems were often not properly calibrated for their entire measuring range.

The variation in the measuring performance was caused by both factors over which loggers had no control, as well as factors they could control. By implementing a log quality program with emphasis on measuring accuracy at the harvesting site, a substantial improvement in the industry-average measuring performance is possible. FERIC concluded that under most western Canadian harvesting conditions, machines in cut-to-length operations should be able to manufacture 90% of the logs within a length tolerance of ±5 cm, while machines in long-log operations should achieve 90% of the logs within ±10 cm.

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Results form this project was previously presented in April 1999 at the Canadian Woodlands Forum (CWF) annual meeting in Thunder Bay, Ontario.

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FOREST ROAD STREAM CROSSING OPTIONS AND COSTS

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ABSTRACT - Permanent and temporary forest bridges are an integral part of achieving environmental Best Management Practices (BMPs) for harvesting operations. Within Virginia Tech's Fishburn Forest, five stream crossings have been installed to improve access and to provide a demonstration area for continuing education purposes.

Approximately 1 mile of abandoned road was re-opened and improved and 850 tons of gravel used to form the new running surface. In addition to a number of existing fords, three new culvert crossings and five new bridges have been installed. These include a two-span 31ft wooden stringer bridge, a 70ft low-water concrete culvert crossing, two stress laminated bridges, and a three-panel cant skidder bridge.

This paper provides basic information regarding permit acquisition and environmental considerations for stream crossings. Location, design and installation procedures for a variety of permanent and temporary forest bridges are presented. Finally, an in-depth evaluation of bridge installation costs, including materials, labor and machinery requirements, are shown for the various permanent and temporary crossing types.

INTRODUCTION

In the Appalachian region fords have historically been used as stream crossings for forest operations and other activities, primarily because they are an inexpensive way to gain access. However, fords can also increase stream sedimentation and decrease water quality and fords may provide unreliable access to property.

In general, the specific location along the stream will be based upon whether or not a ford or elevated structure is desired. The type of stream crossing desired depends on factors such as the overall purpose of the crossing, the amount and weight of traffic, how long the crossing must survive, cost considerations, and design and construction options.

In the Fall of 1998 a program was begun on the Virginia Tech Fishburn Forest to replace existing fords with alternative types of stream crossings and to document the expenses associated with each type of crossing. In addition to culverts, five types of crossings were installed on the school forest between 1998 and 2001: stress laminated bridge constructed of 2 inch thick material (2 panels), stress laminated bridge constructed of 4 inch laminated material (2 panels), stress laminated bridge constructed of 8 inch laminated material (3 panels), wooden stringer bridge, pipe and concrete low-water crossing. Costs ranged from approximately $400 to almost $24,000. Overall, costs had the following pattern: ford < panel < stringer bridge < concrete and pipe low water crossing, although the permanency and potential for water quality problems followed the exact opposite trend.

Unfortunately, little information has been published that actually quantifies costs of various stream crossing location and construction activities. The purpose of this paper is to provide examples of some of the costs associated with location and construction of temporary and permanent minimum standard stream crossings that fully meets all Virginia forestry BMP requirements in the Appalachian Mountains of Virginia.

SITE DESCRIPTION

The Fishburn Forest is a 1350-acre parcel of mountainous forestland that is managed by the College of Natural Resources at Virginia Tech. J. B. Fishburn, who had purchased 35 smaller parcels in order to acquire coal-mining rights, originally owned the tract. In 1953 he abandoned the coal mining activities and donated the property to Virginia Tech. Since 1953 primary activities conducted on the forest include undergraduate and graduate student field teaching exercises, forestry research projects and various demonstration projects.

Access to the parcel was severely limited and consisted of one county road on the western side of the property and one state route on the southern side of the property. Interior roads consisted of old mining and farm roads circa 1860-1930 that crossed two first order perennial streams, Stroubles Creek and Slate Branch, repeatedly with fords.

Unfortunately, the fords had steep approaches and soft bottoms, making them unreliable for heavier traffic and causing turbidity problems when used. Between 1998 and 2001, these fords were replaced with alternative stream crossings, which improved access, reduced water quality problems, and currently serve as excellent teaching and demonstration areas on the school forest.

STREAM CROSSING CONSIDERATIONS

Some of key stream crossing considerations include location, purpose, traffic, longevity, cost, design and construction.

Typical expenses and the type of equipment and material required for various crossing options are:

- Fords: $100 - $1,000 (machine, stone)
- Culverts: $200 -$1500 (Pipe, equipment)
- Portable skidder bridges: $2,000 - $4,000 (initial purchase, installation, transport)
- Simple wooden stringer bridges: $5000 - $40,000 (labor, machine, materials)
- Low water crossings: $10,000 - $50,000 (concrete, pipe, labor, machine)
- Steel stringer: $10,000 - $80,000 (material, labor, machine)

For the actual design type, the longevity of stream crossing must be considered. For temporary bridges, fixed wooden structures or portable steel or wooden structures are logical choices. For permanent crossing, treated wooden bridges or even concrete or steel should be considered

If a bridge is to be designed for public access or unusual conditions then we recommend the use of a professional engineer.

ACQUIRING A PERMIT

In Virginia, a permit is required for stream crossings having watersheds > 3000 acres or where modification of wetland areas would occur. This is a joint permit process involving US Army Corps of Engineers, Virginia Department of Environmental Quality, and Virginia Marine Resource Commission.

Completion of the permit application requires some basic knowledge of the wetland delineation process, general construction techniques, and basic surveying skills. The permit itself is a 41 page document plus addendum, but not all sections are applicable. The actual application process can be sped up by submitting a copy to all three agencies simultaneously, and the applicant should remember to answer all applicable questions as incomplete files are delayed. An on-line copy of the permit is available at the following internet address: www.deq.state.va.us/.

COST AND MANPOWER SPECIFIC OF STREAM CROSSINGS AT VIRGINIA TECH

Faculty, staff, and students from the College's Industrial Forest Operations group performed all of the necessary steps of the stream crossing location, including reconnaissance, crossing width determination, approach layout and in some cases construction or installation. The construction of the low water concrete bridge was contracted out. The wooden stringer bridge and the stress-laminated bridge using 2 inch material were built in the Forest Harvesting Lab workshop and installed on site.

The two larger stress laminated bridges were donated by Hopewell Hardwood Sales of Hopewell VA and Forestry and Wildlife Consulting Services of Gretna, VA. They were lifted into place using a large excavator.

The following section details actual costs of the stream crossing options used in the Fishburn Forest at Virginia Tech.

Concrete and Pipe Low Water Crossing

The low-water crossing was constructed in 1998. Table 1 provides a detailed breakdown of the construction of this bridge.

Tasks for the concrete bridge included 12 hours of permit data collection and write up, 6 hours of field visits to collect bids, 16 hours of culvert and form transport, and 80 hours of culvert installation. Finally 16 hours was spent pouring concrete.

Table 1. Estimated costs for concrete-pipe crossing.

Items for Concrete Bridge	**Cost**
130 man hours @ 12.50/hour on bridge	$ 1625
120 yd3 of concrete @ 75/yd3	$ 9000
8 36 in. x 20 ft. culverts @ 300.00/ea.	$ 2400
4 24 in. x 20 ft. culverts @ 240.00/ea.	$ 960
30 tons of gravel delivered @ 6.25/ton	$ 187
40 hours of backhoe @ 45/hr rented	$ 1800
2 rolls of reinforcement wire at 65.00/roll	$ 130
Estimated profit for contractor	$ 6897
Total	**$23000**

Timber Stringer Bridge

It took approximately 12 man-hours to collect the data, fill out the forms and apply for the bridge permit.

The central bent was pre-constructed in the workshop (28 man hours). The stream was ditched to lower the water level, the road was cleared and trees felled and removed for the new approaches (16 man hours). The headwall trenches were dug and the headwall assembled and then backfilled (32 man hours) and the sides of the headwalls completed to retain the soil for the road approach (8 man hours). The trench for the central bent was dug and the bent placed and supported (16 man hours) and concrete bags placed around the central bent (8 man hours).

Finally the 16 stringers were put in place (12 man hours) and the decking nailed onto it (12 hours). Rehabilitation work around the bridge (including straw placement and grass seeding) took 16 hours. Costs of the timber bridge are provided in Table 2.

Table 2. Estimated costs for timber bridge.

Items for Timber Bridge	**Cost**
156 man hours @ 12.50/hour on bridge	$2,090
24 man hours @ 16.00/hour on plats, threaded rod, etc	$384
80 feet 3/4 inch threaded rod @ 2.50/ft	$200
20 ft2 1/4 inch steel plate @ 5.00 ft2	$100
84 washers, and nuts @ 1.50 each	$126
150 bridge spikes @ 0.50 each	$75
40 hours of backhoe @ 45/hr rented	$1,800
50 bags of quick-crete @ $3 each	$150
3 boxes of 16d nails @ 5.00 each	$15
bent = 5 8"x8"x12' ties @ 60 each	$300
2 headwalls = 10 8"x8"x16' ties @ $79	$789
2 headwalls 24 2"x8"x12' boards @ 1.50	$36
2 wingwalls = 10 8"x8"x12' ties @ $60	$600
stringers = 16 8"X8"X16' ties @ 79 each	$1,263
deck = 45 2"x8"x12' boards @ 1.50 each	$67
100 feet of 1/2 inch rebar @ 0.30/ft	$30
Total	**$8,026**

Self Constructed Stress Laminated Bridge

Personnel of the Industrial Forestry Operations group designed and constructed a simple two-panel, 18 ft length stress laminated bridge with the following dimensions: 8" deep, 18' long, 4' wide. All lumber was sawn, drilled, assembled and then transported to the field. Cost estimates are provided in Table 3.

Table 3. Estimated costs for construction of a stress laminated bridge.

Lumber	= $ 300
Threaded rod, nuts, bolts	= $ 300
50 hrs transport, measuring, drilling, assembling @ 12.50/hr	= $ 625
12 hrs for transport, installation @ 12.50/hr	= $ 150
8 hrs of backhoe work at 50/hr	= $ 400
Total Cost for this scenario	= $1775

Culvert Cost Example

Culverts are used to drain ditches and to provide stream crossings. We installed a culvert crossing for an intermittent stream. Culvert size was determined via Talbot's formula. Costs for this operation are provided in Table 4.

Table 4. Estimated costs for culvert installation for crossing an intermittent stream.

Backhoe transport	= $ 50
1 hour Backhoe time @ 57/hr	= $ 57
20 feet of 36 inch steel pipe @$20/ft	= $400
Total Cost for this scenario	= $507

Purchased Panel Bridges

We also installed two manufactured stress laminated bridges. These bridges had identical dimensions and potential payloads and were installed using the same machines and techniques. These 32ft long x 8in deep x 4ft wide panels are too heavy to move without the aid of a knuckleboom loader or excavator type machine. These types of crossings (and the steel equivalents) have tremendous advantages in that they are effective, relatively low in cost, easy and quick to install, and can be moved after operations are complete. Costs for the two panel bridges are presented in Table 5.

Table 5. Estimated costs for purchase and installation of panel bridges.

Purchase price	= $3600
Transport Cost	= $ 300
Labor for installation Cost 8 hrs @ 12.50/hr	= $ 100
4 hours excavator @ 80/hr	= $ 320
Total Cost for this scenario	= $4320

Ford Cost Example

Fords are the least desirable type of stream crossing in terms of water quality and all weather access. However, in some instances, fords may provide an acceptable short term solution. For this reason, we included estimated costs of installing an acceptable ford in Table 6.

Table 6. Estimate costs of constructing a ford crossing (40 ft wide drain).

Location 1 worker for 2 hours	= $ 25
Dozer transport	= $ 75
2 hours Dozer time @ 75/hr	= $ 150
Stone for approaches	= $ 129
(100 ft X 12 ft X .33 ft x100 lb/ft3 /2000lbs/ton X $6.50/ton)	
Water diversion on either side	= $ 75
Total Cost for this scenario	= $ 454

SUMMARY

Stream crossings are an integral part of harvest planning and can significantly affect the cost of accessing a parcel. Simply crossing a stream with machinery, or filling the waterway with timber to create a temporary crossing is not acceptable and stream crossings are now required over all significant waterways by law, although the specifics vary from one state to another. This report has presented many of the practical aspects of stream crossing construction and costing for the Appalachian forest area.

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CABLE LOGGING IN APPALACHIA AND OPPORTUNITIES FOR AUTOMATED YARDER EQUIPMENT

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ABSTRACT - The Appalachian forest terrain, typically with sloping hills over 30% slope, lends itself to cable yarder operations. To date, ground-based operations are still the most common harvesting techniques employed but in some places are no longer acceptable from an environmental point of view. The use of professional helicopter logging crews to access the higher value timber in the more remote areas of the Appalachians has provided local forest managers with an expensive but trouble free 'turn-key' solution to their current problems.

This paper reviews why there are too few cable-logging contractors that operate successfully in this area. The most common problem is a lack of planning and management expertise and the absence of enough true cable logging contractors with modern equipment. There is considerable opportunity for increased use of this harvesting technique and the newly developed medium sized automated yarder equipment from Europe may present opportunities for providing a cost effective remedy to the current situation.

INTRODUCTION

In the late 1970's and early 1980's a large amount of information was published regarding cable logging in the southern Appalachians. This was a result of increased focus on environmental issues and difficulty reaching second growth timber on steep slopes using conventional ground based logging methods (Gochenour et al. 1978). A variety of cable logging systems were tested in the region and compared for optimum productivity (LeDoux 1985).

Since then, however, there has been considerably less activity in terms of cable logging operation in the region. Helicopter logging has become favorable to many forest land owning companies because they provide a 'turn-key solution'. This means that a company that has purchased stumpage will hand over all harvesting aspects to the helicopter logging company, including the felling. This requires little or no on-site management.

Cable logging crews have, however, typically been managed in a similar fashion as the ground based crews, including the need to face issues such as frequent location changes, lack of pre-harvest planning, quotas and truck scheduling problems. This means that most cable logging crews never became 'extraction specialists'. The resulting inefficiency meant that cable logging has become too expensive to compete with ground based operations and too complicated to manage relative to helicopter operations.

Considerable innovations are being made in cable logging. Many advances in the industry have the potential to offer increases in productivity and safety over the systems analyzed two decades ago. This includes the introduction of steep terrain harvesters for improved cable extraction efficiency and reduced felling costs (Visser and Stampfer 1998), new systems such as self-propelled carriages and automated yarders (Visser and Pertlik 1996), and accessory equipment such as radio-controlled chokers.

This report analyzes the resources available in the Appalachian region suitable for cable logging activities. While planning and experienced personnel for all aspects of cable logging can be seen as critical to the successful development of a cable yarding workforce for the Appalachian region, this report will focus on improving the efficiency of these operations through the introduction of modern equipment and systems.

RESOURCE AVAILABILITY

FIA plot data shows almost 70 Billion Board Feet (BBF) of timber located on sites with more than 5 MBF/acre of saw timber in the central Appalachian mountain region, as shown in Figure 1. We assume 5 MBF/ac be the cutoff for forestland with enough valuable timber to make cable logging justifiable.

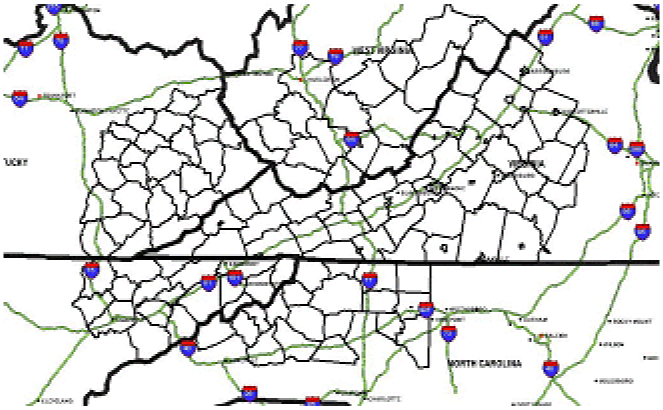

Figure 1: Central Appalachian area under consideration for cable harvesting operations.

Just over half of this total (38 BBF) is on slopes over 30% (Figure 2), which is the commonly recommended limitation for ground-based machinery. Furthermore, 17 BBF is on slopes over 50%, which represents a reasonable upper limit for even the most modern steep terrain harvester systems.

A typical yarder is capable of extracting approximately 2 million board feet a year. Considering the area of land in the slope class greater than 40%, and assuming 50% of this is actually available for harvest, then a just over 14 BBF will be available for harvest. Converting this to a number of potential yarders to operate in this area, using a 100-year rotation period, the potential for approximately 70 yarders exists. Currently only about 8 yarders are actively working in the region.

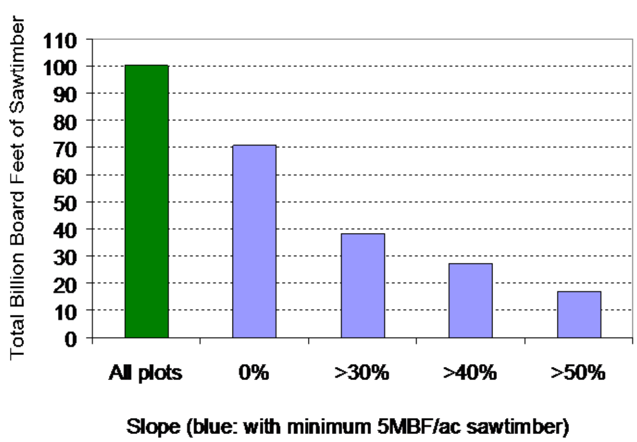

Figure 2: Timber resources availability in Appalachia according to slope class.

For the majority of timber conditions in the southern Appalachians, a medium sized cable yarder (30-40 ft. spar) is the most profitable choice to harvest timber (LeDoux et al. 1995). While a yarder of this size can handle most sawlogs found in the Appalachians, being able to yard conventional 16-foot logs as opposed to tree length material would aid in maximizing payloads.

IMPROVING PRODUCTIVITY

Review of Productivity Studies

Table 1 shows a summary of productivity studies carried out in the Appalachian region, and includes one additional data set intended to demonstrate the potential benefits of modern cable yarders systems.

The Visser and Stampfer (1998) study used a harvester to fell and pre-bunch logs close to the corridor. The other studies used tree-length material unless it was deemed too large for the yarder, in which case it was bucked into 16-foot logs. All of the studies used two choker-setters and had comparable corridor widths. Clearly, the harvester – automated yarder combination system produced the shortest cycle time.

Table 1: Average delay-free yarder cycle times (in minutes) from studies of four separate cable yarding systems

	Sherar et al. (1986)	Biller and Fisher (1984)	Huyler and LeDoux (1997)	Visser and Stampfer (1998)
Carriage out	1.32[1]	0.52	0.43	0.31
Hook-up	1.75	2.25	2.22	1.50
Carriage in	2.15	1.77	2.70	1.19[3]
Unhook	0.47	0.96	[2]	0.64
Total Cycle	4.99	5.50	5.35	3.65

[1]This operation used a swing yarder. The swinging phase added to carriage out and carriage in times.
[2]Unhooking time is contained in the "Carriage in" time
[3]A portion of this is waiting for the yarder operator to finish loading before pulling the logs to the landing.

Steep Terrain Harvesters

The logging industry is continually under pressure to improve safety and productivity. One of the major improvements over the past decade has been increased mechanization, which has taken workers off the ground and put them in machinery (Shaffer and Roberts, 2000). In cable operations, this trend can also be adopted to some extent.

In felling of trees, use of steep terrain harvesters equipped with harvester heads allows timber to be felled, delimbed and bucked from the safety of a machine cab. Using a steep terrain harvester, such as shown in Figure 3, it is possible to pre-bunch cut-to-length timber closer to the cable corridor and minimize lateral yarding distances (Visser and Stampfer, 1998).

Figure 3: Timberjack 608L cut-to-length harvester

Steep terrain harvesters are being improved constantly, but there are still areas in the Appalachians where they are either not able to cut because of terrain, slope or tree size considerations. On these sites, chainsaw felling may still be the only option. However, the use of a harvester can reduce felling costs through increased productivity and improve extraction by reducing cycle times and increasing average payloads. The new generation of steep terrain harvesters has proven capabilities up to 50% slopes, with some reports of successful felling operations on up to 70% slopes.

Radio Controlled Chokers

Radio controlled chokers have shown great potential for improved productivity in addition to safety advantages. The use of radio-controlled chokers can eliminate the need for a chaser at the deck and thereby improves safety. The yarder operator can lower the logs to the deck and release the chokers with a remote mounted in the cab of the yarder (Johnson Industries). Depending on the average number of chokers used and the yarding distance, productivity increases of 10-20% are possible.

In almost all time-studies for cable logging operations, the choker setting comprises one of the, if not the, major time component in each cycle. Table 1 shows that unhooking of logs at the deck can comprise up to a full minute of cycle time on the average. In addition, some of the studies listed waiting for the chaser as a major source of operational delays (Huyler and LeDoux 1997; Biller and Fisher 1984).

NEW YARDER SYSTEMS

Mechanization has started a trend in the Piedmont and coastal plain of the southeastern states towards fewer, large logging companies with multiple crews capable of cutting large acreage quickly. The topography and mixed hardwood timber of the Appalachians has limited that trend somewhat in this region.

As a result smaller logging operations are still relatively common. Self-propelled carriages and automated yarders are two newer cable systems that provide separate benefits of their own.

Self Propelled Carriages

A system that has not received a great deal of attention, but has been used widely in Japan and central Europe is the self-propelled carriage (Figure 4). These units require either just one or two cables to operate and have internal motors that propel themselves using the skyline itself, or use a secondary driveline. They also have an interior dropline that is radio controlled and can be lowered by either the choker-setters or the operator at the deck.

Although the earlier very large two line models had typical limits of 4400 lb., most of the carriages in operation today have 2200 lb. capacities (Stampfer et al, 1998).

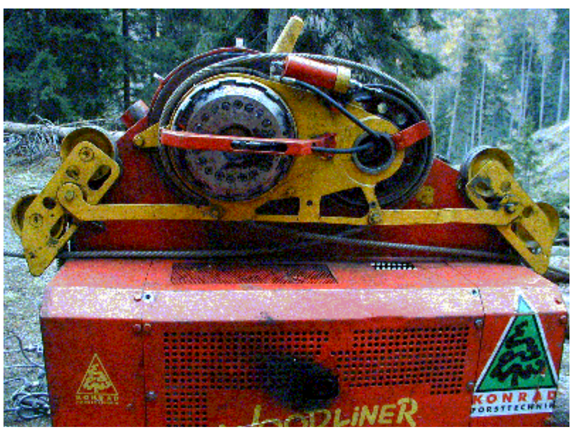

Figure 4: Woodliner self-propelled carriage

The limited availability of productivity data limits a complete analysis of this system, but a comparison with some medium-sized yarders shows that productivity is somewhat lower (approx. $9m^3$/hr. vs. $13m^3$/hr.). This lower productivity may be overcome in terms of cost by utilizing a smaller crew and not needing a cable yarder.

This system is limited to mostly downhill extraction of cut-to-length logs because of the power in the carriage itself. As a result, a road and suitable landing would need to exist on the downhill side of tracts to harvest them at the lowest costs. Development of better carriages in the future may alleviate this problem. Also, if a winch is utilized, suitable spar trees will be needed at the landing. These limitations, however, should not overshadow the potential for this system for small cable operations in this area.

Automated Yarder Systems

The last development that has true potential for increasing the productivity of cable operations is a 'automated' yarder such as the Syncrofalke (Visser and Pertlik, 1996) (Figure 5). These systems use a computer to control the inhaul and outhaul of the carriage. Outhaul is either to the last location it stopped or to a preset distance, and inhaul is automatically set to stop 10 or 20 meters from the yarder for safety reasons. Automating the movement of the carriage frees up both the yarder operator and the choker-setters to carry out their tasks while the carriage is in motion.

Productivity data from a machine of this sort working with a harvester is presented in Table 1 for Visser and Stampfer. Clearly, this data shows the fastest cycle times by far of the systems represented. While the topography description and yarding distances are comparable with all of the studies in Table 1, this operation was carried out in Austria.

Another beneficial characteristic of this system is the integration of a knuckle-boom loader on the same trailer as the yarder. Here the yarder operator has controls for both the yarder and the loader in the cab of the machine. While the carriage is in the woods, the operator works the knuckleboom clearing the chute and sorting logs at the deck.

Figure 5: Syncrofalke automated yarder

The automated yarder system is more flexible to harvesting conditions than the self-propelled carriages. These yarders have three drums that allow them to operate in a wide array of rigging set-ups. They can also yard up or downhill. The major disadvantage of using this machine is the capital investment trade-off versus the cheaper self-propelled carriages, to achieve that added flexibility.

CONCLUSION

There are a number of opportunities for improving the productivity of cable logging operations in the Appalachians. While adoption of entirely new cable logging systems could provide advantages in total productivity or in reduced costs, merely adding new features such as radio controlled chokers or cut-to-length harvesters to existing systems will also provide benefits.

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A Computer Simulation Model for Predicting the Impacts of Log Truck Turn-Time on Timber Harvesting System Productivity and Cost

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ABSTRACT- The Log Trucking System Simulation (LTSS) computer model was designed to represent a logging firm's wood delivery system from the woods landing to the consuming mill(s). The model, based on the STELLA systems modeling software package, allows the user to simulate a timber harvest with multiple product sorts delivered to different receiving mills, each with unique driving and mill unloading times. The LTSS model requires relatively simple input data, and provides a user-friendly tool for predicting the impact of factors such as haul distance/travel time, mill unloading time, product sorting, log truck fleet size and configuration, and in-woods harvesting productivity on overall harvesting system production and cost. For example, the LTSS model could be used to predict the effect on overall harvesting cost from an excessive truck unloading time at a key delivery point, or the number of trucks needed to maintain system productivity with a large number of product sorts on a specific tract. The model was tested with harvesting and trucking system data collected in the Appalachian region, and proved to be useful in identifying specific harvest system "bottlenecks", as well as providing sensitivity analysis to identify the optimum harvesting and trucking system setup for each harvest site and product mix.

INTRODUCTION

In the Southeastern United States independent logging contractors typically supply the wood to forest products mills. The independent logging contractors are responsible for felling and preparing the trees, transporting them to a concentration point or landing, and then loading and trucking the wood to the consuming mill. The balanced operation of the logging contractor's trucking and harvesting systems is essential for the system to operate efficiently. Storage capacities for wood at the landing are often limited; in order to continue operating efficiently, a contractor must have sufficient trucking capacity to deliver wood from the harvest site to the mill in a timely manner to avoid running out of product storage space at the landing.

Much attention has been focused on predicting production rates from the in-woods harvesting system, although trucking capacity can often be a limiting factor. A survey of West Virginia loggers indicated that trucking is one of the most frequently cited factors limiting production, especially for smaller producers (Luppold et al., 1998).

This paper discusses a simulation model that was developed at Virginia Tech in cooperation with Westvaco's Harvesting Research project in Rupert, West Virginia. The Log Trucking System Simulator (LTSS) was designed to assess the impacts of changes in truck turn times on the efficiency and productivity of a logging contractor's operation.

MODEL OVERVIEW

The LTSS model was developed using STELLA® systems modeling software from High Performance Systems, Inc. This software package is well-known for creating dynamic models using a toolkit of simple components (Heinemann, 2000).

The model represents a system of truck delivery of wood produced from a logging contractor's harvesting and trucking operation. The model illustrates the impacts on logging contractors as changes in truck turn times affect the contractor's system. The LTSS model was constructed at a generalized level so that it could serve as a user-friendly tool for illustrating the potential magnitude of impacts to logging contractors without requiring excessive data collection to operate the model.

The model is capable of representing the time that trucks spend at the mill, at the logger's in-woods landing, and driving time to and from the mill. Rather than requiring detailed inputs to predict production rates from the harvesting system, the LTSS model assumes a known harvesting production rate. The model focuses on the potential impacts that can occur when changes in the trucking system affect the contractor's costs and productivity.

After an initial model was developed, it was calibrated using work-study data from several logging operations in the Appalachian region. Setting model parameters such as production rates and delivery times to match the values obtained from the work-study data allowed us to verify model outputs such as average number of loads per day and days to complete harvesting.

Once the model was calibrated for the operations being studied, the model was used to perform incremental analyses using a sample contractor's system inputs (Table 1). Varying the size of the trucking fleet illustrated the general nature of impacts to the logging contractor's production caused by changes in the trucking system.

Table 1. Contractor's production and cost inputs used for example simulations.

Production input parameter	Value used for example scenario
Stand size in tons	4000 tons
Maximum product storage at landing	100 tons
Harvesting rate	20 tons per hour
Loading rate	75 tons per hour
Merchandising rate	50 tons per hour
Scheduled hours per day	9
Average truck payload	25 tons
Average mill turn time	21 minutes
Cost input	Value used for example scenario
Annual fixed harvesting cost	$165,000
Labor cost per hour for harvesting crew	$160
Variable cost per productive hour	$70
Days worked per year	230
Cost per day to own and operate a truck	$525

RESULTS

Example simulations performed with increasing drive times to the mill (Figure 1) illustrated that when a contractor's trucking system has excess delivery capacity, increases in turn times do not necessarily result in decreased total production. However, as total trip delivery times increase, excess trucking capacity is lost and a critical point is reached where increasing average turn times by only a few minutes can result in the loss of a load of wood per day that the trucking system is capable of delivering. As a result, the number of loads per day the trucking system can deliver will decrease in a stair step pattern.

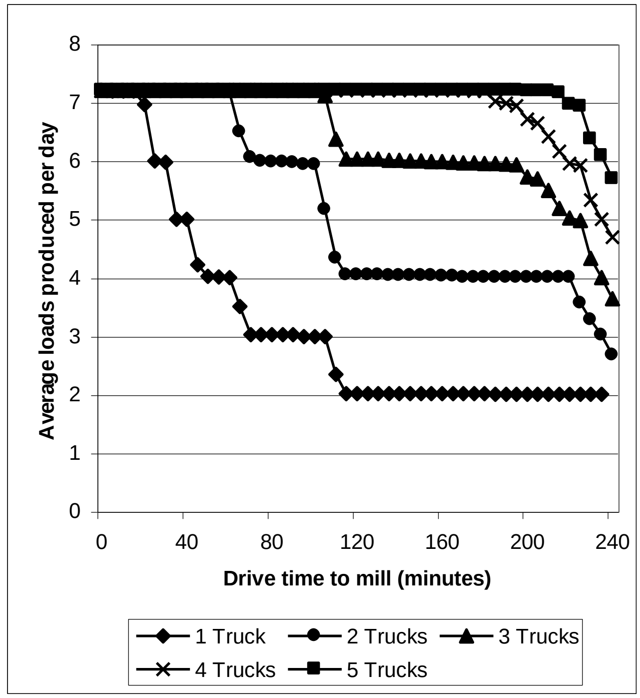

Figure 1. Average loads produced per day across different trucking scenarios as drive times to the mill increase.

The model illustrated that the primary impacts on logging contractor's costs and productivity associated with truck turn times occurs when the increased delivery time decreases the number of loads per day the trucking system can deliver and causes trucking to limit the contractor's total production. If excessive delivery times cause the trucking system to limit the logger's production, additional trucks must be added to the logger's trucking fleet in order to maintain maximum production from the harvesting crew. If additional trucks are not added to the contractor's system, harvesting costs per ton (Figure 2) increase as the delivery capacity of the trucking system limits the contractor's production. However, with shorter delivery times, harvesting production is the limiting factor and the cost of operating additional trucks in the contractor's fleet simply adds additional trucking costs and does not result in increased production (Figure 3).

The incremental analyses with different sized trucking fleets across a range of total trip times to the mill illustrated that for each operating distance from a delivery point, there is an ideal size trucking fleet that allows a contractor to operate at the least total cost. The area of least total cost for the contractor is the range of delivery times where the increased production from adding an additional truck more than offsets the additional cost of adding the truck (Figure 4). Thus, an optimal trucking configuration for each delivery distance can be derived from the cost values (Table 2).

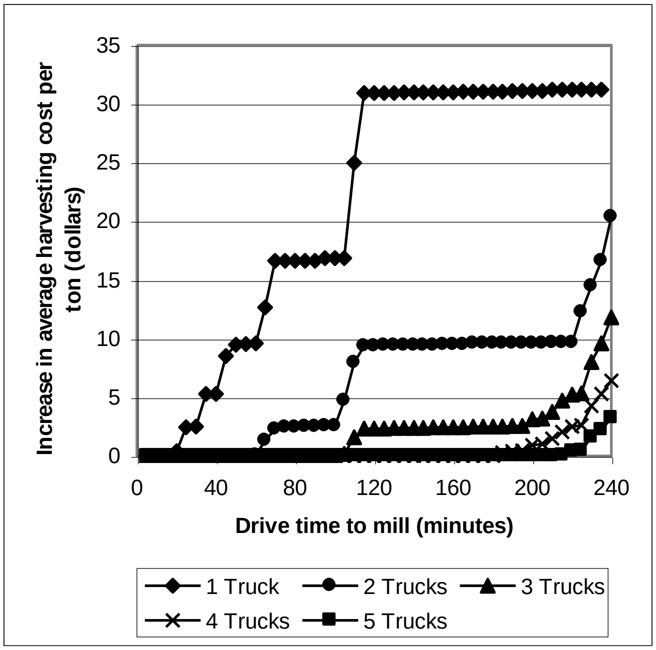

Figure 2. Increase in average harvesting cost per ton across different trucking scenarios as drive time to the mill increases and trucking limits production.

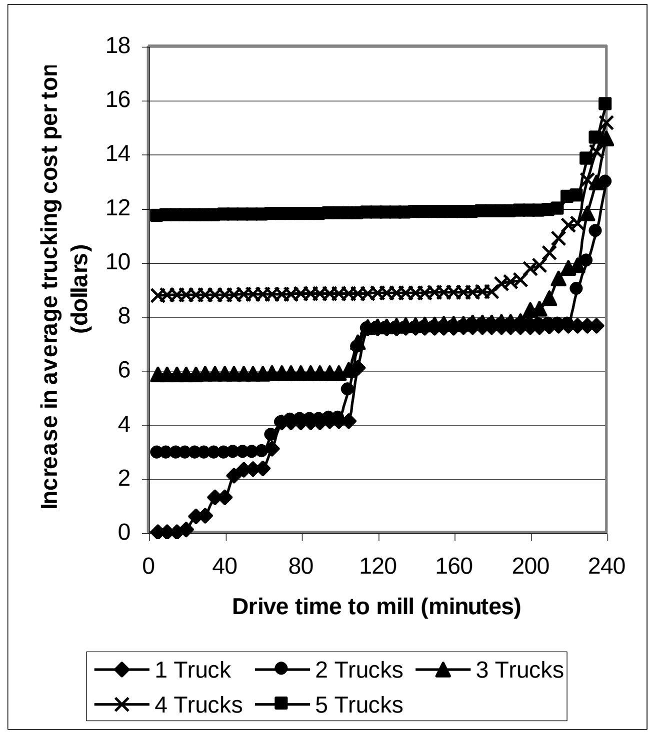

Figure 3. Increase in trucking cost per ton across different size trucking scenarios as drive time to the mill increases

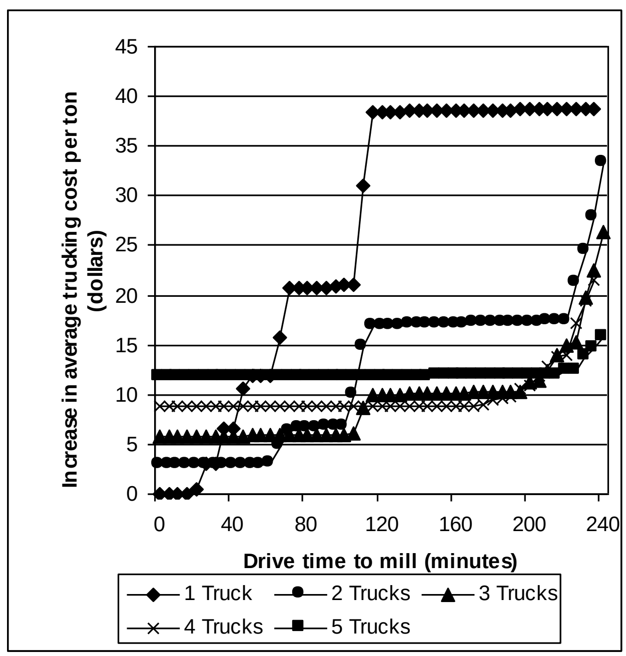

Figure 4. Increase in total cost per delivered ton across different trucking scenarios as drive time to the mill increases.

Table 2. Optimum number of trucks for ranges of drive times to mill for example contractor configuration.

Drive time to mill	Optimum number of trucks
0 to 20 minutes	1 truck
21 to 65 minutes	2 trucks
66 to 110 minutes	3 trucks
111 to 210 minutes	4 trucks
211 to 2410 minutes	5 trucks

The LTSS model also allows for simulation of situations common in the Appalachian region where multiple products are merchandised at the contractor's landing. Each product that is trucked from the landing can have a different mill destination where each mill has a different average turn time as well as different drive times to the mill. Example simulations with the model indicated that as more product sorts are required at the logger's in-woods landing, increased storage capacity is required at the landing and can lead to decreased average daily productivity. The decreases in average productivity were a result of increased product inventory stored on the landing and increased idle time for trucks as they wait for enough of a particular product to complete a truckload.

Figure 5 is an example that represents the same contractor's scenario (Appendix A) with 3 different drive times to the mill. For contractors with shorter drive times to the mill that have more excess delivery capacity in their trucking systems, average mill turn times must increase to a higher level before they cause the loss of a load per day and cause the trucking system to limit total production. While the exact point at which an increase in mill turn times will cause the loss of production from the contractor's trucking system depends on the individual contractor's system, the receiving mill is one point through which trucks from many contractors systems must pass through. Even though a higher average mill turn time may not impact a contractor's system with excess trucking capacity, the same turn time may be enough to cause another contractor to lose a load of production per day.

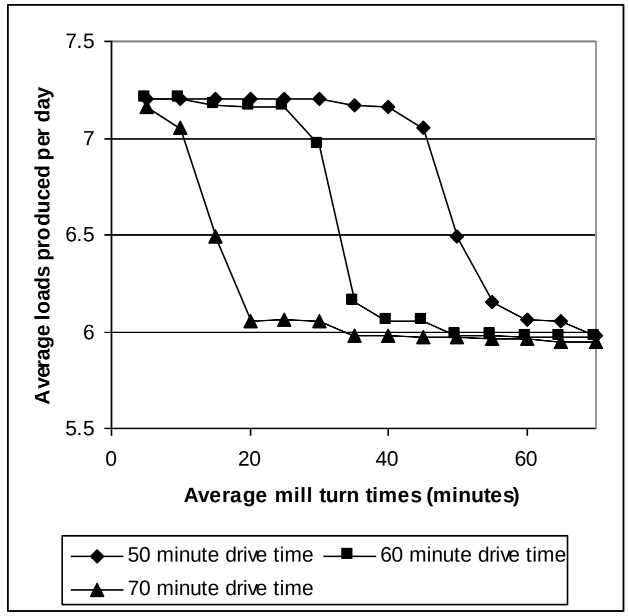

Figure 5. Average loads produced per day across three trucking scenarios as average mill turn time increases.

The model illustrated that for an individual contractor's trucking system there is a range where turn times can increase but will not impact the total number of loads per day the contractor can deliver. However, a point is then reached where even a minor increase in turn times will decrease production by a load per day. The LTSS model could be useful in identifying contractors who would be most likely impacted by increases in turn times. Giving priority to trucks from those contractor's systems and moving them through the mill as quickly as possible could potentially increase the productivity of the contractors at critical points in their delivery system without decreasing the overall productivity of the other contractor's trucking systems.

SUMMARY

The LTSS model provides the user with a tool for predicting the magnitude of cost and productivity changes to a logging contractor based on changes in the contractor's trucking system. The model can be utilized without an excessive amount of data collection and could allow foresters or logging contractors to evaluate the potential impacts to the contractor's production based on moving to a new harvest location where drive times and mill turn times may be different. Or the model could also be useful for decision making regarding allocation of stand harvests among different contractors, where it could help identify the adequacy of a contractor's trucking system based on drive times to the different receiving mills.

The LTSS model cannot predict all of the possible human, environmental, and mechanical interactions that can cause system variability and changes in logging contractor's production on a day-to-day basis. However, the LTSS model provides a tool that can be utilized with relatively simple input data to examine the operations of logging contractor and illustrate the potential magnitude of impacts that can occur as the logging contractor's trucking system affects overall system costs and productivity.

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USING MACHINES TO HARVEST HARDWOODS IN FRANCE

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ABSTRACT - In France, 13 million cubic meters of hardwoods are harvested every year. Until a recent time, the job was completely done by manual crews. But things are changing for different reasons. The number of chainsaw operators doesn’t stop decreasing. It is more and more difficult to find operators who still want to harvest small size trees, especially in areas affected by December 99 hurricanes. Consequently several companies (pulp mills and some saw mills) start to use machines to harvest hardwoods. There are several strategies, depending on the size of the trees to be harvested and on the type of operation (clear cutting, thinning…). Some of them use CTL methods and machines built for softwoods (single grip harvesters). Others use specific machines designed for hardwoods cutting and processing. AFOCEL studied some of these different logging operations: the preliminary results seem encouraging.

INTRODUCTION

In French broadleaved forests, 13 million cubic meters are harvested every year : 5 million as pulpwood, and 8 million as timber. The traditional way of harvesting is a two stage system :
1 - motor manual felling, delimbing and cross-cutting at the stump.
2 – hauling with forwarders or skidders, depending on the size of the logs, the slope...

More and more people think that this system is becoming out-of-date and that as softwoods, hardwoods have to be harvested by machines, for different reasons:
1 – number of chainsaw operators is decreasing,
2 – higher productivity,
3 – improving security,
4 – easier management…

Nevertheless several questions have to be answered, especially about feasibility, costs and social acceptability. AFOCEL is involved in several research projects : the aims are to study productivity and site disturbances of different systems of hardwood harvesting (tracked or rubber-tired machines, small or large harvesters...). In this paper, we presented three examples of very typical situations.

FIRST THINNINGS OR HARVESTING SMALL TREES

In state forests, the common way to manage oak and beech stands (these are the two widespread species in France) is natural regeneration, several spacing operations, and then several thinnings before final cutting of high quality timber.

The problem that happens concerns the first thinning: the size of the trees is so small (< 0.100 m^3 in average) that these can be used only as firewood or pulpwood. That means poor value products, and low productivity: no contractor is interested any longer in doing such a job. So the idea is to mechanize this operation, which is still considered by foresters as a crucial one to produce high value timber.

AFOCEL and ONF (National Forest Office) experimented from December 1999 to September 2000 mechanizing first thinning in three different stands with rubber-tire CTL harvesters usually used for softwood harvesting. These were driven by experienced operators used to work in softwood thinnings, and no special mechanical adaptation to hardwoods had been done on the material.

The machine moves in strips 4m width, every 11 or 12m, processing pulp or fire logs 2m length (top diameter 7, 8 or 10cm). Stand characteristics, productivity and damages on future crop trees have been studied, but also logs quality (*Cf*. Table 1).

These three experiments showed that:
- mechanizing first thinnings in broadleaved forest is possible,
- log quality and length accuracy can be ensured if right adjustments are done (increasing feed roll pressure, reducing knives pressure...),

- if the driver is very careful, very little damage is done, especially on future crop tree (most of injuries are above 1m height, and very few concern sap wood),
- productivity is not high enough to pay the cost of the work.

Table 1 Stand characteristics, productivity and damages on trees in 3 experiments of first thinnings mechanization

Experiment	N°1	N°2	N°3
Carrier & Head	SILVATEC 856 TH MD3 445	SILVATEC 896 TH 445 MD50	TIMBERJACK 1270 B 762 C
Cutting capacity	55 cm	50 cm	55 cm
Stems/ha before thinning	2220	1757	1750
% of trees removed	59 %	35 %	53 %
Total volume removed	40.3 m^3/ha	68.8 m^3/ha	85 m^3/ha
Mean volume of stem removed	0.037 m^3	0.092 m^3	0.095 m^3
Productivity	3.9 m^3/PMH*	8.5 m^3/PMH*	6.3 m^3/PMH*
Injured trees	13 %	4 %	18 %

* PMH : Productive Machine Hour

HARVESTING CHESTNUT COPPICE

Some areas in France (Charentes, Dordogne, Isère…) are well known for their chestnut coppices and their flooring and wainscoting industry. Usually, stands are harvested every 25 years, when trees DBH is about 15-20cm.

The problem is that December 1999 hurricanes blew down a lot of coppices, which are still to be harvested. And working in this kind of stand is so difficult and dangerous that very few people accept doing the job. For industries, it has become harder and harder to get a supply from chestnut coppices. To face the situation, some of them decided mid 2000 to use machines to harvest chestnut coppice.

For the moment, AFOCEL studied only two operations but others studies will soon be done with other machines (TIMBERJACK 770…), sometimes modified (addition of a top saw by example).

The two first studies concern clear cutting in pure chestnut coppice (*Cf.* table 2), done by two different kind of CTL harvesters built for softwood processing : a rubber-tired harvester (TIMBERJACK 1270) and a combo tracked excavator – harvesting head (LIEBHERR + WOODY 50). In both studies, the harvester had to process four different logs with special length (1.8, 2.1, 2.5 or 4m) and diameter constraints.

Results on these two studies are not really surprising :

- Feasibility of mechanizing coppice harvesting had been already proved. From 1993 to 1997, AFOCEL tested it with a compact CTL machine called SIFOR 614. The results showed that only some coppices with special characteristics could be economically and technically mechanized (fine branches, rather straight stems, size between 0.100 and 0.200 m^3…).
- Productivity measured on the KONRAD is far lower than the one measured on the TIMBERJACK when trees size is twice. This is not the fact of the machine, but the operator's (the operator on KONRAD machine is still training). Skilled operators are really crucial in hardwood mechanization, because of higher difficulties than in softwoods stands.

Table 2 Stand characteristics and productivity of mechanized clear cuts in 2 pure chestnut coppices.

Study	N°1	N°2
Carrier	TIMBERJACK 1270 B	LIEBHERR 900
Head	TIMBERJACK 762 C	KONRAD WOODY 50
Cutting capacity	55 cm	55 cm
Stems/ha	2500 (10 % windfalls)	1000 (50 % windfalls)
Total volume	273 m^3/ha	264 m^3/ha
Mean volume per stem	0.109 m^3	0.264 m^3
Productivity	8.2 m^3/PMH*	5.1 m^3/PMH*

* PMH : Productive Machine Hour

As both machines concerned by these two first studies are more powerful than the SIFOR 614, we presume that these machines will be able to process larger trees than 0.200 m^3. But after a few hundred hours of work in hardwoods, operators are already aware that breakdowns happen far more frequently than when working in softwood (problems with hoses…). And the larger the trees are, the more problems there are. That means maintenance costs increasing.

In the near future, further studies will be done to determine the optimum range concerning tree size for these machines, considering productivity but also cost of maintenance.

HARVESTING A MIX OF SMALL AND LARGE TREES

In the center part of France where soil conditions are rather poor, broadleaved stands haven't ever been really managed. Owners are farmers used to consider the forest as a wood store: they only cut special size or special species, depending on their needs, and they always leave some standing trees. As a result, the stands now look like a mix of small, medium and large sized trees but also a mix of species (oak, birch, beech, chestnut…). Most often, tree quality is poor : harvesting products are mainly pulpwood and a few saw logs.

Considering that conventional rubber-tired CTL harvesters built for softwoods aren't robust and powerful enough to process big and very limby hardwoods, International Paper Company entered in partnership with a Belgian manufacturer (FORICOM) two years ago to design a harvesting head able to process large hardwoods (*Cf.* figure1). This one surprised very many French foresters by its size and its disc saw, things never seen in France before.

HAC 2564

- Weight : 2900 kg
- 56 cm cutting capacity
- 52 cm delimbing capacity
- Butt saw : intermittent disk saw
- Topping saw : bar saw (30 cm capacity)
- 5 knives
(1 fixed top knife + 4 moving knives)
- 4 feed rollers

Figure 1. Principle characteristic of FORICOM head, designed for hardwoods harvesting.

Today five TIMBCO 425 tracked carriers equipped with this kind of head are working in hardwoods for the French IP pulp mill, mainly processing pulp logs 4m length.

AFOCEL did 15 productivity studies on these machines, 50% in blowdown. Productivity varies from 4 to 24 cubic meters per Productive Machine Hour, depending on the size of the trees (between 0.08 and 1 m^3). For the moment, technical cost doesn't seem different from traditional high cutting capacity rubber-tired harvesters (TIMBERJACK 1270…).

CONCLUSION

These three examples point to the fact that in France, hardwood harvesting can't be considered as one single problem : needs differ, depending on stands characteristics, on the kind of operation to be done (clear cutting or thinning). That means that probably there won't be one single solution either.

But more and more contractors, especially since December 99 hurricanes, want to mechanize hardwood logging. They do not choose the same technical solution (small or large harvester, tracked or rubber-tired carrier…), but they all work with the CTL system. Some of them are just experimenting, others are becoming skilled.

AFOCEL will continue studies on hardwood logging, and especially on maintenance costs, because it is too early to conclude if the right solution to each given problem already exists or not, from technical and economical points of view.

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Forest Fuel Reduction Through Energy Wood Production Using a Small Chipper/CTL Harvesting System

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ABSTRACT – In the summer of 2000, fire destroyed millions of acres of forest across the United States. This study investigates the feasibility of harvesting to reduce forest fuel buildup and produce energy wood. Cut-to-length (CTL) harvesting coupled with a small in-woods chipper provides a low impact way to harvest pre-commercial trees and tops along with merchantable logs. While CTL harvesting systems have been used successfully with full sized chippers, it requires two or three CTL teams. A smaller, less expensive, chipper which is expected to have similar productivity to a single harvester – forwarder team and have reasonable ownership and operating costs, will allow operations to stay small and efficient. A CTL/small chipper system is projected to be an efficient way of reducing forest fuel loads and less expensive than fire suppression and stand-replacement costs after wildfire. Energy wood from fuel reduction harvesting could be used as an alternative energy source. The benefits of energy wood become more important as fuel prices increase. The feasibility study suggests that if energy equivalent values were obtained, a CTL/small chipper system could provide income rather than expense for site conversion, cleanup operations.

INTRODUCTION

Most forest industry professionals agree that smaller trees will be the wood and fiber source of the future. With increased intensive forest management practices, trees are growing faster and producing value more quickly. This forces industry and land managers to look into new and more innovative ways of harvesting small trees. Fire control and exclusion have led to an increase in the non-commercial midstory and understory components of forested stands (Mitchell and Rummer 1999). Most of the national forests, as well as other federal, state, and private landowners, have problems of overstocked and stagnated stands of trees. Typically, these stands have very large numbers of stems per acre and their growth has stagnated before the trees have reached a size that would contain marketable material by conventional standards. Besides being a utilization problem, these stands are very vulnerable to fire or insect attack because of the stressed nature of the trees. Conversion of these stands, removing the existing trees and re-establishing more appropriate species, is also cost prohibitive because of the lack of efficient harvesting methods for this material (Karsky 1992).

In densely overpopulated stands, which have developed without stocking controls, small trees can cause fire hazards by high levels of fuel loads. Small trees tightly spaced in the understory of mature forests create a fire ladder increasing the risk of a possible stand destroying fire. Small trees, limbs, and tops, without current merchantable value, are potential targets for in-woods chipping operations. Some advantages of an in-woods chipping system include the ability to recover fiber from limbs, tops, and un-merchantable wood, high productivity, and advanced site preparation (Stokes 1988). Current in-woods chipping operations also have the disadvantage of requiring large tracts of timber for successful operations due to the high cost of moving and setting up large, expensive chipping machines from tract to tract.

SYSTEM BACKGROUND

Cut-to-Length (CTL) harvesting systems have proven to efficiently harvest a variety of tree sizes including first commercial thinnings. Studies have shown CTL to be a low impact form of harvesting. It provides minimal residual stand and site damage and requires less manpower and leaves fewer slash piles than traditional tree-length systems (Lanford and Stokes 1995).

Many CTL harvesting systems offer state-of-the-art equipment and the best available technology to maximize timber utilization, and protect water quality and other natural resources at the same time. In CTL operations, the two-machine system, a harvester and a forwarder, balance to give an efficient operation for smaller tracts. The harvester provides the felling, limbing, and bucking functions. Harvesters can be mounted on excavator carriers using tracks or purpose-built carriers with bogie rubber tires with tracks, which reduces soil compaction especially when a bed

of limbs is placed in the tread way. Many harvesters fell and process trees with an attachment mounted on a boom, therefore using a swing-to-tree motion for felling, as opposed to the drive-to-tree method used by most feller-bunchers. The harvester reaches many trees from a single location without moving, which reduces the amount of travel throughout a stand. Less travel means less soil compaction and damage to residual trees.
The second machine in a CTL system is a forwarder. This machine can have four, six, or eight tires and appears similar to a skidder with a loader and trailer attached. Instead of using a traditional skidder, which drags wood on the ground, a forwarder carries wood clear of the ground. Due to large payloads, a forwarder can haul wood economically for long distances and needs only minimum skid trails and landings. Less soil is displaced, rutted, and compacted. The onboard loader can place logs for stream crossings and easily remove them when the crossing is no longer needed. The short length of a forwarder and wood package translates into less stand damage (Hartsough, Drews, McNeel, Durston, and Stokes 1997, Lanford and Stokes 1995).

This system varies from the typical southern tree-length system because the trees are limbed and bucked into lengths at the stump, leaving limbs and tops evenly distributed throughout the tract (Stokes 1988). With social and aesthetic concerns becoming increasingly important, CTL operations stand to become the system of choice.

CTL systems with only a single harvester and forwarder do not match well with traditional in-woods chippers. Traditional chippers are very costly and require two to three CTL teams to provide an adequate supply of wood. Since it would be highly desirable to combine the advantages of this low impact system with in-woods chipping, a possible solution would be to use CTL with a smaller chipper.

A smaller, less expensive chipper might have reasonable ownership and operating costs and allow operations to stay small and efficient. A CTL/small chipper system could also prove to be an efficient way of reducing forest fuel loads. Recent wildfires in the Western US have destroyed millions of dollars of valuable timber and property. Public demand for wildfire protection is growing. Recent drought years, tree species composition changes, and declining forest health within fire dependent ecosystems have exposed a large number of communities to a potential for stand-replacement fires. For many reasons, including fire suppression, forests that were once relatively open have become dense with trees and understory brush. Fire exclusion has allowed trees to fill stands that were once characterized by widely spaced fire resistant trees. Large wildfires can have major ecological impacts on soils, fish, wildlife, water resources, timber resources, recreation uses, air quality, visual quality, archeological sites, homes, developed structures, electronic sites, and human life. Wildland fuels have been accumulating over the past fifty years due to wildland fire management policies, wildland management practices, and other factors. As a result, the number and size of large, intense fires have grown over the last decade, resulting in higher fire suppression and preparedness costs and greater damage.

The suppression and stand-replacement costs from these fires are expected to be higher than many fuel reduction methods. Fuel reduction is not an easy operation to execute. Traditionally, forest fuels have been reduced by prescribed fire, but prescribed fire is unpopular due to increased liability concerns and state and federal regulations associated with smoke management.

The use of commercial thinning in dense stands for fuel reduction can also be difficult and expensive within the current merchantability standards. Thinning of a stand for fuel reduction with most stems being of non-merchantable size is expensive for conventional tree-length and CTL systems due to low production, and therefore, high costs of wood produced.

PROPOSED SOLUTION

Use of a CTL/Small Chipper operation may be a possible solution. This system may be able to reduce forest fuel loads by reducing the number of trees per acre and removing slash produced during the harvesting operation. In overstocked, even-aged stands and multi-storied stands alike, reduction in the number of trees per acre will open the forest canopy releasing the better trees to grow in value. With this approach, previously non-merchantable stems will become merchantable.

For trees with only energy value, it is anticipated that harvesters will be more productive by only felling without processing. Forwarders will carry entire trees off the ground in full tree form (stem, top, and limbs) along with limbs and tops from merchantable trees, therefore leaving minimal slash for future fire hazards. The larger payload of forwarding is preferred over ground skidding to keep the material free of dirt, which provides longer life for chipper knives.

Even if the smaller chipper cannot provide chip quality acceptable for pulp due to bark content, chips will be useable for energy wood. With fuel prices at an all time high, energy wood from this type operation could prove very marketable. Since CTL operations excel in the merchandising of small sawlogs, even from overstocked stands, the combined value of chips and merchandised products might be very profitable. Also, landowners may be willing to accept a reduced stumpage payment if they get the "cleanup" of this type of operation.

The use of wood as a fuel source works extremely well in the forested U.S., especially in areas where alternative sources are scarce. Only a small fraction of the total amount of wood biomass available for fuel is actually used to produce energy. Because of technical, economic, and social reasons, the utilization of wood fuel has been slow to gain wider acceptance (Stokes 1989). Fuel chips are fairly homogeneous which makes the product work well with existing handling systems from storage to the furnace. In eastern Canada, fuel chip burning installations are typically found in schools, hospitals, greenhouses, factories, etc (Stokes 1989). In the U.S., fuel chips can be used to fire kilns at lumber mills and digesters at pulp mills. They also have municipal purposes such as mulch for landscaping and organic matter for flower gardens. With technology increasing daily, uses for wood fiber, as an alternative energy source, are expected to expand.

A metric green tonne of chipped slash at 45 percent moisture content has an energy content of approximately 8750 mJ and, assuming a 65 percent energy conversion efficiency, it will produce 5687 net mJ in a furnace. In comparison, a barrel of bunker "C" oil contains 6508 mJ and, assuming 85 percent energy conversion efficiency, will yield 5532 net mJ. A metric green tonne of chipped slash is therefore roughly equivalent to one barrel of bunker "C" oil (Stokes 1989).

With rising gas and oil prices, and the positive effects of producing energy from a renewable natural resource coupled with reducing forest fuel buildups for fire prevention, the CTL/small chipper approach seems to have promise for the future.

CONCEPT FEASIBILITY

In order to better understand the cost relationships of in-woods chipping with CTL harvesting, a target stand of trees was identified from forest inventory records (USFS 2001) (Table 1) and harvested using the Auburn Harvesting Analyzer methodology (Tufts et al 1985). A review of current efforts to reduce fire hazards has not identified a "typical" stand, but it is expected that this stand will probably represent a high fire hazard situation. The harvesting of this stand will represent a conversion from a high fire risk to a cleared area ready for planting. Since all material will be harvested, the site will need little or no additional site preparation before planting. It is recognized that other fire hazard reduction scenarios exist such as thinning of young overstocked even aged stands and removal of understory with some merchantable overstory removal.

The stand in Table 1 would be considered half stocked or less with merchantable trees, most of which are of saw timber quality. Total tons are expressed as the green weight of the total tree (wood, bark, and foliage) above the stump. Merchantable tons are expressed as the green weight of the stem (wood and bark) to a 4-inch top (not including limbs, tops, or foliage). The merchantable portion of the stand will be merchandized into products and delivered to a mill for maximum revenue. Non-merchantable tons are defined as the difference between total tons and merchantable tons. This is the portion of the stand including limbs, tops, and foliage from diameters of 5 inches or greater and total trees with diameters less than 5 inches. It is assumed that all non-merchantable material will be chipped for energy wood. Approximately 27 percent of the total above ground biomass is currently considered non-merchantable.

Table 1. Typical Natural Southern Pine Stand in the Southeastern United States with a Dense Non-merchantable Understory

DBH	Trees per Acre[1]	Total Height[1]	Total Tons per Acre[2]	Merchantable Tons per Acre[2]	Non-Merchantable Tons per Acre[2]
1	78.38	10	0.10	0.00	0.10
2	62.96	15	0.43	0.00	0.43
3	57.94	15	0.82	0.00	0.82
4	43.06	25	1.65	0.00	1.65
5	12.08	30	0.82	0.71	0.11
6	9.87	40	1.29	1.10	0.18
7	8.08	45	1.63	1.38	0.25
8	6.64	55	2.14	1.80	0.34
9	5.93	55	2.45	2.04	0.42
10	4.01	65	2.42	2.00	0.42
12	3.63	70	3.45	2.81	0.65
14	2.94	75	4.13	3.31	0.82
16	2.06	80	4.08	3.23	0.85
18	1.16	80	2.95	2.31	0.65
20	0.93	80	2.96	2.29	0.68
TOTAL	299.67		31.33	22.97	8.36

[1] USFS National Forest Inventory and Analysis Database Retrieval System
[2] Clark and Saucier 1990

Cost and productivity estimates of CTL harvesting were based on a study by Lanford et al (In review). The small in-woods chipper costs and productivity were projected from personal conversations and chipper manufacturer literature. Costs and productivity were estimated for cutting the total stand and chipping the non-merchantable portion. Costs from this calculation were compared to costs of harvesting only the merchantable portion. The difference of these costs would be the incremental increase in cost caused by harvesting the non-merchantable portion.

During harvesting, non-merchantable trees will be felled and piled along with limbs and tops from merchantable trees. Merchantable portions will be processed into log lengths and piled separately. The forwarder will transport the non-merchantable material to a chipper and merchantable log lengths to setout trailers. The forwarder will feed the non-merchantable portion, with its onboard loader, directly into the chipper, which will blow the energy chips into a van.

Cost assumptions, as shown in Table 2, represent a compilation of user and manufacturer recommendations for CTL systems and small chippers.

Projected harvesting costs for a forty-acre tract with a stand as shown in Table 1 using a CTL/small chipper system are shown in Table 3. To balance the harvester and forwarder productivity, the forwarder was operated for two shifts with different operators. While tonnage increased by 36 percent when all biomass was harvested, the average DBH declined by 50 percent. Harvesting of merchantable and non-merchantable components increased onboard costs by 61 percent as compared to harvesting only the merchantable portion.

Table 2. Cost Assumptions for a CTL/Small Chipper System

Machines	Harvester	Forwarder	Chipper
Initial Cost ($)	422,000	267,000	60,000
Expected Life (yrs)	6	6	5
Fuel and Lubrication ($/PMH)	7.03	6.42	9.26
Repair ($/PMH)	10.79	5.06	171.43
Labor ($/SMH)	12.50	25.00[1]	0.00

[1] Labor cost is for two forwarder operators; each working one shift per day to balance the system.

The difference in cost between harvesting only the merchantable portion of the stand and harvesting the merchantable and non-merchantable portions will be equal to the cost of harvesting non-merchantable material. For the stand in Table 1 harvesting costs will be $334.20 per acre for the non-merchantable material. This translates into a $39.98 per ton cost.

Table 3. CTL/Small Chipper Cost Projections

Harvested Portion		Merchantable Portion Only	Total Above Stump Biomass
Average DBH (inches)		9.09	4.58
Tons / Acre		22.97	31.33
$ / Ton	Fell and Process	2.96	4.27
	Forward	2.74	3.53
	Chip	0	2.40
	Support	2.07	2.35
	Total (Onboard Truck)	7.77	12.54
	Haul (75 miles)	14.33	14.33
	Total (Cut-and-Haul)	22.10	26.87
Total $ / Acre		507.64	841.84
Delivered cost of energy wood		**$334.20 / Acre $39.98 / Ton**	

Dubois et al (2001) reported the following per acre stand regeneration costs: shearing, raking, and piling - $144.53; chemical site preparation - $95.05; burning - $22.13. While chemical treatments were not added during the CTL/small chipper harvest, the tract will benefit equivalent to having it sheared, raked, piled, and burned for a total savings of $166.66 per acre.

In addition, the material removed as chips can be converted to energy. Based on Stoke's (1989) conversion to crude oil, a metric green tonne of chipped slash roughly has an energy content equivalent to one barrel of crude oil. (One imperical ton equals 1.0160 metric tons.) At current oil prices of $25.59 per barrel for crude (Nymex, April 2001), energy wood is worth $26.00 per ton. For the stand in Table 1, this equates to an income of $217.36 per acre.

Combining harvesting costs with site preparation savings and income from energy wood sales gives a net saving and income of $49.82 per acre. Assuming that this net income could be realized, a complete site preparation would only cost $45.23 per acre if a chemical treatment were included.

Another approach might compare the CTL/small chipper application to manual pre-commercial thinning. Dubois (2001) reports pre-commercial thinning costs to be $82.67 per acre. Taking the energy income from the harvesting cost leaves a cost of $116.84 per acre. While more expensive than pre-commercial thinning, the resulting stand would have the non-merchantable material still on the ground that might be a fire hazard. If the harvesting treatment can be counted for site preparation, the added saving ($166.66 per acre) would again put the CTL/small chipper approach as an income producer rather than a cost center.

CONCLUSIONS

The proposed harvesting system not only harvests material economically, but also provides energy wood, a product to be sold for monetary gain. The CTL/small chipper system also utilizes the non-merchantable portion of merchantable size trees, which in the past has normally been wasted. The gain from the value of energy wood and merchandized logs makes this system attractive in monetary terms, not to mention the fuel reduction gains received.

Based on this brief feasibility examination, there appears to be an opportunity to reduce fire hazards and create income from energy wood using a CTL/small chipper harvesting system. There are a number of questions that will be answered during field studies such as 1) productivity of the harvester felling very small trees, 2) productivity of the forwarder transporting and feeding the chipper with the non-merchantable material, 3) productivity and costs for the small chipper, and 4) amount of non-merchantable material that can be recovered with this approach.

For this report, only a stand conversion scenario was explored. Partial cuts in young and mature stands need to be examined. Also, $26 per ton energy wood value exceeds current market rates. Only after field verifications of costs would industry seriously consider a large-scale use of energy wood. Although it is felt that with proper utilization this value can be realized.

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Designing a Forest Road Network using Heuristic Optimization Techniques

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ABSTRACT - This study developed a methodology for generating good alternative locations for road networks using heuristic solution techniques. Locations for road networks are determined based on road standards, timber harvesting and transportation costs, and topographic conditions. The main access road route is designed first and then single stand access roads are located as branches. A Genetic Algorithm (GA) is used to optimize main access road locations. Feasible solutions forming an initial population for the GA are generated by Simulated Annealing. This paper explains the methodology and presents a preliminary result for a simple application. The result implies that heuristic techniques may be useful tools for solving complicated forest road location problems.

INTRODUCTION

Developing a forest road network to access multiple stands is a challenging task. Traditionally engineers have developed road networks manually using a topographic map, but it is not an easy task to find a good road location while simultaneously considering economic, topographic, and forest management activities.

With the purpose of assisting engineers in developing forest road networks, various computerized methods have been introduced. Reutebuch (1988) developed a computer program, ROUTES, to help engineers with estimating grades and distances along a possible route using a digital terrain model (DTM). Liu and Sessions (1993) developed a methodology to find the least cost road segments from entry points to destinations while considering construction, maintenance, and transport costs over multiple time periods, and various topographic conditions. NETWORK II (Sessions 1985), a computer software program for solving transportation planning problems, was used as an optimization tool in the study of Liu and Sessions (1993). Branch evaluation, a heuristic method developed by Dean (1997) is an automated method of developing a road network designed to access any number of potential harvesting sites while minimizing the overall cost of the network. Both models by Liu and Sessions (1993) and Dean (1997) have the ability to solve multiple target access problems with designated targets and predefined cost matrix or link variables. In some cases, however, especially in developing skid trails or temporary access roads for timber harvest, the ending location of each road branch is not always fixed. Dahlin and Sallnas (1992) tried to find the optimum road location without a designated target while considering trade-offs between off-road transportation cost and road construction cost. They applied a simulated annealing (SA) method to optimize road location and suggested the algorithm could be possibly used for planning a road network.

This paper presents a computerized method for generating good alternatives for a forest road network using a DTM. Two different road standards are considered in the network (Figure 1). The main access road route is designed first and then single stand access roads are located as branches. The objective of this study is to apply heuristic optimization techniques to solve a forest road location problem and to evaluate their usefulness. A genetic algorithm (GA) combined with SA is used for optimizing road location. It is not within the scope of this paper to compare this method with other possible optimization techniques.

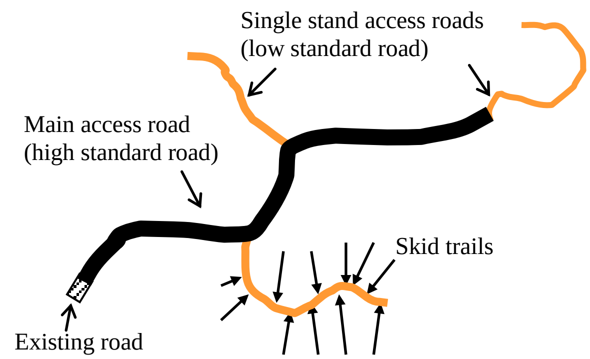

Figure 1. A forest road network consists of roads with different road standards.

HEURISTIC SOLUTION TECHNIQUES

SA and GA are used in this study to optimize road location. Both algorithms are based on a Monte Carlo method and have been widely used to solve large combinatorial problems in various fields (Kirkpatrik et al. 1983, Srinivis and Patnaik 1994).

SA uses a local search in which a subset of solutions is explored by moving from one solution to a neighboring solution. To avoid becoming trapped in a local optimum, the procedure provides for an occasional acceptance of an inferior solution in order to move away from a local optimum. In forestry, SA has been investigated by a number of researchers including Lockwood and Moore (1992), and Murray and Church (1995), to solve spatial harvest scheduling problems involving adjacency constraints. SA has also been applied to a forest road location problem by Dahlin and Sallnas (1992).

GA developed by Holland (1975) is based on the mechanics of natural selection and genetics. It starts with a set of feasible solutions called a population. Solutions are selected from the population either randomly or according to an objective function value and are combined by a crossover and mutation process to form new solutions. This procedure is repeated until a stop criterion (i.e. homogeneity of solutions) is satisfied. In forestry, GA has been used by Lu and Eriksson (2000) and Mullen and Butler (2000) for forest operational planning and harvest scheduling problems. However, we could not find applications of GA to forest road location problems in the literature.

ROAD NETWORK DESIGN METHOD

The method developed in this study for designing a forest road network with two different road standards (main access road with a high standard and single access road with a low standard) consists of the following two steps:

1) Optimizing main access road location using GA. SA is used to generate initial solutions for the GA process.
2) Optimizing the location of a single stand access road for each harvest unit using SA.

OPTIMIZING MAIN ACCESS ROAD LOCATION

A main access road to multiple harvest units is projected considering accessibility to each unit, harvest volume, topographic conditions, and road construction cost. The projection process starts with finding the weighted centroid by timber volume in each unit. Then SA generates and evaluates random solutions and finds good possible alternative routes. Using the solutions found by SA as initial solutions, GA optimizes main access road location and provides the best route as a 'good' alternative for a main access road.

Finding a weighted centroid in each harvest unit

Locating a main access road requires consideration of access to each harvest unit. Distance from the centroid of a unit might be a possible approximation to measure the accessibility of the main access road. In this study, the weighted centroid by harvest volume is used in order to consider unevenly distributed volume within a unit. Location of a centroid on the DTM is determined as the grid cell with the minimum sum of distance times volume from all the other cells within the unit (Figure 2).

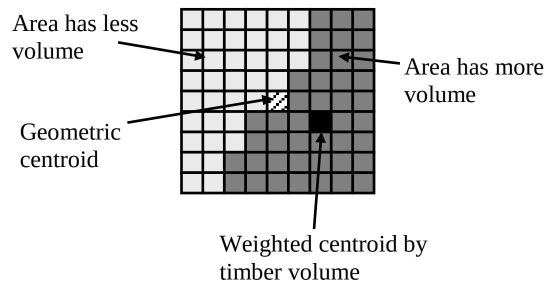

Figure 2. Weighted centroid by timber volume in a harvest unit having unevenly distributed timber volume.

Generating a random feasible route on the DTM by SA

A random feasible route can be generated by the following steps:

Step 1: Select one of the grid cells in the current solution (road route) as a starting point of the next solution. If the current solution does not exist, the starting point will be the connecting location with the existing road.

Step 2: Randomly select a total number of cells that are to be used in constructing the next route. The range of possible values could be provided beforehand depending on the size of the area in consideration.

Step 3: Randomly select and move to one of the candidates available for the next road cell (Figure 3). The candidate cells should meet road design criteria based on a given road standard. Road design criteria could include maximum road gradient or maximum deflection angle. (Figure 3)

Step 4: If the total number of road cells on the route exceeds the selected number in Step 2, then stop projecting. Otherwise, go back to Step3.

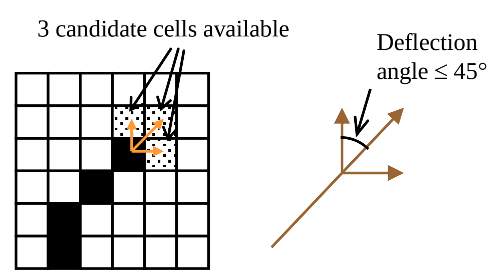

Figure 3. Finding a next road cell in DTM

Evaluating an alternative solution

Each route is evaluated by calculating its objective function value. The objective function includes total road construction costs including main access road and all single stand access roads, and timber transport costs along the single stand access roads (Equation 1). In each unit, the shortest distance from the centroid to the main access road multiplied by a weighting factor is assumed to be the total length of a single stand access road for the unit (Figure 4).

[Eq. 1] $$\mathrm{Min}\left(\begin{array}{l} \sum_{i=1}^{I}\left(RC1 \times SF_i \times Dist1_i\right) \quad + \\ \sum_{j=1}^{J}\left(RC2 \times Dist2_j \times WF \; + \; TC \times TV_j \times \; Dist2_j \times WF\right) \end{array} \right)$$

where,

I = total number of cells on the main access road
$RC1$ = main access road construction cost ($/m)
SF_i = a slope factor for weighting road cost by side slope at the grid cell *i*
$Dist1_i$ = distance over the grid cell *i* (m)
J = total number of harvest units
$RC2$ = single stand access road construction cost ($/m)
$Dist2_j$ = shortest distance from the centroid of harvest unit j to the main access road (m)
WF = a weighting factor for estimating the length of single stand roads
TC = timber transport cost over single stand access roads ($/m^3-m)
TV_j = total timber volume in stand j (m^3)

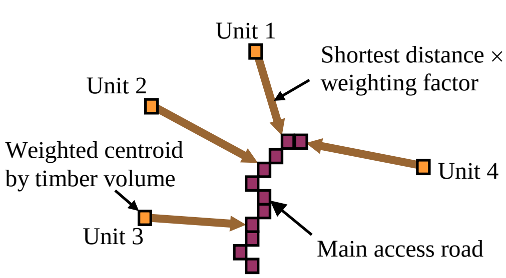

Figure 4. An example of evaluating the accessibility of a main access road to each harvest unit.

Optimization process by GA

GA is used for optimizing the main access road location in this algorithm. GA starts with a set of solutions forming an initial population that could be either generated randomly or pre-selected by the SA algorithm. With an initial population, GA optimizes road location using the following steps:

Step 1: Select two solutions (parents) from the initial population. These can be selected randomly or based on their objective function values.
Step 2: Find grid cells shared by both parents. If no shared grid cells exist, go back to Step 1 and select another solution for the second parent.
Step 3: Randomly Select one of the shared grid cells (crossover points) and then swap head and tail between the two parents resulting in two new solutions (Figure 5).
Step 4: Check if the new solutions meet road design criteria. If a new solution violates any of criteria (i.e. maximum deflection angle or maximum grade of road), penalize the solution by adding a large number to its objective function value.
Step 5: Evaluate the new solutions. Select and keep the best solution among the two new solutions and the two parent solutions for the next generation.
Step 6: Repeat step 1 through step 5 until the variation in the population becomes smaller than a given threshold.

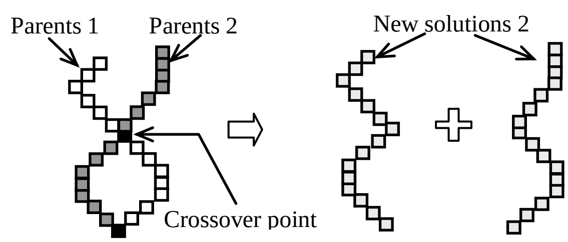

Figure 5. Generating new solutions by GA.

OPTIMIZING SINGLE STAND ACCESS ROADS

After a main access road is developed, single stand access roads are projected out from the main road. Among the multiple harvest units, the closest unit to the main road is selected and the routing process starts from this unit in order to avoid "overriding roads." The closest point on the main road from the selected unit becomes the origin of an access road. After an access road for the first unit is developed, the procedure moves to the next closest unit from any of the roads already planned in the network and begins optimizing road location for the unit. The origin location this time would be the closest point on any road in the network. GA, SA, or the combined algorithm can be applied to optimize single stand access road location. Trade-offs between road construction cost and off-road timber transport cost (skidding or forwarder cost) are considered in evaluating alternative routes. The objective function is presented in Equation 2.

[Eq. 2] $$\mathrm{Min}\left(\sum_{k=1}^{K}\left(\mathrm{RC2}\times \mathrm{Dist3}_k \times \mathrm{SF}_k\right)+\sum_{l=1}^{L}\left(\mathrm{SC}\times \mathrm{Dist4}_l \times \mathrm{TV}_l\right)\right)$$

where,

K = total number of cells on a single stand access road route
RC2 = single stand access road construction cost (\$/m)
$\mathrm{Dist3}_k$ = distance over the grid cell *k* (m)
SF_k = a slope factor for weighting road cost by side slope at the grid cell *k*
L = total number of cells in the harvest unit
SC = skidding cost (\$/m^3-m)
$\mathrm{Dist4}_l$ = shortest distance from each grid cell to the single stand access road (m)
TV_l = timber volume in the grid cell *l* (m^3)

EXAMPLE

To demonstrate how the method works, a preliminary road network plan for a small area (625 ha.) is developed from a DTM with a 25m × 25m grid cell size. The area was divided into 9 sub-harvest units and timber volume ranging from 100m^3/ha to 500m^3/ha was unevenly distributed regardless of the unit boundary. Ground based timber harvesting operations are to be used over the entire area. Currently no road exists except for a road located in the southern portion of the area.

The network developed in this example has two different road standards: main access truck roads with rock surface, and dirt roads to access each single stand. Figure 6 presents the main access truck road developed by the combined method of GA and SA. One hundred solutions generated by SA formed an initial population for the GA process. GA found the best solution after ten generations and it improved the solution by 7% from the best initial solution (Figure 7). Figure 8 shows each single stand access road generated by SA. Table 1 shows the road parameters and costs used in this example.

Table1. Road parameters and costs for example.

Maximum gradient		16%
Maximum deflection angle		45°
Rock surfaced truck road cost (RC1)		\$31,250/km
Dirt truck road cost (RC2)		\$4,375/km
Slope factor (SF)	< 20%	1.0
	20% - 30%	1.5
	30% - 40%	3.0
	40% - 50%	6.0
	> 50%	12.0
Timber transport cost (TC)		\$0.3/m^3-km
Skidding cost (SC)		\$40.0/ m^3-km
Weighting factor (WF)		10

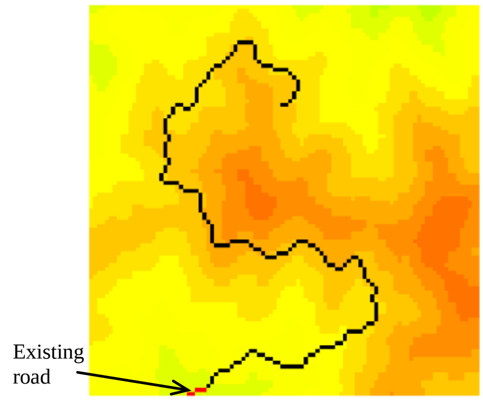

Figure 6. Main access road developed by GA combined with SA.

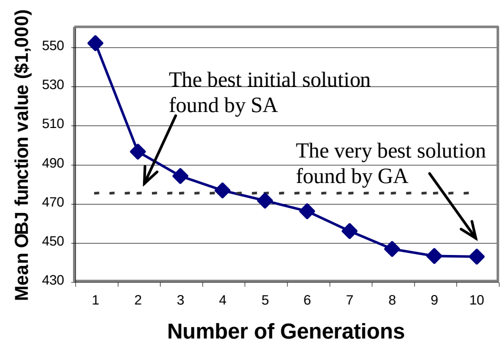

Figure 7. Optimizing process in genetic algorithm.

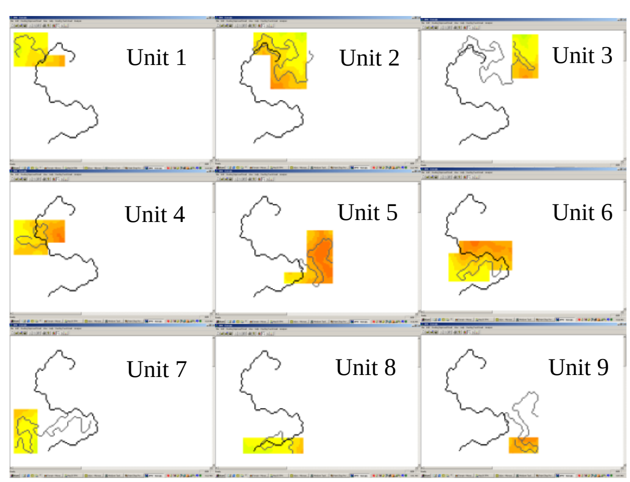

Figure 8. Single stand access roads developed by SA.

DISCUSSION

Although heuristic solution techniques are widely used to solve large combinatorial problems, they have not been often applied to solving road routing problems. The reason may be because of the difficulty in generating feasible solutions using a random method due to road connection problems. This study investigated two heuristic solution techniques, SA and GA, to solve a road routing problem. The following limitations of both methods in the application have been found:

- Neighborhood search in SA might be limited in this application because changing a portion of a route could easily make a solution infeasible. Further work on generating feasible neighbors should be conducted for the better performance of SA.
- The GA technique implemented in this application may also have limitations in generating new solutions because the process of random crossover and mutation could be restrictive. Due to this limitation, GA may not be able to explore enough of the solution space and the final solution could be largely influenced by the initial solutions.

Despite these drawbacks, SA and GA techniques with further study may be possible methods to solve road routing problems and could generate 'good' alternative routes for a road network plan. The ability of SA to handle a large combinatorial problem and its applicability to various problems is attractive. The ability of GA to combine different routes while retaining parts of them may be useful. Once we have good alternative routes, the GA process might be able to generate a better alternative route by combining 'good' parts taken from different alternative routes.

With further study, the methodology presented in this paper could provide engineers with good alternative choices for a forest road network plan. Engineers could generate alternative routes and conduct sensitivity analysis by changing road parameters and costs. The ability of this methodology to deal with multiple road standards may be useful in developing a road network associated with a specific harvest operation system. A well-designed road network and harvest operation plan would be able to reduce environmental impacts as well as overall harvest operation costs.

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Managing Existing Road Systems: How Should Priorities Be Set?

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ABSTRACT - The management of existing road systems has become increasingly difficult as structures such as culverts and bridges have reached the end of their useful life, environmental concerns for aquatic habitat have become increasingly important, and budgets are fixed. A method is needed to prioritize possible road construction and reconstruction projects within a given budget. It is clear that managers want to receive the greatest environmental benefit for every dollar spent. What is not clear is what factors should be included in a measure of environmental benefit and how these factors should be measured. This paper reviews the available literature and identifies gaps in the knowledge base. Suggestions are made as to how these gaps can be filled.

INTRODUCTION

Due to increased environmental concerns, especially for aquatic habitat, the management of existing road systems needs to not only take economic factors into consideration, but environmental impacts must also be taken into account. One approach is to prioritize road maintenance and reconstruction activities on the basis of a cost: benefit ratio where the cost is the cost in dollars of completing a given project and the benefit is some measure of environmental impact.

This paper will look at five measures of environmental concern that many agree should be included in any road management system in western conifer forests:

- Risk of road-induced landslides,
- Estimate of landslide runout and sediment delivery potential and quantity to perennial streams,
- Risk of road failure due to undersized culverts and other structures,
- Sediment entering streams from culvert failures and surface erosion, especially traffic-induced surface erosion, and
- Quantifiable measures of salmonid habitat quality.

The literature will be reviewed for each of these five measures. The practical application of each will be discussed. Gaps in the knowledge base will be noted and suggestions will be made as to how these gaps may be filled.

LANDSLIDE RISK

Review

Mass failures have long been regarded as major contributors to the sediment budgets of Western forested watersheds (Dietrich et al., 1982) and serve the important roll of adding complexity in the form of sediment and woody debris to stream channels (Naiman et al., 1992, Swanson et al., 1982). However, roads have been found to significantly increase the risk of landslide occurrence (Amaranthus et al., 1985, C.L. Rosenfeld, 1999) by as much as 88% (Megahan et al., 1979) beyond natural conditions (Reeves et al., 1995).

Rosenfield (1999) analyzed a video transect across the Oregon Coast Range after the 1996 storms and found that the majority of landslide events occurred on slopes steeper than 30° and were associated with sedimentary bedrock. Topographic position is also a factor of many landslide risk models (Montgomery and Dietrich, 1994, Dietrich et al., 1995). This is accomplished by adjusting risk ratings based on upslope contributing area as well as soil type.

Iverson et al. (2000) introduced and extrapolated on a mathematical model (Iverson, 2000) that uses soil water content, groundwater pressure head, and contributing area to predict landslide occurrence on a site-specific basis.

Discussion

For landscape-scale estimates of landslide risk, those measures that can be easily calculated using a geographical information system (GIS) will be the most useful. Iverson's (2000, Iverson et. al., 2000) work is helpful in understanding the mechanisms that control landslide occurrence, but uses measures that are not easily obtainable on a large scale. Factors such as local slope, soil type, and upslope contributing area are easily calculated using a GIS. Road construction date and method (i.e. side cast versus full bench construction) could be used to scale risk ratings.

LANDSLIDE RUNOUT AND DELIVERY

Review

Major and Iverson (1999) have conducted flume experiments to determine the mechanics of debris flow runout. Particle size distribution and pore-fluid pressure were determined to be the major factors affecting the runout of a debris flow.

Discussion

While Major and Iverson's work is important in a theoretical sense, it is not useable on a large scale. Models will need to be created or refined from landslide inventory data to determine reliable factors that can help predict landslide runout. These data may also be useful in creating models for landslide volume. However, our knowledge may not be great enough at this time to predict landslide volume and averages may need to be used.

ROAD FAILURE DUE TO UNDERSIZED CULVERTS

Review

The field of civil engineering has long used intensity-duration-frequency (IDF) curves and contributing upslope area to determine minimum culvert sizes (AISI, 1994). This is the same method used today to determine minimum culvert sizes for forest roads.

Discussion

From empirical evidence, the primary cause of culvert failure is not flow beyond what a culvert can pass, but debris dams at the culvert inlet. Much of the debris that blocks culvert inlets is sticks and other vegetation. The blockage of a culvert due to a debris dam is not a factor that can be well predicted using a GIS or any other means.

In order to assign a risk rating to an individual culvert, one option is to use an IDF curve to estimate the volume of water that can be expected to pass through a pipe with a given intensity storm. This value can be compared to the existing culvert size to get a relative risk of failure.

Another approach may be to survey culverts that have and have not failed and attempt to model factors that may influence the durability of a given installation.

SEDIMENT DELIVERY TO STREAM NETWORKS

Review

Sediment production from forest roads is a subject that has been studied for some time. Reid (1981) and Reid and Dunne (1984) have compiled estimates of road sedimentation for Washington and Megahan (1974) and Megahan and Kidd (1972) for the Idaho batholith.

The R1-R4 Model developed by the US Forest Service (USDA Forest Service, 1981) has been widely used to predict sedimentation from disturbed areas such as forest roads. Ketcheson et al. (1999) used BOISED, a regional variant of the R1-R4 Model to compare actual sedimentation from three experimental watersheds in Idaho to model predictions. BOISED consistently over-predicted sediment delivery from forest roads by 2.5 times.

Discussion

Like most models, the R1-R4 Model is most useful when used to compare alternatives and should not be expected to give accurate sediment volumes. Relative sedimentation levels are appropriate when indexing sites, but may not be as useful when combined with other measures of sediment input into a stream network. Regional variants of the R1-R4 Model, or a similar model, may have the ability to be parameterized so as to give more accurate sediment volumes that can be compared with other sediment sources.

When culverts do fail, the amount of sediment introduced into a stream system is highly variable. Again, an analysis of culvert instillation surveys may help to gain insight into factors affecting sediment volumes entering stream networks. Another option is to estimate the fill volume surrounding the culvert that has the potential to enter the stream network if the culvert were to fail.

SALMONID HABITAT QUALITY

Review

High quality salmonid habitat is both complex and diverse (Naiman et al., 1992). The primary measure of habitat complexity is pool spacing (Montgomery et al., 1995). The major factor influencing pool spacing, and therefore habitat complexity, is large woody debris (LWD) (Keller and MacDonald, 1995, Lisle, 1995, Wood-Smith and Buffington, 1996, Madej, 1999). Wood-Smith and Buffington (1996) created a three-variable model used to discriminate pristine from disturbed stream reaches. The three variables used were total number of pools, the ratio of residual pool depth to bankfull depth, and the ratio of critical shear stress of the average particle size to bankfull shear stress. The third variable, shear stress ratio, could be dropped with no adverse effects on prediction, but the authors suggest the resulting model may be severely weakened.

Stream temperature has been shown to be an important factor affecting salmonid habitat quality (Fukushima and Smoker, 1997). Land use, specifically forest practices, can markedly increase stream temperatures (Binkley and Brown, 1993). Riparian vegetation, specifically trees, can serve to minimize fluctuations in stream temperature, however this effect is decreased as stream width increases (Nakamura and Dokai, 1989).

Brown and Krygier (1970) developed a method to predict the effect on stream temperature of removing streamside vegetation. Park (USDA Forest Service, 1993) developed the SHADOW model to estimate the stream shading parameter of Brown and Krygier's model. SHADOW uses latitude and longitude to determine the angle of the sun for each hour of the day and combines this information with aspect, channel width, vegetation height, and shade density to calculate stream shading. Brown and Kryiger's equations are then used to estimate the five-day average maximum stream temperature for a given reach.

Another factor that can be affected by forest management is the introduction of fine sediments into the stream network (Binkley and Brown, 1993). Sediments can fill up gravel spawning beds and decrease available nitrogen.

Discussion

While forest roads can have an influence on stream temperature and LWD, their influence is relatively minor. Roads located parallel to stream channels can decrease the amount of shading a stream receives. Roads can have an impact on LWD through road-induced landslides.

The major impact of roads on salmonid habitat is the introduction of fine sediments to a stream system. Much of this sediment is a result of surface erosion from cut banks, fill slopes, and road running surfaces. The volume of sediment from roads can be estimated using a variation of the R1-R4 Model and routed through the stream network.

CONCLUSION

This paper looked at the literature available to model five measures of environmental quality: the risk of road-induced landslides, estimates of landslide runout and sediment delivery potential and quantity to perennial streams, the risk of road failure due to undersized culverts and other structures, sediment entering streams from culvert failures and surface erosion, especially traffic-induced surface erosion, and quantifiable measures of salmonid habitat quality. For some of these measures, adequate models are available. For others, such as landslide runout and road failure due to undersized culverts, models need to be developed to adequately estimate environmental impact at a landscape scale.

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Mobility of Timber Harvesting Vehicles

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ABSTRACT – Ground-based harvesting technologies are still the most efficient and economical way to harvest timber. For that reason the Scandinavian ”harvester-forwarder“ concept has emerged as state-of-the-art technology for cut-to-length systems. Under difficult terrain, trafficability is limited by vehicle gradeability, which is defined as an interaction of soil-bearing capacity, vehicle/tire combination, and topography. To predict gradeability, we have developed a GIS-based model framework called TES (Trafficability Evaluation System). TES incorporates hydrological and topological aspects as well as terra mechanics and soil-vehicle interactions. Using this system, harvesting planners and decision makers can predict and map gradeability for a set of vehicle/tire or vehicle/track combinations.

INTRODUCTION

Ground-based harvesting technologies are still the most efficient and economical for harvesting timber. Technological changes over the last years have moved operations toward fully mechanized harvesting systems. As a result, the Scandinavian ”harvester-forwarder“ concept has emerged as state-of-the-art technology for cut-to-length systems. However, under difficult terrain conditions mechanization is restricted by limited or impossible trafficability. Few tools are currently available to decision makers and harvesting planners for finding the most suitable and economic harvesting technology for given local site conditions. Even with highly sophisticated tools, such as PLANEX, trafficable terrain is bounded by a 30% slope. One possible solution is to model trafficability as a function of both soil and vehicle properties.

Our study presents an approach to combining mobility models and spatial terrain parameters to predict gradeability for ground-based harvesting systems.

BACKGROUND

Empirical traction-prediction equations were developed in the early 1930s. Initial research focused on predicting tractive performance. In 1972 Wismer and Luth [1] developed a set of traction equations that described the soil-vehicle interaction on a single tire. Later, Brixius [2] and Ashmore [3] based their mobility models on the work of Wismer and Luth. Both used the Cone Index (CI) to characterize soil properties. CI, a measure of soil strength, is the force required per base unit to press a normed cone into the soil at a steady rate. While Brixius focused his studies on agricultural tractors, Ashmore developed a model for forest-skidder tires. Equation [1] shows the theoretical background for both traction models. The torque applied to the wheel (Q) is assumed to be equal to a gross thrust (Q/r) acting at an effective moment arm (r). The gross thrust can be divided into motion resistance (M), i.e., the resistance to the movement of the wheel through the soil, and net pull (P), the force that moves the vehicle:

$$GrossThrust\left(\frac{Q}{r}\right) = MotionResistance(M) + Net\,Pull(P) \quad (1)$$

Equation [1] was developed for use on plains. To apply this to hilly and mountainous terrain, we must consider the downhill slope action or declination force (F_s). Because uphill starting is the critical effect, an additional acceleration force (F_a) is also included in equation [2].

$$\frac{Q}{r} = M + P + F_a + F_s \tag{2}$$
$$\text{where:}$$
$$F_a = Acceleration\ Force$$
$$F_s = Declination\ Force$$

The vehicle is in motion as long as P > 0. Maximum gradeability is reached when net pull (P) = zero. The equation for a single wheel or single track is formulated for powered, uphill motion in Equation (3); for braked, downhill motion in Equation (4); and for powered, downhill motion in Equation (5) [4].

$$\frac{1}{\gamma_r} * \frac{Q}{r} = [\, M + F_s + F_a \,] * \gamma_g \tag{3}$$

$$\frac{1}{\gamma_r} * \frac{Q}{r} = [\, -M + F_s - F_a \,] * \gamma_g \tag{4}$$

$$\frac{1}{\gamma_r} * \frac{Q}{r} = [\, M - F_s + F_a \,] * \gamma_g \tag{5}$$
$$\text{where:}$$
$$\frac{Q}{r} = Gross\ Thrust$$
$$M = Motion\ Resistance$$
$$F_s = Declination\ Force$$
$$F_a = Acceleration\ Force$$
$$\gamma_r = Resistance\ Factor$$
$$\gamma_g = Action\ Factor$$

Downhill motion requires two equilibrium conditions because M can become greater than the sum of the slope action and the deceleration action.

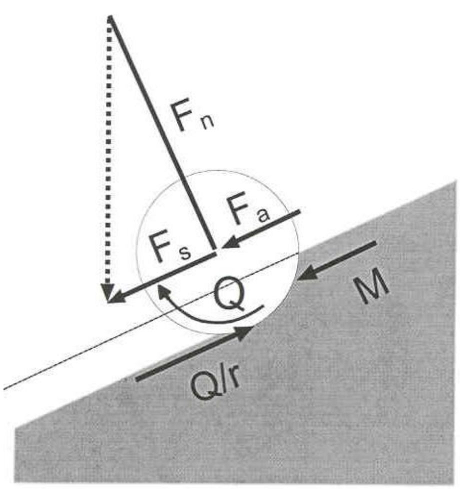

Figure 1: Tire/Soil interaction

MODEL FRAMEWORK

To estimate trafficability, we have devised a system called TES (Trafficability Evaluation System). TES is designed as a spatial decision-support system (SDSS), and is based on three main components: (1) data, (2) models, and (3) user interface (Figure 2).

DATA
The database contains spatial information, such as topology, geology, USCS soil classes, roads, stretches of water, and stand parameters. Vehicle-related data, such as weight, wheel load, number of tires, engine power, and ground clearance, are stored in a vehicle database (Table 1). That database also contains information about tire properties, e.g., type, size, section width, overall diameter, rim diameter, and deflection (Table 2). For each vehicle in the database, sets of different tires are available for identifying the best vehicle-tire configuration.

MODELS
Two models for estimating spatial variability predict (1) spatial water content (*WC*) and (2) spatial Cone Index (*CI*).

$$WC = f(F_h, F_t, F_v) \tag{6}$$
$$\text{where:}$$
$$WC = gravimetric\ water content$$
$$Fh = hygrological\ factors$$
$$Ft = topological\ factors$$
$$Fv = vegetation\ factors$$

We assume that *WC* is a function of hydrological, topological, and biological factors. Surface runoff is accounted for by the topoindex (F_t) from Bevens TOPMODEL [5]. For each cell we calculate a runoff index (topoindex). Because of increased spatial variability in water content for ridges and hollows, topology elements are considered [6, 7]. Biological factors, such as tree diameters and vegetation units, are included to model evaporation. Daily precipitation also must be integrated in our model framework because it affects soil water content. Therefore, Sullivan and Bullock's 'Soil Moisture Strength Prediction Model' [8] is included. This allows us to calculate the change in water content using daily precipitation and pan evaporation as input parameters.

$$
\begin{aligned}
&CI = f(WC, soil, geol)\\
&where:\\
&CI = Cone Index\\
&WC = gravimetric\ water content\\
&soil = USCS soil class\\
&geol = geological underground
\end{aligned}
\quad (7)
$$

Based on these soils models, the potential spatial gradeability can then be calculated. As in mountainous areas, harvesters on tracked platforms are becoming more popular, so we have analyzed gradeability for tracked vehicles using the mobility model of Ahlvin et al. [9]. Depending on the soil type, tracked vehicles can work on slopes of up to 80% [4].
For wheeled vehicles, two different mobility models have been implemented, based on the work of Ashmore and Brixius. In their evaluation, Rawlins et al. [10] have found that the Ashmore equation is a better predictor of gross traction and net traction, whereas the Brixius equation is more suitable for predicting motion resistance. Therefore, a third model has been developed and implemented that uses Ashmore's equation (8) as a predictor for gross and net traction and Brixius' (9) for predicting motion resistance. This model also allows us to vary inflation pressure to optimize gradeability.

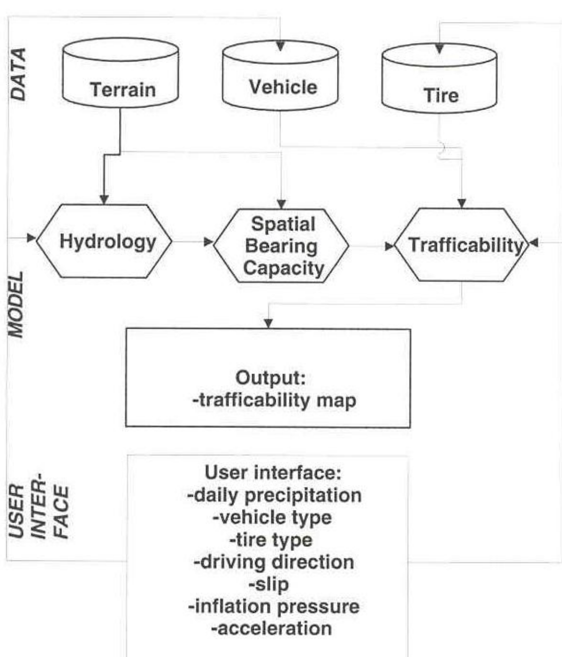

Figure 2: Model framework

Ashmore:

$$
\begin{aligned}
&\frac{Q}{r} = 0.47*(1-e^{-0.2*C_n*S}) + 0.28*\frac{W}{W_R}\\
&where:\\
&\frac{Q}{r} = Gross Thrust\\
&C_n = Wheel Numeric\\
&S = Slip\\
&\frac{W}{W_R} = Dynamic Load Ratio
\end{aligned}
\quad (8)
$$

Brixius:

$$
\begin{aligned}
&M = W*(\frac{1}{B_n} + 0.04 + \frac{0.58}{\sqrt{B_n}})\\
&where:\\
&M = Motion Resistance\\
&W = Wheel Load\\
&B_n = Mobility Number
\end{aligned}
\quad (9)
$$

USER INTERFACE
Our system requires user interaction. First, the harvest site must be defined. Input data of daily precipitation and evaporation are necessary for calculating the spatial soil-bearing capacity. The user also selects a suitable vehicle with a set of tires, after which the model then calculates the potential gradeability.
The difference between gradeability and slope (derived from the DTM) is a continuous measure of trafficability. By studying a variety of vehicles and vehicle-tire combinations, a set of solutions can be generated.

SAMPLE APPLICATION

Our sample study covered an overall area of 2.3 km^2 near Zurich (47° 20' N, 8° 35 E). Elevations range from 500 to 650 m, average annual precipitation is 800 mm, and the mean temperature is 10° C. Local geology comprises moraines from the Wuerm and Riss ice age, with primarily sandy or clay soils.

The test vehicle was a Timberjack Skidder 360C, a powerful vehicle with excellent maneuverability. Calculations were made with two different tire types (Table 2).

Table 1: Data for Timberjack Skider 360C

Mass [kg]	10240
Number of front tires	2

Number of rear tires	2
Front wheel load [kN]	31.5
Back wheel load [kN]	19.7
Ground clearance [m]	-
Engine power [kW]	110
Tire size	23.1/26

Overall, gradeability varied little between the two tire types (Figure 3). However, when inflation pressure (IP) was decreased from 200 kPa to 120 kPa, gradeability increased by up to 10%, depending on the CI. For Figure 4, trafficability was calculated for the whole harvesting site, running a C360 with a Nokian TRS inflated to 200 kPa.

Table 2: Tire parameters

	Bridgestone Firestone, Forestry Special	**Nokian Forest King, TRS LS- 2 SF**
Size	24.5/32	23.1/26
Section width [m]	0.62	0.59
Overall diameter [m]	1.80	1.63
Rim diameter [m]	0.81	0.66
Static loaded radius k [m]	0.83	0.74
Section height [m]	0.49	0.49
Deflection [m]	0.08	0.08

CONCLUSIONS

Spatial variability on a small scale is difficult to predict. Our selected method explains about 60% of the overall value. Empirical trafficability models, such as the one presented here, may not always perform well for given site conditions. However, for most situations no suitable theoretical alternatives are currently available that score better. The difference between gradeability and slope is a continuous measure of trafficability. Terrain rated with a trafficability value clearly <0 is not passable with the selected vehicle tire combination. In contrast, cells with values far greater than zero are easily passable. However, if the trafficability value is close to zero, the terrain may or may not be passable, because the accuracy of the model prediction is insufficient to draw clear conclusions in this range (Figure 4).

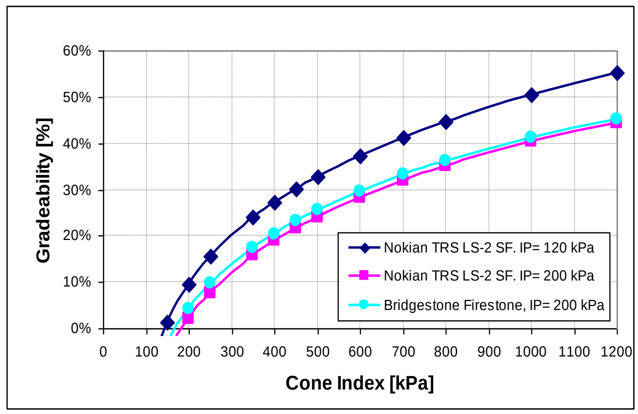

Figure 3: Gradeability for Timberjack 360C

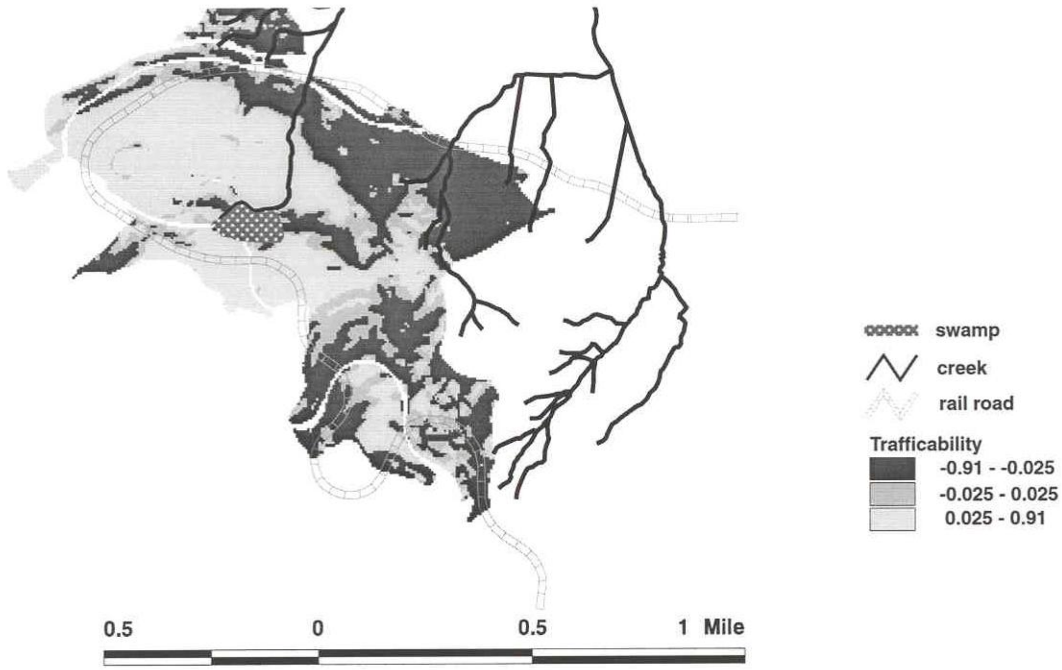

Figure 4: Trafficability map for Timberjack 360C on November 24th 2000

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Synthetic Rope Used in Logging: Some Potentials

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(Mention of trade names does not constitute an endorsement)

ABSTRACT - Provides information on the use of synthetic rope in logging applications to reduce workloads and increase efficiency. Field studies were conducted with synthetic rope in cable rigging applications and winch-lining using a skidder. Laboratory tests provided information on the engineering properties of synthetic rope that reaches the strength of wire rope at the same nominal diameter while weighing one-tenth of the weight of wire rope. Ergonomic improvements are described as well as operating efficiencies from selected applications. Further potentials of synthetic rope are outlined and future research is described.

INTRODUCTION

Wire rope is currently used in many logging applications. It has contributed to the advancement of cable logging and is used around the world in quantities of thousands of miles annually. Wire rope is also heavy per unit of length and helps make logging one of the most difficult jobs known. Cable logging in steep terrain is near the top of the most difficult jobs in terms of energy demands. Consequently, fatigue is often present when serious accidents occur. When opportunities arise to replace wire rope in some logging applications, substantial ergonomic and efficiency improvements are possible. New synthetic fibers spun into ropes offer promise in various logging applications. The current OSU research project described is funded by the Worksite Redesign Grant Program of the Oregon Occupational Safety and Health Administration (OR-OSHA, 2000).

Our project began from a trial by a logging contractor, Anderson Resources, of Washington (Anderson and Temen, 1999) reporting on the use of synthetic rope used for static guylines. Japanese researchers have also reported on their use of synthetic ropes for guylines on towers (Takumi, 1998). Earlier Forest Engineering Research Institute of Canada (FERIC) researchers used synthetic ropes in ground-based logging in Eastern Canada (Golsse, 1996). One OSU project is nearing completion and two more are scheduled to start soon to further address important developments with synthetic rope in logging.

SYNTHETIC ROPE

A number of synthetic ropes have been introduced into industrial use including ropes constructed from plastic fibers including nylon, polyester, polyethylene, and polypropylene. AMSTEEL and AMSTEEL-BLUE, products of the American Group of Ferndale, Washington (www.theamericangroup.com) , are two members of a family of synthetic ropes constructed of polyethylene (lightweight thermoplastic) fibers. The polyethylene fibers are combined into yarns and the yarns are combined into strands that are put into various rope constructions including twisted, plaited, and braided. AMSTEEL and AMSTEEL-BLUE are high (HMWPE) or ultra high (UHMWPE) molecular weight polyethylene 12-strand braided ropes. The rope properties include a higher breaking strength to weight ratio than steel, high flexibility, low stretch (other than the eye splice), a specific gravity less than one (floats), and can be easily spliced. Coatings can be applied to increase resistance to abrasion, prevent contamination, and increase ease of splicing used ropes.

The material is generally the same material commonly used for fuel containers in logging. For a given diameter, it weighs less than a tenth of the weight of comparable lengths of wire rope. The synthetic rope is also flexible and does not produce "jaggers" (sharp broken wire strands) as handling hazards common to wire rope. The cost is approximately four times wire rope in the specially-produced quantities now available. The off-shore drilling (anchoring) and towing industries use similar synthetic ropes in parallel applications.

Table 1 shows comparisons between some common wire rope published breaking strengths and those published for AMSTEEL-BLUE. Rope elongation is also shown for AMSTEEL-BLUE under loads in Table 2.

CURRENT PROJECT

The current project began in summer 1999 with field tests followed by laboratory testing. The OSU Student Logging crew used the synthetic rope and wire rope in tasks common to the work they do in cable logging and skidder logging using a winch line. The limited sample of workers was composed of generally fit young adults ranging in age from 19 to 44 years. Both males and female workers are included in the sample. The sample included two summers of work and the size of the sample ranges from 6 to 13 subjects performing the standardized tasks. Such tasks included: pulling and carrying steel and synthetic ropes on roads and slopes, climbing and rigging intermediate support trees, and pulling winchline to logs for skidder logging.

Table 1. Ultimate breaking strengths of common diameter ropes used in logging applications: comparison of steel wire rope with AMSTEEL-BLUE UHMWPE synthetic rope.

Breaking Strength (pounds)			
Nominal Diameter (inches)	Extra Improved Plow Steel	Swaged Steel	AMSTEEL BLUE Synthetic
1/2	26600	31000	32600
9/16	33600	39200	40100
5/8	41200	48400	53100
3/4	58800	69800	62600
7/8	79600	94800	88400
1	103400	124000	104400

Table 2. Elongation as a function of loading for AMSTEEL-BLUE UHMWPE synthetic rope.

LOAD (Percent of breaking strength)	ELASTIC ELONGATION (percent)	Tensioned Length of a 100-foot section (feet)
10	0.44	100.44
20	0.62	100.62
30	0.79	100.79

Time-per-task was measured along with a heart rate profile during the tasks for each subject. Laboratory tests of rope breaking strengths were conducted in the Knudson Wood Engineering Laboratory of Richardson Hall on the OSU campus. The small number of subject workers and limited breaking tests make the research a pilot study rather than a large-scale replicated research effort. Details of the testing apparatus and study procedures are available from the authors and are not outlined here to save space.

SOME INITIAL FINDINGS

Our research and analysis are continuing but we can offer some insights on synthetic rope used in logging from three perspectives: laboratory tests, ergonomic implications, and economic potentials. Much more testing is planned and more refined analysis will help our understanding as the current project concludes and other projects are initiated.

LABORATORY TESTS

Splicing of AMSTEEL BLUE involves a buried eye splice similar to the concept of the common children's finger puzzle where the harder the pull, the tighter the device grips the fingers. The rope is tapered and inserted into the middle of the twelve-strand rope with a "fid" to form an eye. The fid is an aluminum tapered needle-like rod with a hollow end to hold the rope and a pointed end to ease passage down the center of the strands. The American Cordage Institute (1997) prescribes testing procedures to follow for standardize testing. We conducted a variety of tests to gain experience with the synthetic rope. Here are some general findings that confirm existing experience with this rope. Figure 1 shows a sample test for a rope segment involving cycled test procedures for a long-splice.

- Most synthetic ropes we tested break at the end of the inserted section of the eye-splice in the rope, making the breaking strength actually a measure of a splice. Wire rope breakage is given from the actual rope strength and reductions are made for the end connectors.
- Compression fittings common to wire rope are not possible with synthetic rope.
- Knots of various types are used in some applications but AMSTEEL BLUE did not hold knots or they broke at relatively low breaking strengths. Spliced or other end connectors are recommended.
- Elongation of the rope samples on initial loading is high, due to effect of the eye-splices and the rope itself. Testing procedures call for cycling the rope ten times to 20 percent of its nominal breaking strength to remove elongation before final loading to failure.
- The permanent extension due to rope construction deformation, rope compaction and yarn deformation was on the order described in product literature. Ropes may need cycling and partial loading before

their length may be predicted for specific uses, e.g. guylines.

- Our cycled (per Cordage Institute test protocols) and uncycled tests produced similar breaking strengths.
- A rope section soaked in water overnight confirmed that AMSTEEL BLUE does not take up water and breaking strengths were not reduced.
- Rope failures, while violent and sudden, seem to fail in-line with the rope tension without wide swings due to stretch. See Figure 2 for testing apparatus.

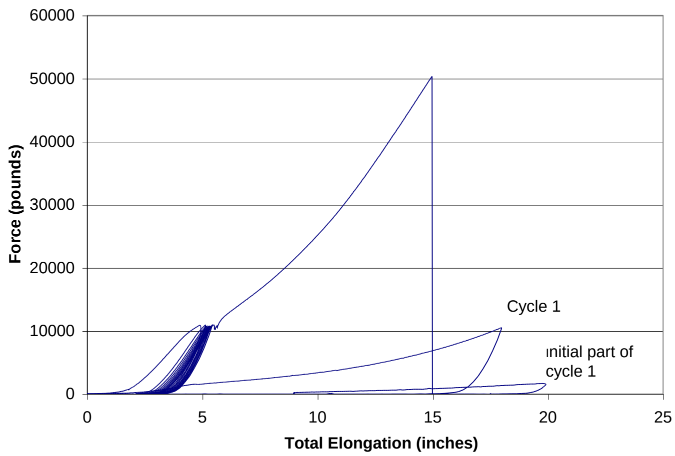

Figure 1. Ultimate load test for 5/8-inch diameter AMSTEEL-BLUE UHMWPE synthetic rope section containing a long splice.

Figure 2. Failed test section showing break at the end of splice.

ERGONOMIC IMPLICATIONS

The benefits from reduced weight for lines can be measured in part by the reduction in heart rates or by a reduction in time to recover after the task completion. An additional measure is the reduced time per task for heavy task work. Results of heart rate profiles are still being analyzed; however, some observations are pertinent. The study confirmed the high demand on workers as shown by the level of heart rates in the subjects. Pulling, carrying, climbing and using wire rope produces energy demands and subsequent heart rates to fuel the muscles with oxygenated blood. When heart rate levels and/or time to recover is reduced when using synthetic rope, overall fatigue may be lessened.

Both male and female workers expressed subjective preferences for using synthetic ropes during the trials. More specifically, an example chart of a 25 year-old, male subject, weighing 200 pounds, can help illustrate differences between carrying steel wire rope and synthetic rope for 150 feet. The task was conducted on a 25% slope with a 150-foot rope, 5/8 inch in diameter. Weight of the steel was 111 pounds while the comparable length of synthetic rope with steel thimbles included was 18 pounds.

Figure 3 below shows the difference in heart rate for the task and a difference in time for the task itself. Also shown is the longer recovery time needed for the more demanding task involving steel wire rope. Depending on task frequency, it is not hard to see where workload reductions using synthetic ropes are possible. We found similar profiles for male and female subjects in pulling ropes on roadways and slopes, carrying synthetic and steel ropes, and climbing and rigging trees as intermediate support trees or tail trees.

The study also included trials using steel and synthetic rope as a winch line on a John Deere 540 skidder. Turns of logs were winched both uphill and downhill with steel and synthetic ropes by the Student Logging Crew. Measures of time per task and heart rates were taken. Reductions in workload were noted and the time to pull the line to the logs was reduced. However, downhill line pulling with steel wire rope tends to push workers perhaps "aiding" their speed. More specific assessments of ergonomic benefits are planned as the current project concludes.

ECONOMIC POTENTIALS

Everyone who handles the synthetic rope is curious to know how much it costs. Compared to steel wire rope of the same breaking strength or diameter, AMSTEEL-BLUE costs from four to six times the cost of steel. Current markets for synthetic ropes are for specialty applications and in produce-to-order quantities. It is unclear what price structure will evolve if substantial quantities of synthetic ropes are used in the logging and forestry sector.

However, it is clear that gains in effectiveness can offset the costs of synthetic rope at current prices. For example, if the gain to pulling winch line for single machine operators setting their own chokers might be about 25%, then a 10% increase in productivity on a daily basis might be possible. For a skidding operation where the machine cost is \$65/hour, the operator is paid \$17/hour, profit and risk is 10%, and daily production is 10,000 board feet, the return to the operator would be \$72.16/thousand board feet. If the synthetic rope allowed 11,000 board feet per day production without changing operation rates during a comparable 110 day logging season, the cost savings would be \$7,938. That is enough to buy 7 winch lines of synthetic material.

If synthetic rope could increase payloads for cable systems or allow access to difficult terrain, substantial benefits might be attributed to the synthetic rope. Gains might also come during cable equipment set-up, faster manual work, use in helicopter logging, balloon logging and many applications not yet considered.

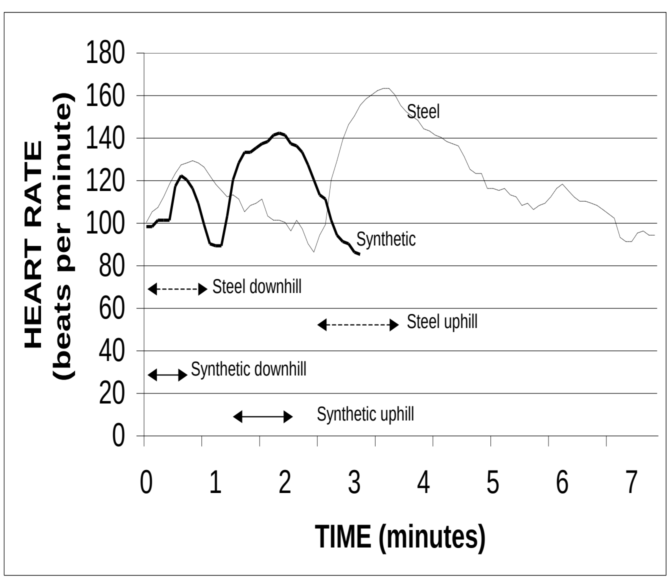

Figure 3. Heart rate and task duration to carry a 150-foot coil of rope 150 feet on a 25 percent slope. Rope diameter 5/8-inch, steel wire or AMSTEEL-BLUE synthetic construction.

FUNDED FUTURE RESEARCH

Based on promising results to date, OR-OSHA has funded two additional research projects on using synthetic rope in logging at about the same level each as the current project. The projects will run for two years commencing in July, 2001.

PROJECT 1: FIELD APPLICATIONS OF SYNTHETIC ROPES

The Synthetic Rope Research Team will now take the ropes to the field for trials with industry in the following applications.

- Static lines as guylines, etc. with 3 industrial logging contractors
- Establish wear and damage criteria for uses
- Verify ergonomic potentials with ground-based logging with Student Logging Crew and logging contractors
- Test new rope formulations with different coverings and braiding construction
- Test the use of synthetic ropes to replace wrappers on log trucks with three firms including one woman log truck driver
- Produce an illustrated user's guide for synthetic rope applications in logging
- Summarize ergonomic and workload reductions from using synthetic ropes

PROJECT 2: END CONNECTORS AND RUNNING LINE APPLICATIONS IN LOGGING

Two major areas above need further research and development for synthetic ropes in logging. We will test, develop and evaluate new products and uses.

- Evaluate end-connectors comparable to those now available for wire rope
- Use synthetic rope in running line applications and develop design criteria for cable harvesting software
- Conduct materials properties tests for running line applications
- Evaluate manufacturer's rope coverings for running line applications

- Assess drumline mechanics and spooling issues of synthetic rope
- Identify operating limits and procedures for running lines
- Work with a carriage manufacturer to develop slack-pulling and tensioning device for spooling
- Assess the ergonomic benefits from running line applications
- Estimate the economic benefits from using synthetic rope with running lines.

Both of the projects above involve the rope manufacturer, companies that make end-connectors, a carriage manufacturer, and many logging industry cooperators.

SUMMARY

We expect to learn a great deal about logging applications with synthetic ropes with exciting research in the next few years. Great promise exists for improvements in logging safety, worker ergonomics, and economic efficiency. Quantification and description of safe applications, limitations, and useful life/replacement criteria may lead to industry-wide implementation and benefits. As with the case of many logging activities, innovation can then be advanced further once in the hands of the practitioners.

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Setting Analyst: A Practical Harvest Planning Technique

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ABSTRACT – Setting Analyst is an ArcView extension that facilitates practical harvest planning for ground-based systems. By modeling the travel patterns of ground-based machines, it compares different harvesting settings based on projected average skidding distance, logging costs, and site disturbance levels. Setting Analyst uses information commonly available to consulting foresters, timber buyers, or loggers for harvests on non-industrial private forest timber sales (NIPF). We discuss the techniques, illustrate its practical applications, and compare logging plans generated with Setting Analyst on a recently harvested site.

INTRODUCTION

Operational harvest planning involves the design and organization of a timber harvesting operation and focuses on locating improvements such as roads, logging decks, skid trails, and stream crossings. The planner’s objective is to find a procedure that balances economic efficiency with environmental considerations while ensuring legal compliance and minimizing potential safety hazards for all associated parties. The harvest planner may be a consulting forester who works for the landowner, a procurement forester who purchases the timber, or the logging contractor who actually performs the harvesting or combination of the above. The planning horizon influences the amount of information acquired and how the information is stored. Information technologies such as global positioning systems (GPS), geographic information systems (GIS), and the Internet are advancing rapidly and present new opportunities for collecting information pertinent to timber harvesting.

Harvest/sales planning is common practice in many parts of North America and in other parts of the world. However, for various reasons formal harvest planning has not been as widely used in the southern USA. The principle reason is the lack of regulations that require it. State forest practice acts are rare in the South and most southern states employ non-regulatory Best Management Practices (BMPs) to protect water quality. The terrain in the South is relatively gentle, hence the planning required for cable or ground-based harvesting on steep terrain is not needed. Non-industrial private timberlands provide a significant portion of the southern timber harvest, often in small tracts or small timber sales. Finally, harvesting is performed exclusively by contractors, not company-owned crews. Harvest planning may be increasingly important in the future as more environmental regulations are adopted. Regulation of harvesting at the local or county level has increased rapidly in many states. In Georgia, for example, 101 0f 158 counties have county timber harvesting regulations and ordinances (WSFR Service and Outreach, 2001). Some local and county governments now require the submission of formal harvest plans to obtain a permit or approval to harvest timber in their jurisdictions. In addition, forest managers and contractors are increasingly expected to justify their decisions in the event of a disagreement or for a third party audit. Private and corporate landowners are concerned about site disturbance and damage during logging. As clearcuts get more complex in shape to meet aesthetics objectives, skid trail design will be increasingly important. Machine travel paths may be predetermined rather than simply evolving during skidding. As always, there will be an increasing push for economic efficiency and greater emphasis on reducing environmental impacts by either market or regulatory forces.

OBJECTIVE

The objective of this project was to develop a computer based harvest-planning tool that would allow the comparison of alternative harvest settings based on estimates of harvesting costs and site disturbance. Our focus was to keep the model simple and use the resources commonly available to forest managers, wood buyers, and logging contractors. This tool should be an aid to, not a replacement for, field-based harvest planning and should help document the planning procedures used. Finally, it should work with commonly available software.

BACKGROUND

Estimating harvesting costs is a crucial component of harvest planning. The aim is to design an operation that will minimize road construction, logging deck construction, equipment setup, and skidding costs. Matthews (1942) provided the early groundwork for harvesting cost analysis and inspired the further development of the average skidding distance principle. Average skidding distance (ASD) is a variable that can be used in the cost analysis of a harvest plan. ASD is the average distance a machine must travel from felled wood to the logging deck for a particular setting. ASD can be used to give an estimated total direct skidding cost.

Suddarth and Herrick (1964) described a method to ASD estimation for irregular tract boundaries. It is called the approximation method. This method forms the foundation of this research project, as it is consistent with raster or pixel-based GIS data structure. The horizontal area of the setting is divided into a finite number of mutually exclusive rectangles. The sum of the area-weighted distances from the logging deck to the geometric center of each rectangle divided by the total area of the setting gives an estimate of the ASD. As the number of subdividing rectangles approaches infinity, the calculation produces the exact average skidding distance.

Vehicle traffic during logging can cause soil compaction, rutting, loss of soil structure or other types of soil damage. Numerous studies over many years have shown that the number of machine passes over a piece of ground is highly correlated with site damage and that most damage occurs during the first five passes (Reisinger *et al.* 1988). Tree growth and survival are influenced by soil properties, hence travel intensity or the number of passes through a particular area, is often a concern to foresters and harvest planners (Carruth and Brown 1996, Aust *et al.* 1998). Wang (1997) found that no programs simulated harvesting systems from the standpoint of travel intensity and included it as a component of an interactive computer simulation program. A travel intensity grid was produced in which the pixel value was equal to the number of machine passes through the cell. Areas of high travel intensity could be used in conjunction with soil maps to compare skid trail configurations and identify a configuration with an acceptable level of compaction matched to soil types.

SETTING ANALYST

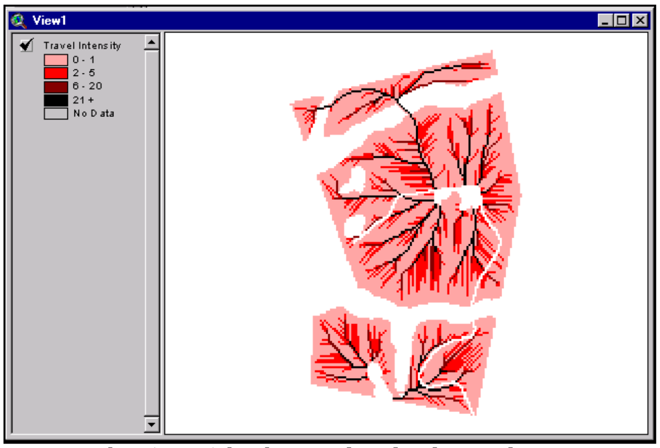
We created a tool dubbed Setting Analyst in the ArcView GIS 3.2 environment. ArcView was selected for its popularity, cost, and capabilities. Setting Analyst estimates economic measures such as skidding and improvements costs. Improvements costs are the cost of opening and closing features such as roads, logging decks, and skid trails. In addition, Setting Analyst highlights areas of greatest machine travel thus identifying areas of potential soil compaction. The tool works as a simulation allowing the comparison of alternative user-defined scenarios. Setting Analyst is not an optimizer but rather simulates using information provided by the user and lets the user decide the preferred setting.

Setting Analyst was written in Avenue, ArcView's built-in object-oriented scripting language. The functionality contained in the scripts is packaged in the form of an ArcView extension. Extensions expand ArcView by enhancing the working environment with additional objects, scripts and customization independent of the current working session (ESRI, 1999). A certain level of ArcView and GIS knowledge is required. Setting Analyst relies on the Spatial Analyst extension, which is used for grid or raster data. Setting Analyst uses existing functions to model machine travel in what is effectively a grid-based network analysis. The model consists of a series of Spatial Analyst grid functions, reclassifications, binary masks, and grid manipulations. The user creates a cost or friction surface that controls the machine travel through the tract. The tool then uses the CostDistance function to generate a Machine Path grid based on this cost surface. This is then used by the FlowAccumulation and FlowLength functions to calculate travel distances and travel intensity.

The Cost Surface grid is the essence of Setting Analyst. A cost surface is a grid surface where the cell value is the cost-per-unit distance of passing through that cell. The CostDistance function selects the lowest cost path through the cost surface. Low cost cells are preferred; thus by assigning low cell values to skid trails and high values to areas to avoid, we can control the machine travel. While harvesting, the felling machine will make piles or bunches of logs in preparation for the skidding phase of the operation. Setting Analyst assumes that each bunch is removed with a single visit from the skidding machine. The tool randomly generates a representative distribution of bunch locations based on the harvested timber tonnage per acre and the extraction machine's payload. Each cell with a value represents a bunch. The machine travels to that cell to collect the logs and haul them to the logging deck. The FlowAccumulation function generates the travel intensity grid that relates to the number of machine passes through a cell. The FlowLength function calculates distance along the machine path for each cell. In the resulting grid each cell value represents the distance from that cell (a log bunch) to the nearest deck along the machine path. The average cell value of this grid is the average distance from all log bunches to the nearest logging deck or the ASD.

OPERATING PROCEDURE

The initial stages of planning a harvesting operation are to conduct a field reconnaissance to get an understanding of site features and consider possible locations for logging decks, skid trails, stream crossings, and roads. Back in the office using ArcView, the planner begins by creating shape files representing these features in potential locations. At least four methods are available to create shape files: digitized onscreen with a digital orthophoto background, digitized onscreen with a digital



raster graphic (DRG) background, upload GPS data, or existing data sets (Figure 1). All the shape files are converted from a vector to raster (grid) data structure with a 5m (~ 0.25 chain) cell size.

Figure 1. Setting features compiled from GPS data and by onscreen digitizing.

The next stage involves generating a random bunch distribution grid. The user enters machine payload (tons/turn) and the number of tons of timber harvested per acre via the dialog box. Next, the user creates a cost surface to control machine travel through the tract. Selected feature grids are assigned weightings and then combined to form a composite or cost surface grid. The user can select from two cost surface generation approaches: merge and addition. The addition approach takes into account original cell values whereas the simpler merge approach does not. The cost surface is modified to incorporate stream crossings. The resulting cost surface restricts machine movement through the SMZs forcing the machine to cross at designated locations. A further modification accounts for prohibited areas such as ponds. This forces the CostDistance algorithm to guide the machine around rather than through. The user selects the appropriate boundary, deck, cost surface, bunch distribution, and road grids that make up the setting to be analyzed. The simulation is run and the resulting grids added to the Setting Analyst Output view. The Summary Statistics function produces a summary report for the setting configuration. Overall tract ASD and the maximum skid distance are calculated. The Travel Intensity grid is reclassified in 0-1, 2-5, 6-20 and 21+ passes and the area in each travel intensity class is reported (Figure 2). Cost Calculator, the final stage of the analysis, uses previously generated statistics and user entries to calculate skidding cost, improvement cost, and total cost on a per ton basis.

FIELD TRIALS

Ten recently harvested tracts were modeled in an effort to further refine Setting Analyst and test its capabilities. Notable features were recorded by GPS (Figure 3). Additional unimproved skid trails were subjectively added to direct the flow of machine traffic. In addition to the actual harvest settings two alternative settings were designed for each tract, modeled with Setting Analyst, and then contrasted with actual settings. The first setting type, "with existing roads", assumed that all the

actual roads were present before harvest planning commenced (Figure 4). In this situation, the planner has the option to use the existing roads or not and simply locates decks and other additional features. This scenario often occurs where the tract is on industrial land with an existing road network. This setting type was designed with each deck servicing at least 20 acres. The second setting type, "without existing roads", assumed there were no or minimal existing roads (Figure 5). This setting type had fewer restrictions. The number of decks was of less concern, but truck stream crossings were avoided wherever possible in favor of temporary skidder crossings. A situation like this often occurs on non-industrial private lands.

Figure 2. Travel Intensity grid indicating the simulated number of machine passes through each cell.

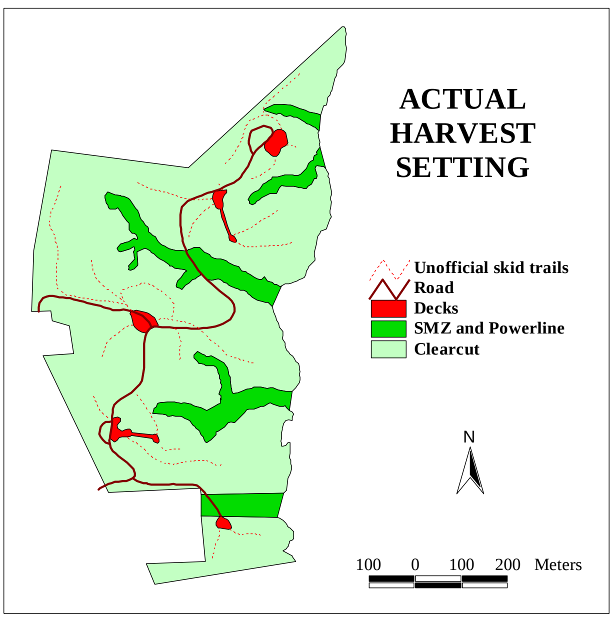


Figure 3. Example of an actual harvest setting.

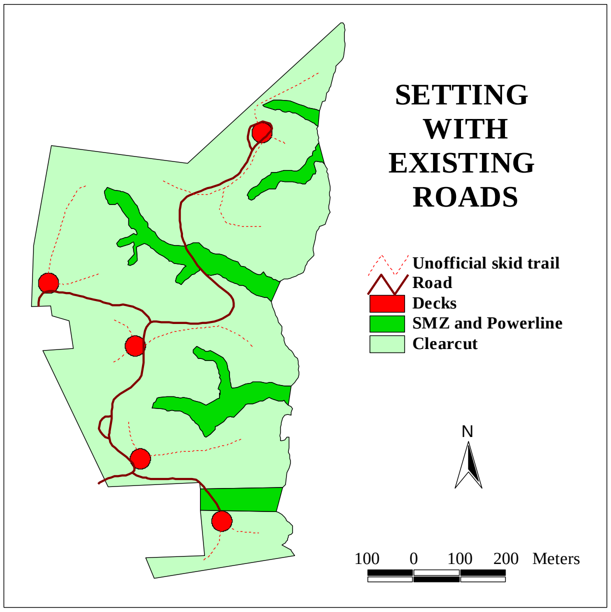


Figure 4. Example of a setting designed with an existing road network.

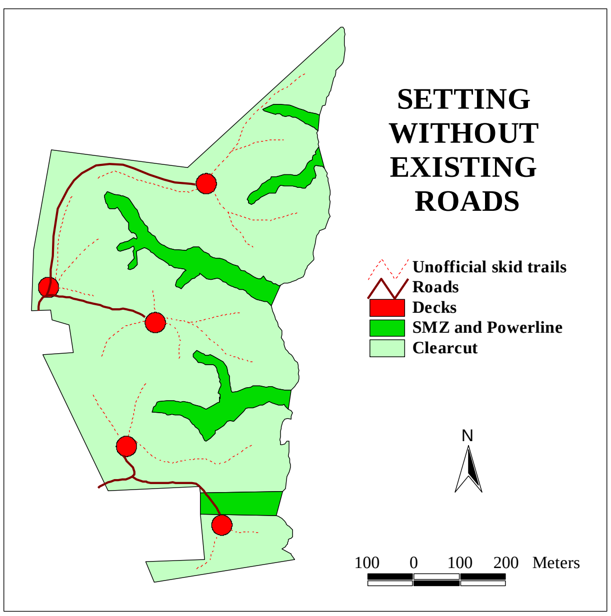


Figure 5. Example of a setting designed without an existing road network.

DISCUSSION

The obvious question after modeling will be which is the best setting. It depends on the objectives the planner is trying to meet and the priorities. Cost estimates provided by Setting Analyst can be interpreted in two ways. The costs can be regarded as either percentage differences or as approximate dollar figures. Again, the reason for planning will indicate the appropriate interpretation.

The nature of ASD makes model verification difficult. A hands-on approach to model verification could include using a GPS unit mounted on a skidder in an actual harvesting operation. The actual vehicle movement pattern and resulting travel intensity could be compared with that predicted by the model using a series of point samples. Setting Analyst does not currently take slope into account. The tool was developed with gentle or rolling terrain in mind. However, incorporating slope would further increase the tool's utility. Incorporating soil maps to indicate potential for compaction into the model would be advantageous. A soil grid with high values for soils prone to compaction could be incorporated when constructing a cost surface. However, soils data are often not available to planners when planning sales on NIPF lands.

CONCLUSION

Setting Analyst is a tool that can assist harvest planners in preparing sales using software and data that are readily available. The tool allows comparison of alternative settings based on economic and site disturbance evaluations. It provides a means of formally documenting proposed settings. Setting Analyst is a simple and straightforward tool that should find utility with a range of sale planners, including forestry consultants, wood buyers, and logging contractors.

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Productivity of a cut-to-length harvester family - an analysis based on operation data

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ABSTRACT - In forest operations, productivity analyses have mainly been based on time studies. With the increasing application of computer technology, operation data could be captured automatically or at least semi-automatically. Under central European conditions, operation data are usually recorded on the cutting-unit level. The aim of this study was to develop a productivity model for a whole family of cut-to-length harvesters. More than 2200 data records were available, covering 12 different harvester types. The statistical analysis was based on a linear model with covariates and factors. Here, stem volume explained about 63% of the total variability, while machine type contributed about 11%. The two major findings from this study were that: (1) it is possible to quantify productivity differences among harvester makes, and (2) the influence of technological advances can be estimated. However, data quality was inconsistent because of differences both in recording productive-system time due to registration methods (manual, electronic, mechanical), as well as in stem volume calculations (e.g., harvester computer, volume calculation at the mill, volume designated according to grading rules). The next steps for improvement will be to standardize data capture and develop productivity databases on a regional or even an industry level.

INTRODUCTION

Understanding productivity is a decisive factor in improving operational efficiency of harvesting systems. Numerous productivity studies have been documented in forest operations research literature. However, because most investigated only a single machine type, the interaction between machine type, technological advance, and productivity is not yet understood.

An experimental study layout to consider several harvester types would be very demanding and costly. Therefore, a more promising approach might be based on operation data collected at either the shift level (Fokema et al., 1981) or the cutting-unit level (Rieger, 1983). In Germany, forest services in different states have gathered long-term cutting-unit data for Nordic cut-to-length (CTL) harvesters. The available data cover a broad range of operational conditions and 12 different harvester types. The present study used traditional statistical procedures to analyze survey data. Additionally, it combined them with methods from technology forecasting (Dodson, 1970, 1985).

This study aimed to quantify and evaluate the importance of harvester type and harvester technology as sources of variation in productivity. The scope of the investigation was limited by the available operation data that covered stand conditions and by the harvest regimes typical for Germany. Additionally, the quality of the data could not be controlled because it was collected by local harvesting managers over several years. Here, the hypothesis, data definitions and statistical procedures are first described, followed by analyses of the two model approaches: i.e., a factorial representation of harvester types and a representation of harvester type by technological measures.

METHODOLOGY

Study profile

The state forest services of Lower Saxony, Rhineland-Palatinate, Hesse, Baden-Wurttemberg, and Bavaria (Germany) began to systematically gather data on cut-to-length harvester operations in the early 1990s. The stands consisted mainly of Norway spruce (*Picea abies*) and Scotch pine (*Pinus sylvestris*), along with broadleaf species. Both thinning and final-cut operations were considered. The mean volume extracted per unit was about 50 m^3/ha, and ranged from 10 to 150 m^3/ha. Mean stem volume was about 0.48 m^3 under bark, varying from 0.06 to 0.41 m^3. More than 2200 data records were collected and recorded in a central database at the "Kuratorium für Waldarbeit und Forsttechnik" KWF.

Subject matter model

Numerous investigations on productivity have demonstrated that stem volume, harvesting intensity, and tree species are the main influences. To include harvester types and technology, the following productivity hypotheses were used:

$$Prod_{type} = f(svol^{e}, intensity, HARVESTER, SPECIES)$$

where $Prod_{type}$ = *system productivity*
svol = *mean stem volume*
e = *exponent (curvature)*
intensity = *harvesting intensity (volume per area)*
HARVESTER = *harvester type*
SPECIES = *tree species*

$$Prod_{tech} = f(svol^{e}, intensity, technology, SPECIES)$$

where $Prod_{tech}$ = *system productivity*
svol = *mean stem volume*
e = *exponent (curvature)*
intensity = *harvesting intensity (volume per area)*
$techn_i$ = *technology measures i*
SPECIES = *tree species*

The first hypothesis assumes that productivity can be modeled by stem volume, harvesting intensity, harvester type, and tree species. The corresponding mathematical model uses a 0/1-coding to represent different harvester types. This approach considers the influence of a single harvester as a qualitative variable but does not allow quantifying the relationship between technical performance and productivity. Therefore, a second hypothesis has been established to describe machine characteristics via technical parameters. Technology measures (Dodson, 1985) aim to map functional properties of components and whole machines. The main functions of harvesters are power supply, handling abilities of the boom, and processing capabilities of the harvester head. However, although it is well known that operator variability also influences productivity, this influence had to be ignored because information was lacking.

Data capture

The observational unit consists of one harvest unit instead of a single tree as in conventional time studies. This results in one data record per unit, comprising response, factor, and covariate variables (Table 1). The answer variable, productivity, is a quotient of volume over time. Therefore, the accuracy of time and volume measurements is crucial. Operating time is recorded using a Productive System Hour (PSH_{15}) standard, which includes delays of up to 15 minutes. Harvester operators record time manually, although automatic recording devices sometimes are used. Several procedures are followed to determine harvesting volume as measured in m^3 under bark. These include automatic volume determinations at the mill gate, as well as those based on length and diameter (measuring tape and caliper), harvester sensors and computer, and special procedures for pulp wood. The use of different time and volume recording procedures may result in inconsistent productivity values that must be considered in the analysis and interpretation.

In addition to the data stored in the database, six technical parameters are derived from manufacturer information for each harvester type: engine performance, boom reach, lifting moment, slewing moment, maximal felling diameter, and feeding force of the harvester head. Technology measures are calculated by using the principal component analysis of Dodson (1985). This makes it possible to rotate the coordinate system so that the highest possible amount of total variability can be mapped on the first and second principal components. The first principal component represents about 70% of the total variance, whereas the second principal component maps about 14%, thereby requiring only two variables, rather than six, for the analysis.

Survey layout

Observational units are classified by two factors, harvester type and tree species. For the 2219 observational units, frequen-

Table 1: *Definitions of variables for data capture*.

Variable type		***Characterization***	***Dimension***
response	time	total time for one yarding cycle	PSH_{15}[1]
	volume	total load volume for each yarding cycle	m^3 u.b.
	prod	volume/time	M^3 u.b. / PSH_{15}
factor	HARVESTER	factor to represent 12 different harvester makes	12 levels
	SPECIES	factor to represent the main harvested tree species	3 levels
covariate	svol	volume/pieces, mean volume per stem	u.b.
	pieces	number of trees harvested	number
	area	area of cutting unit	ha
	intensity	volume/area, harvesting intensity	m^3 u.b./ha
	tech1 tech2	harvester technology measures, 1st and 2nd principal components of 6 physical performance measures: (1) engine performance in kW, (2) boom reach in m, (3) lifting moment in kNm, (4) slewing moment in kNm, (5) max. felling diameter in cm, (6) feeding force in kN.	

cies of the combination of factors are shown in Table 2. The classification is, unavoidably, very unbalanced. A balanced layout would require cell frequencies of about 60 for each of the 36 cells. Two of the harvester types clearly were overrepresented, the Timberjack 1270 and the Rottne Rapid 860. In contrast, the Skogsjan 687 was underrepresented, which had to be accounted for in the analysis and interpretation. The factor of tree species was even more poorly distributed, with the dominating species being Norway spruce and broadleaves only marginally represented.

Table 2: *Factorial survey layout (12 x 3) of the data recorded on the cutting-unit level.* (For a balanced layout, cell frequency should be about 60.)

Harvester	***Species***		
	Norway spruce	**Scotch pine**	**Broad-leaf**
NOKKA 6WD/H	54	87	3
ÖSA SUPER EVA	60	0	1
PONSSE HS 15	86	0	0
ROTTNE RAPID 860	313	196	0
SILVATECH 854 TH	195	63	4
SILVATECH 860 TH	44	1	1
SKOGSJAN 687 XL / 601	19	50	3
SKOGSJAN 687 XL / 650	5	0	0
TIMBERJACK 1270	606	0	0
VALMET 901/4	68	0	0
VALMET 901/6	267	85	1
VALMET 901/6 II	1	6	0
Totals	1718	488	13

Statistical analysis

Data are analyzed with the software package S-Plus (Venables and Ripley, 1994), using the following strategy:

- Weighting each observational unit to consider the differing importance of representation,
- Estimating the effects of factors and covariates and their statistical significance,

[1] Productive System Hour, including delays less than 15 minutes

- Analyzing non-linearity of stem volume via power transformation,
- Analyzing the interaction of factors and covariates,
- Using model diagnostics to evaluate the correctness of model assumptions (analysis of residuals).

The use of weights is a special feature of the present analysis. Because each observational unit provides mean values that represent different numbers of work cycles, a weight factor is introduced, i.e., the number of trees per unit divided by the total number of trees in all units, multiplied by the number of observational units. This approach results in the same number of degrees of freedom as for the non-weighted analyses, a precondition for the correctness of statistical tests.

RESULTS AND DISCUSSION

Analysis of effects

Results from the covariance analysis (Tables 3 and 4) demonstrate the importance of the different variables related to total variability. Careful interpretation is necessary because the analysis of variance is based on mean values, not on work cycles as is documented in most productivity studies. The share of explainable variance, expressed by the r^2 value, is therefore much higher (78% for the factorial model and 71% for the technology measure model). Stem volume has the main effect on productivity, explaining about two thirds of the total variance. The second most important effect is harvester type, which explains about 15%. The influence of tree species is significant, resulting in a productivity increase of about 1 m^3/PSH_{15} for Scotch pine compared with that for Norway spruce. Model diagnostics result in the correctness of the model assumptions.

Table 3: *Effects influencing productivity for the factorial representation of harvester types, MANOVA results.*

Source of variation	***DF***	***SSQ***	***SSQ (%)***	***Signi-ficance F value (%)***
$svol^{0.4}$	1	12839.84	63%	0.00
HARVESTER	11	2322.86	11%	0.00
$svol^{0.4}$ HARVESTER	11	534.10	3%	0.00
SPECIES	2	243.74	1%	0.00
intensity	1	63.58	0.3%	0.00
residuals	2192	4307.51	22%	
		20311.63	100 %	

The second model, investigating the influence of technology measures, results in the same effect of stem volume. These technology measures are highly significant, mapping about 7% of the total variability. However, that is only half of the factorial representation of harvester types. This outcome may be caused by the incomplete representation of harvester efficiency by the six physical measures, which are represented by only two principal components. In addition, the factor of harvester type maps a men-machine system, but no data were available for quantifying the influence of operator variability. Model diagnostics show some additional inconsistencies. The predicted productivity of some harvester types (Skogsjan 687, OSA Super Eva, and Ponsse HS 15) was biased, showing systematic over - and underestimations.

Table 4: *Effects influencing productivity for the representation of harvester types by technology measures, MANOVA results.*

Source of variation	***DF***	***SSQ***	***SSQ (%)***	***Signi-ficance F value (%)***
$svol^{0.25}$	1	12501.30	62%	0.00
$(tech1+4.1)^{0.4}$	1	526.51	3%	0.00
tech2	1	566.95	3%	0.00
$(tech1+4.1)^{0.4}$ $svol^{0.25}$	1	247.85	1%	0.00
SPECIES	2	381.85	2%	0.00
Residuals	2188	5738.89	29%	
		19962.65	100 %	

Productivity models

Figure 1 shows the productivity models corresponding to the analysis of variance in Table 3. The expected mean values of the entire investigated harvester family range from 4 to 14 m^3/PSH_{15}. This represents the state of technology in about 1990. The Skogsjan 687 and the Timberjack 1270, both introduced around 1994, have productivities clearly above average. However, the results for the Skogsjan 687 must be considered carefully because of its under representation in the survey layout (see Table 2). The productivities for the Nokka 6WD and OSA Super Eva are clearly below average. These machines represent the state of technology around 1986. The range of productivity functions covers a time span of technological advancement of about 10 years. Comparing these results with those from scientific productivity studies is difficult because of the difference in time measurement standards. However, the range is within that known from experience.

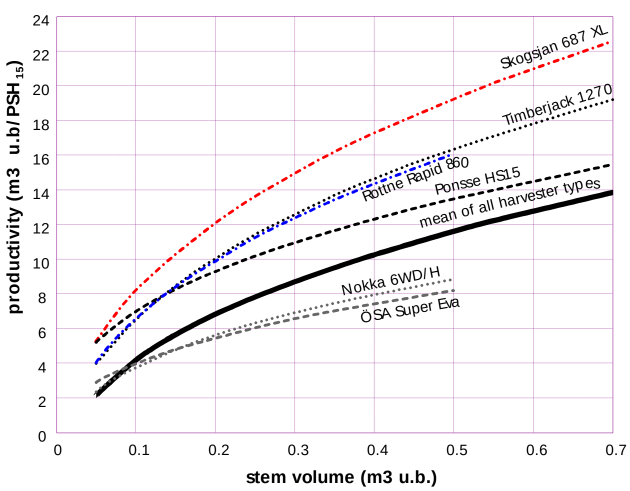

Fig. 1: *Productivity models based on factorial representation of the harvester type.*

Figure 2 illustrates the technology measure model (Table 4), using an analysis of the Timberjack 1270. Compared with the factorial model, this model predicts lower productivities for a stem volume >0.4 m^3. Interestingly, this approach might be used to estimate the productivity of a harvester, which has not yet been investigated. When the physical values of the Timberjack 1270 B model are considered, the shift of the function is about 1 m^3/PSH_{15} for small stem volumes, and about 2 m^3/PSH_{15} for larger volumes. The possibility for estimating the influence of new machine designs is promising, although some inconsistencies still exist in the proper mapping of harvester performance based on physical parameters and in the consideration of operator variability.

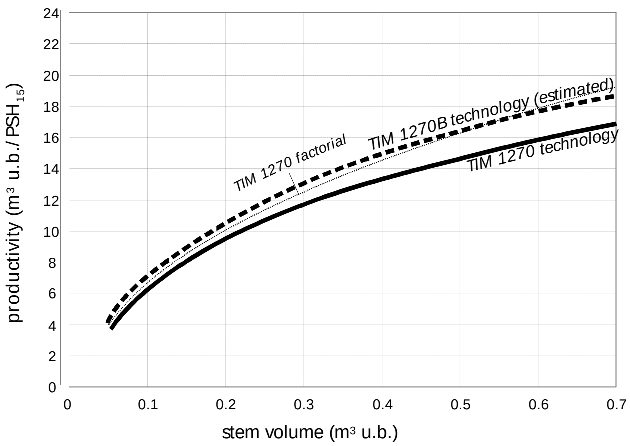

Fig. 2: *Productivity models based on technology measures representing the harvester type.*

CONCLUSIONS

The study objective was to investigate and evaluate the effect of harvester type and harvester technology on productivity. Findings include: (1) Stem volume as the major effect influencing productivity, (2) harvester type and technical performance being the second most important source of variation, and (3) a significant trend in technological advances that affects an increase in productivity. The first effect has been investigated, and is well-known as the "stem-volume-principle". According to our knowledge, however, the quantification of the relationships between harvester type, technological advance, and productivity is a new concept.

However, some inconsistencies in data quality also require our attention. (1) The registration procedures for the Productive System Hour PSH_{15} must be standardized by using automatic or semiautomatic devices, (2) variability in the present procedures for volume determinations should be decreased by using only one volume measure, i.e., the one automatically calculated and recorded by the harvester computer, and (3) the adequacy of technology measures needs further research (Dodson, 1985, Knight, 1985, Martino, 1985). The survey layout was unavoidably very unbalanced, which limited standard statistical procedures (Searle, 1987). Special weighting procedures could help to overcome these inconsistencies (Searle, 1987). Because the productivity analysis of the cutting-unit operation data was very promising, the data capture network should be extended, if possible, to the industry level.

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POTENTIAL FOR SHARED LOG TRANSPORT SERVICES

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ABSTRACT – A simulation model of a log transport logistics network was developed. The model could be structured to either share truck capacity among a group of loggers, or to assign a fixed number of trucks to individual loggers. Another variation of the model allowed the use of a staging yard to set out loaded trailers and deliver them to destinations using dedicated shuttle trucks that operated continuously. Pooling trucks among loggers provided more flexibility in dealing with driver shift length constraints, and consequently delivered more wood to mills than did individual ownership. The magnitude of the difference was related to dispatch method. Accounting for logger status when dispatching trucks increased wood volume moved and reduced average trailer waiting times for all loggers. Staging yards were effective in maintaining delivered volume of wood when severe delays were probable at destination mills.

INTRODUCTION

Application of information and planning technologies are potentially of primary importance in increasing the efficiency of timber harvesting. Greene and others (2001) reported, for the period 1987 to 1997, an increase in labor productivity of 78 percent for Georgia loggers, while capital productivity remained constant. Given nearly flat logging rates over the same period, marginal returns most likely did not increase while investment risk more than doubled. In a business environment with an oversupply of harvesting capacity, loggers have no incentive to further invest in expensive equipment to increase unit productivity. Efficiency gains in timber harvesting, therefore, are more likely to come about as a result of applying knowledge capital, rather than financial – loggers will have to work smarter to stay in business. Traditional approaches to logging can potentially be redesigned to benefit from the application of information technology, resulting in efficiency gains with a relatively low price tag.

Log transport, representing nearly half the delivered cost of wood fiber, is a particularly good candidate for investigation of the benefits of applying information technology. Tree-length logging contractors in the South typically transport their own product to consumption points. They tend to use a fixed number of trucks to haul wood regardless of the distance from the logging job to the consuming mill, and this leads to inefficiencies. When tracts are far from the mill, overall logging system productivity may suffer because of insufficient truck capacity. And conversely with tracts close to the mill, the logger must accept trucks idling at the deck awaiting a load to haul. Sharing a pool of trucks among a group of loggers could potentially decrease the number of rigs required to haul a fixed amount of wood to the mill, thereby reducing costs. There are problems associated with this approach that must be solved before it is implemented. Some central agency would be required to dispatch trucks among loggers, and do so in a fair and efficient manner. Communication and planning technology would need to be developed to ensure that best use was made of available trucking capacity to serve loggers equitably and move the maximum possible amount of wood.

This study was done to investigate, using a simulation approach, the potential for sharing log transport resources among a group of loggers. Factors important in evaluating such a shared transport system were identified as the ability to serve loggers equally, move the greatest amount of wood with a given number of trucks, and be relatively immune to external influences, particularly changes in woodyard configuration or operation characteristics. Specific objectives of the study were:

1. Develop a realistic simulation model of a log transport logistics network that pooled truck resources among a group of loggers.
2. Investigate alternative methods of dispatching trucks given a shared logistics system.
3. Determine the relative influence of woodyard operating characteristics on log transport logistics performance, and evaluate the effectiveness of using a 'staging yard' in minimizing the influence of woodyard operations on transport efficiency.

MATERIALS AND METHODS

The transport simulation model was constructed assuming that a central dispatch agent was available to direct trucks to one of a group of loggers, who in turn represented some portion of a procurement system supplying a set of consuming mills. For this study, tracts consisted of a mix of up to three products and each product was to be transported to a single destination. A group of 10 loggers was to be served. Each was assigned parameters that represented a rate at which trailers could be loaded, a location that corresponded to the amount of time necessary to haul a load to a specific mill, and a set of probabilities that defined the amount of each product type on the tract being logged. Loggers did not move between tracts during the simulations.

The three destination mills were identical in their model behavior, but differed in the amount of time needed to process a truck through the woodyard, and in the number of trucks arriving during the day. One mill in particular was assumed to be the predominant destination for wood (nominally a 'pulp' mill). About 400 trucks per day were processed through its woodyard, with about 100 per day sent to the other two destinations. This made it simpler to investigate the effect of changing woodyard performance characteristics on overall transport system efficiency. Arrival intervals between trucks other than those being explicitly modeled was assumed to be exponentially distributed, with the mean inter-arrival time a function of time of day. Truck arrivals over a 24-hour period were as shown in Figure 1.

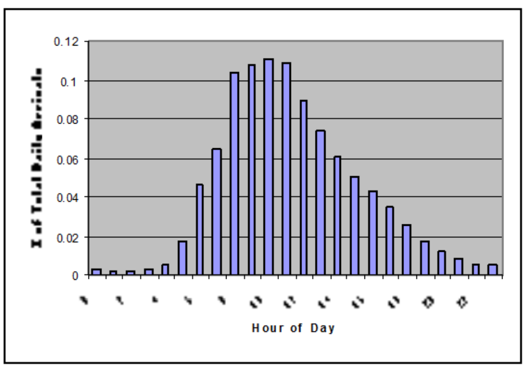

Figure 1. Truck arrival distribution as a function of time of day.

Woodyards were modeled as three server processes in series, nominally an inbound scale, a crane, and an outbound scale. Asynchronous delays were imposed between the servers to represent the amount of time needed for travel within the yard, and for various other necessary functions (e.g. unbinding). Server processing times were defined as being triangularly distributed with an assigned mean and range. Delay times were assumed uniformly distributed, with mean of 8 minutes, and range of 4 minutes.

Trucks were assigned a logger destination as they left the woodyard. Trucks hauled an empty trailer to the appropriate logger, dropped it into a queue for loading, then the next available loaded trailer was picked up and hauled to the mill corresponding to the load type (i.e., no mill destination assignment was made). If no loaded trailer was available, the truck waited until either one was, or the end of the shift was reached. Trucks were allowed to operate for 10 hours per day, with a variable starting time. Truck shift length was evaluated at the time logger assignments were made. If the truck could not make a complete turn (travel empty, travel loaded) in the time remaining on the shift, it was sent home.

Loggers were single-server processes that loaded empty trailers and assigned a load type based on stand characteristics. Loggers worked 9-hour shifts each day, also with a variable starting time.

Trucks were assigned destinations by a dispatch agent that used one of four algorithms to pick loggers: a completely random assignment; a fixed assignment; a 'uniform' assignment in which each logger 'owned' (nearly) the same number of trucks; and an 'informed' assignment. The fixed assignment algorithm used a weighted distance scheme to assign trucks from the pool to a specific logger, and this assignment did not vary over the course of the simulation. The weights used in assigning trucks were the sum of distances from the logger to each mill, scaled by the relative abundance of products of the particular type in the stand. Informed assignment was based on the minimum difference in time between when a logger would run out of trailers (in the queue at the deck plus those in transit) and when the truck being assigned would arrive if sent to that logger.

The simulation was built using a software product known as AnyLogic, version 4.0. Dispatch algorithms were evaluated using five runs of the model for each assignment method, with variations in the number of trucks available in the pool and in pulp mill processing times. Each simulation run modeled 30 working days.

The model assumed that trucks delivered their loads directly to the woodyard at the appropriate mill. Another model was developed that simulated the situation in which road trucks delivered loads to a remote yard facility, picked up an empty trailer, and were assigned another logger destination. Shuttle trucks carried the full trailers from the remote yard to their final destinations. Shuttle trucks were assumed to work continuously.

Simulations based on this model were run using the same number of trucks as in the previous model, but with the trucks divided into over-the-road and shuttle contingents. Simulation runs were made using a single remote yard located near the pulp mill, and with two remote yards, each yard on opposite sides of the mill. Figure 2 shows relative positions of the simulated components used in the models.

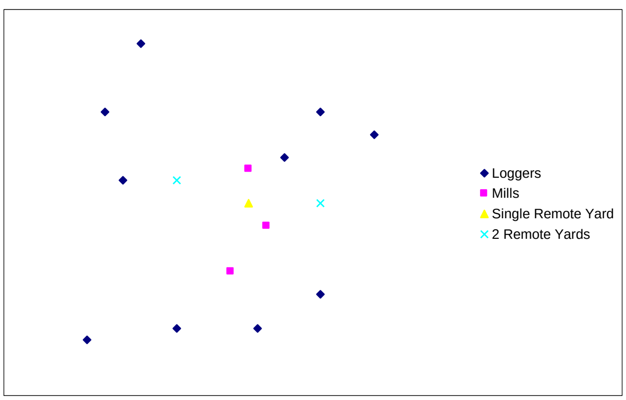

Figure 2. Map showing relative positions of loggers, mills, and remote yards.

RESULTS AND DISCUSSION

Simulation parameters were based strictly on conjecture, and therefore were not necessarily reflective of an actual situation. Values were, however, selected to at least resemble typical operations. In general, the simulations were set up such that about 65 trucks could haul all wood produced by the 10 loggers if no delays at the mill were experienced. The theoretical maximum amount of wood that could be produced was about 490 tons/logger/day.

Dispatch method influenced the amount of wood produced (Table 1). Fixed assignment was the worst performer, moving only about 70 percent of the wood as the best method regardless of the number of trucks available. This was likely a result of the shift-length constraints. There was no flexibility to send a truck to a different logger if the turn could be made in the time remaining on the shift. This was not true for the random and informed dispatch methods, where destinations were prioritized and the truck sent to the logger with the highest priority. Uniform assignment hauled more wood than the fixed dispatch method, probably because it favored loggers closer to the mill, whereas fixed assignment attempted to statically balance idle time among loggers. Informed dispatch moved the greatest amount of wood, about 12 percent higher than random assignment for both levels of truck capacity. This result confirmed the value of logger state information in maximizing the volume of wood moved.

Table 1. Summary of amount of wood hauled by dispatch assignment method.

# of Trucks	Tons Hauled (tons/logger/day)			
	Uniform	Fixed	Random	Informed
60	254	225	281	324
75	295	273	315	359

Although 20 percent more wood was moved, there was not as big a difference in performance of the pooled system versus the uniform assignment as was expected. If uniform assignment is roughly equivalent to the logistics network currently in place, then these results did not indicate a substantial benefit from pooling transport resources strictly from the standpoint of maximizing delivered amounts. There was, however, a significant difference between the assignment methods in the amount of time loggers spent waiting on a trailer to load. Table 2 summarizes waiting time results for the four dispatch methods using 75 trucks. Uniform assignment had both the highest mean and variance in logger waiting time, over twice the mean for the informed method, and the standard deviation was over three times higher.

Table 2. Summary of variation in logger idle time as a function of dispatch assignment method. Situation modeled was: 75 trucks; in-bound scale, crane, and out-bound scale mean process times were 1.5 min, 1.7 min, 1.5 min, respectively.

Assignment Method	Average percent logger idle time			
	Mean	Std Dev	Min	Max
Uniform	26	20	0	58
Fixed	30	14	15	45
Random	21	12	7	34
Informed	11	6	1	19

These results reinforced the idea that distance to the mill is the single most influential variable affecting truck transport efficiency. No dispatch method can change the fact that a tract is 90 minutes form the mill, but using an effective dispatch method can, however, minimize the potential for disparity in logger productivity associated with working at longer haul distances. From that standpoint, pooling truck resources would probably be beneficial. There was also evidence that pooled trucking could haul more wood with the same number of trucks as the current transport system.

Truck time in the woodyard has a large impact on overall transport efficiency. There are two critical factors involved in determining woodyard turn times: number of trucks arriving over a given interval, and woodyard server (scales and crane) processing times. Of these two factors, the most easily influenced is the arrival distribution pattern of trucks. Most log transport trucks operate during normal working hours and consequently the woodyard is most heavily burdened during that time. A remote yard operating continuously shuttling trailers to their destination points uncouples the effect of woodyard loading from log transport. Table 3 summarizes simulation results when using 0, 1, and 2 remote yards to stage trailers before hauling to the woodyard. Variations in the model included using 55, 65, and 75 total trucks, and 3 levels of mean processing time for woodyard servers at the 'pulp' mill (representing about 85 percent of the total wood being hauled). The processing time levels represented low, moderate, and high delay probabilities for trucks going through the woodyard. Figure 3 shows the distribution of queue lengths for the inbound scale when modeling 65 trucks.

There was no improvement shown in total wood hauled when using a remote yard system when the woodyard was not a bottleneck. This was the case regardless of the number of trucks being modeled in the simulations. Increasing the server process times by 15 percent (scales 1.3 to 1.5 minutes, crane 1.4 to 1.5 minutes) dropped the total amount of wood hauled with no remote yard by an average of about 9 percent. When either one or two remote yards were used, total delivered wood amounts were only about 1 percent less on average, and the remote yard transport systems both delivered more wood than using over-the-road trucks only.

When the woodyard was a severe bottleneck, the remote yards delivered about 24 percent more wood than the equivalent number of trucks without the yard. Further, the amount of wood delivered under high delay probability was only about 4 percent less than the situation where the woodyard was not a significant delay. Use of remote yards to stage wood had significant benefits when delays at the woodyard were long and highly probable. Costs for the staging system, however, would be higher because of the added drivers needed to run the yards continuously.

All of these results indicated that there were potential benefits to using a pooled transport system to deliver wood from multiple loggers. The magnitude of the benefits, however, was dependent on numerous factors, particularly trailer unloading times. Woodyard operational parameters used in these simulations were, at best, educated guesses, and the true benefits of using a pooled transport logistics system need to be confirmed using a verified simulation model with accurately estimated parameters.

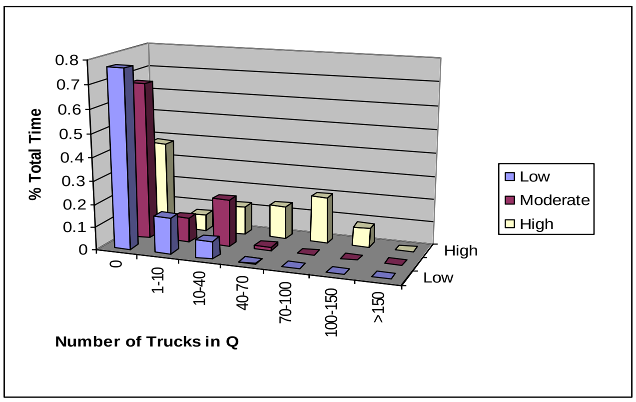

Figure 3. Graph of the percent of time for various categories of number of trucks waiting in the pulp mill woodyard inbound scale processing queue over the course of the simulation. Low, moderate, and high refer to scale processing mean times (1.3, 1.5, and 2.3 minutes, respectively). These results are for the case of 65 total trucks being modeled.

CONCLUSIONS

Simulation results comparing pooled versus contractor-owned trucking networks indicated that more wood could be hauled using equivalent numbers of trucks under the shared transport system. Delivered wood volume was limited by the number of available trucks. Sharing trucks and using a simple dispatch algorithm that accounted for logger status was shown to move 12 percent more wood than random dispatch, and 20 to 30 percent more wood than when ownership of trucks was constrained to a single logger. Advantages of the pooled methods were at least partially related to flexibility in dealing with driver shift length constraints. Pooled dispatch was also much more effective at balancing trailer waiting times among loggers regardless of haul distance.

Table 3. Wood hauled (tons/logger/day) using remote concentration yards. Mill parameters are: in-bound scale, crane, and out-bound scale mean process times. Numbers (in parentheses) show distribution of total trucks to road/yard.

# Remote Yards	# Trucks		
	75	65	55
	Mill Params: 1.3 , 1.4 , 1.3		
0	390	354	305
1	388 (67/8)	349 (58/7)	301 (49/6)
2	392 (55/10/10)	365 (47/9/9)	293 (37/9/9)
	Mill Params: 1.5 , 1.7 , 1.5		
0	359	323	276
1	387 (66/9)	345 (57/8)	297 (48/7)
2	389 (53/11/11)	356 (45/10/10)	312 (39/8/8)
	Mill Params: 2.3 , 2.5 , 2.3		
0	302	271	232
1	376 (62/13)	330 (54/11)	285 (46/9)
2	378 (49/13/13)	342 (43/11/11)	293 (37/9/9)

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The Future of Forest Engineering

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ABSTRACT –The role of the forest engineer is changing. Some of the key issues and trends - in North America and internationally - which are affecting the future of forest engineering as a discipline are identified. This paper focuses on the needs of North America from the points of view of research, teaching, and employment opportunities. The conclusions, however, are pertinent to many other regions of the world.

INTRODUCTION

To understand the future you first have to look to the past. In the early 1980's the catch-cry of forest engineers was that forest operations had to be "physically feasible, economically viable and environmentally acceptable". Today we would add to these words … "and socially and politically acceptable". Dealing with people issues is becoming the forest engineer's biggest challenge.

Mack Hogans, a Senior VP for Weyerhaeuser, told a 1999 graduating class from the University of Georgia that things have changed dramatically over the past few decades. Once we used to say you couldn't see the forest for the trees, now it is "you can't see the forest for the people". People have become our customers, not trees.

In this paper I will give you my views on what are the issues and drivers changing the world of forest engineering, what are some of the international and regional trends and finally what are the implications for research and teaching the forest engineers of the future. These views were recently presented in a seminar to staff and students at Oregon State University so they have a bias towards the Pacific Northwest.

ISSUES AND DRIVERS

Regional and Global Demand for Wood Products

The US population has doubled in the past 60 years. Demand for timber has kept pace with population growth and is forecast to continue growing at approximately 1% per annum well into this century.

Since the 1960's world wood consumption has nearly doubled. Current demand is approximately 3.4 billion tons. If demand continues to match world population growth it will increase by 1 to 1.5% per year. This means, by 2070, world demand for wood will be about 7 billion tons. Despite other pressures, people will continue to want wood.

Regional and Global Demand for Non-timber Values

People are turning to forests for things like clean water, abundant fish and wildlife (e.g. Indiana bat and red-cockaded woodpecker), a place for solitude and renewal, non-traditional crops, wilderness recreation and - above all - opportunities for future generations. The goal of the forest engineer is, not only to produce more wood worldwide, but also to protect other values.

As one web-site noted, values are changing. A decade ago timber was equal to ten times the value of wilderness recreation. Today wilderness recreation is worth more than timber. While the exact numbers could be challenged, the growth in perceived importance of non-timber values cannot be.

Clear-cuts

In 1992 Chief Robertson of the USDA Forest Service pledged elimination of clearcutting on US federal lands. Clearcuts have declined by 80% on these lands in the last 8 years.

In the Pacific Northwest, at least, private timberlands are beginning to follow suit. For example, in 1998 MacMillan Bloedel said it would eliminate clearcuts from its lands in British Columbia within 5 years.

Many, but not all, countries around the world are closely looking at alternatives to clearcutting as the public voices its discontentment with this form of timber harvest.

Urban-Forest Interface

As population grows, the urban-forest interface is putting additional demands on the management of the forest estate – recreation, aesthetic values, fire risk, etc.

For example, it is expected that a million people will move to Oregon in the next 25 years. Many of these people will be looking for a rural/forest lifestyle and want a greater say in how the landscape around them is managed.

Similarly, it has been estimated that 25% of the South's forest resources are located in the urban/rural interface and are facing increasing environmental challenges.

Fire and Forest Health

Two or three years ago resource managers were warning the public about the increased risk of fire and disease as a result of the overstocked areas of forest around the US. Concern about over-stocked forests gained political support after the 2000 fires. The USFS has since identified 39 million acres for thinning and Congress has approved $1.6 billion for a National Fire Plan. The implication is that close to 3 million acres per year will have to be thinned over the next 15 years. Alternatives to traditional sales are being sought.

Roadless Areas

It has been estimated that there are close to 380,000 miles of roads on federal lands and that there is a maintenance and reconstruction backlog of over $10 billion. In 1998 USDA Forest Service Chief Dombeck emotively commented that "unmaintained roads are bleeding into mainstem rivers and degrading our productive wildlife habitat". He also noted that only 40% of roads were maintained to the safety and environmental standards to which they were originally built.

The Forest Service Roadless Area Conservation Policy attracted 1.6 million public comments – 90% of which approved of the policy. This has lead to a ban on road-building and commercial logging on approximately one-third (58.5 million acres) of federal lands.

Salmon and Steelhead Recovery

The State of Washington has as one of its aims – "To improve the condition of the salmon, steelhead and trout resources and the habitats on which they rely, while also maintaining a healthy and vibrant state economy". Other states in the Pacific Northwest have similar aims. These initiatives have lead to hundreds of pages of new rules that the forest engineer and others have to comply with.

It is interesting to note that, in the State of Washington, there is a requirement that policy decisions around this issue should not only be based on scientific information but also on legal, social, cultural and economic considerations.

Regional Employment

58% of the 504 million acres of US forest land is owned by 9 million non-industrial private owners. Many of these owners are dependent on obtaining at least part of their income from timber harvest from these lands. In addition the forest industry provides many jobs; e.g Oregon forests provide ~ 65,000 jobs and southern Appalachian forests have provided 70,000 stable jobs for over two decades. Forestry is the lifeblood for many western and eastern US rural communities.

Global Competition

Competition is something that all timber producers face, including those from the US Pacific Northwest. As examples of this global competition:

- The US South or Canada could easily fill any volume or price gap opened up by the Pacific Northwest.
- Brazil produces wood at 1/4th to 1/3rd of the rotations of the US South and 1/10th of the US North.
- Chile exported forest products to 74 countries last year.
- Within six years New Zealand will have 5 billion board feet of timber available for export.
- USA is South Africa's fourth largest importer of wood.

The strong US$ is also benefiting other suppliers.

INTERNATIONAL AND REGIONAL TRENDS

Thinnings and Smallwood

Many parts of the world are shifting away from clearcuts and towards partial cuts and thinning as their predominant harvesting practice e.g., Eastern and Western Canada, China, PNW USA, UK, Belgium, Germany and parts of Australia. Not all forest regions have a thinnings focus though, e.g Chile, Australia, NZ, South Africa, parts of Scandinavia.

In many parts of the world smallwood harvesting is becoming more common - either due to rotation length or slow growth-rates.

More and more forest owners are using harvest as a means to achieve ecosystem health.

Greater Environmental Sensitivity

This is a worldwide trend; for example, in Europe alone there are 31 institutes currently studying the environmental consequences of harvesting.

Concern about environmental sustainability is not a new issue, however. Some parts of the world have been practicing sustainable forestry for hundreds of years. In France, 655 years ago, King Phillipe VI decreed that the "forests and woodlands may be maintained on a permanent and sustainable basis". Close to 175 years ago, France also had a Forest Code of Practice in use.

More recently in the USA close to 77,000 loggers have been trained in Sustainable Forestry Initiative practices and interest in FSC certification is growing. The Kentucky Forest Conservation Act now requires all logging operations to have a certified master logger on site.

Human Factors

In some parts of the world a shortage of skilled loggers has been noted, e.g. Lakes State, USA, Canada, New Zealand. In some cases this may be rectified with improved training. In other cases, the shortage results from people not wanting to work in the isolated, difficult and sometimes dangerous conditions of a forest environment. Worldwide there is a need to improve the health and safety conditions for forest workers. Safety of the public is also a growing concern in some regions where log truck traffic is high.

The trend, away from company crews and towards contractors, also has implications for people management and the role of the forest engineer.

Mechanization

Cut-to-length mechanized systems (or tree-length to a centralized processing yard) are gaining rapid acceptance in many parts of the world. Improved safety, productivity in smallwood, lower damage to residual crops, lower environmental impacts, improved fiber quality and greater flexibility are some of the benefits claimed for these systems.

These changes have lead to greater interest in machine-tree interactions, machine-terrain interactions and machine-man interactions.

Technology

Advanced technologies are bringing significant changes to logging equipment, planning and training requirements: e.g. control systems, robotics, machine vision, computerised decision support systems, communications and information flow, positioning systems, training simulators. The internet is also changing the way information is gathered and used by loggers.

These advanced technologies, as well as bringing advantages, also bring problems associated with the skill needed to operate and maintain them.

Roading and Transport

There is a move in emphasis from road construction to road maintenance as more areas are opened up. In some areas, fish passage is of higher importance than truck passage in road network design.

Truck transport, however, is likely to remain the dominant form of transport from forest to market. Optimization of transport will continue to be of interest to forest engineers as cost pressures increase.

Productivity/Costs/Value

Global competition keeps a strong focus on productivity, costs and values. For example, when I asked a professor from Virginia Tech to list the top issues industry were focused on in the SE US, he said productivity, costs, value and then planning for water quality management.

Many companies are benchmarking costs and looking for new ways to increase productivity. Improved woodflow control, through the use of technology such as GIS, GPS and communications, is of growing interest.

There is also increased interest in supplying niche markets, not bulk markets. This is leading to: new assortments, higher wood quality, increased revenue, new approaches to sales, computer-aided merchandising, logs in-specification, improved value recovery, and external and internal quality assessment.

Holistic Approach

There are calls for a more holistic focus to forest engineering research, design and implementation. For example, in China a re-focus on their labor costs (relative to machine costs) and maintenance skills have lead to a return in the use of animal and people power in logging. In addition, frequent downstream flooding has led them to look on their forests as water control units, rather than wood production units. This change in policy will result in a reduction in their wood supply.

IMPLICATIONS FOR TEACHING AND RESEARCH

Teaching

If the membership of the Council on Forest Engineering is representative of the profession as a whole, then about 20% will end up teaching and doing research, about 10% will end up in government agencies, and about 70% will end up in private businesses – working for forest companies, consultants or machinery suppliers.

A recent survey by Bryce Stokes (USDA Forest Service, Washington) has highlighted some of the difficulties that may be faced by the forest engineering teaching profession in the future. He found that, in the last 10 years, only 34 PhD's in forest engineering had graduated from the 20 Canadian and US universities offering this post-graduate degree. He also noted that one-third of the FE faculties would not continue once the staff retired and a further 10% of FE faculties were planning to downsize.

The core skills for a forest engineer remain aligned with a strong analytical focus – maths, natural sciences, engineering fundamentals, engineering methods, production economics, harvesting systems and transportation systems. They must also be taught additional skills, however, if they are to solve the complex problems they face in a more people oriented world – leadership and teamwork skills, critical thinking and holistic thinking, communication skills and creative problem solving techniques. In the end the forest engineer must still be able to identify and implement ecologically desirable, environmentally acceptable and financially attractive management and harvesting activities.

Research

It is interesting to see how the forest engineering research focus has changed over the past two decades. In 1984 John Mann reported on the distribution of research effort, covering a total of 117 scientist-years, in the USA and Canada. He found that almost 80% of the research was focused on production and planning issues (harvesting operations 22%, roads and bridges 18%, equipment performance and design 15%, planning tools 22%). Residue recovery, re-forestation/silvicultural issues and environmental impacts – in order of decreasing effort - made up the other 23%.

A survey carried out today would probably see at least half of the forest engineering research centred around habitat enhancement, environmental impacts and silvicultural issues – and an understanding of these issues is vital if the forest industry is to continue to effectively operate; whether it be in the Appalachians or in the Pacific Northwest.

Global competitiveness and regional employment issues, however, demand that forest engineering research continues into developing equipment and methods for managing production and costs and extracting maximum value from the forest estate. Some of the areas of research I believe are essential if future forest engineers are to be able to effectively fulfill their roles involve the development and study of:

- Improved inventory systems, which allow much better understanding of the resource in terms of quantity, quality and location.
- Machine-specific and site-specific production and cost models that can be used in production management and planning.
- Holistic, systems-level harvest planning tools that allow analysis of the trade-offs between timber and non-timber values.
- Improved tactical and operational market supply models that allow the forest engineer to deliver the right product, to the right customer at the right price and the right time.
- In-forest scanning technologies and procedures that allow measurement of both external and internal wood characteristics.
- In-forest optimization technologies that ensure the most appropriate parts of each tree are delivered to the most profitable markets.
- Harvesting systems that are appropriate for the environmental, social and political demands the forest owner has to meet.
- Harvesting systems that make use of rapidly growing technologies such as global positioning systems, inertial measurement systems, on-board computing, and wireless communication systems.
- Improved transport scheduling, log tracking and log stocks management systems.
- Transport systems that are more suitable for handling smallwood.
- Improved log segregation and processing systems.

SUMMARY

Forest engineering continues to have an exciting and challenging future. Global competition will figure more prominently on the forest engineers "tapestry" of interest and force a continued awareness of production, cost control and value management issues. Finding socially and politically and environmentally acceptable solutions will also occupy the forest engineer more as the public takes an ever greater interest in the world around them. "People" skills will become as important as analytical skills.

Let me finish with a story and a quote. In the late 1980's I visited the City of Chester in England where I went for a walk along the city wall. The wall had been lifted in height three times. The top level had been built about 700 years, ago, the middle level had been built about 1900 years ago at the time of the Roman conquests, and the bottom level had been built over 3000 years ago. As I looked out at the beautiful countryside surrounding the City of Chester I marveled that engineers had been at work and man had been living in this area for thousands of years.

Isaac Asimov once wrote that "science can amuse and fascinate us, but it is engineering that changes the world". I believe that the forest engineer will have done his/her job properly if the changes he has made have been for the better and a visitor 3000 years, hence, could stand beside the forest engineer's work and marvel at how beautiful the world still is.

2001 Council on Forest Engineering (COFE) Conference Proceedings: "Appalachian Hardwoods: Managing Change"
Snowshoe, July 15-18, 2001

EVALUATION AND COMPARISON OF TWO TREE-LENGTH HARVESTING SYSTEMS OPERATING ON STEEP SLOPES IN WEST VIRGINIA

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ABSTRACT - A case study and comparison of two partially mechanized, hardwood tree-length harvesting systems (i.e. crews) operating on steep slopes in Wyoming County, WV was conducted during the winter of 1999. The productivity and operating efficiency of a John Deere 650G tracked skidder and John Deere 640 rubber-tired cable skidder was compared with the recently introduced tracked CAT 517 swing-boom grapple skidder and CAT 525 rubber-tired grapple skidder. Both crews were clear cutting hardwood sawtimber and pulpwood manually (i.e. chainsaw felling) on steep slopes ranging from 30-60%. When bunching hardwood stems prior to skidding, the average productivity of the CAT 517 was 36.4 tons/hour compared with only 11.8 tons/hour for the JD 650G machine. For all skidding cycles, the JD 640 cable skidder was slightly more productive (17.5 tons/hour) than the larger CAT 525 (15.8 tons/hour) skidder. Estimated owning/operating costs and general comments regarding operating efficiency and disturbance levels for each machine and system are also compared.

Funding for the evaluation and comparison of the two harvesting systems was jointly provided by Georgia-Pacific Corporation and Caterpillar, Inc., Forest Products Group.

INTRODUCTION

Steep slope harvesting with ground-based systems has always been a challenge in the Appalachian mountain region. Compared to other regions, ground-based systems in the Appalachians typically have low system productivities and often result in unacceptable amounts of soil disturbance and residual stand damage because of the need to construct an extensive network of skid trails/roads. Consequently, alternative approaches to ground-based harvesting on steep slopes are being sought to reduce the negative site impacts while maintaining or increasing production levels.

Several variations of ground-based and cable harvesting systems have been recently tried in an attempt to find a satisfactory solution to the traditional problems of logging steep slopes in the Appalachians. A southwest Virginia logger that has been successfully using a tracked swing-boom grapple skidder for several years reports a 20% increase in production and a 25% reduction in skid road construction with the CAT 527 machine (Smith, 1999). Another contractor operating in West Virginia utilized an "Idaho Jammer" mobile cable yarding system to shovel log slopes too steep for conventional skidding (Bridwell and Cook, 1999). The Jammer used 400 foot of cable and large metal tongs to "cast" and yard tree-length hardwood to the skid road. The contractor estimates that his production is comparable to conventional ground-based skidding, but 40% fewer skid roads are required because of wider road spacing (i.e. 400 feet).

The objective of this case study is to evaluate the productivity of a new and smaller tracked skidder with a swing grapple (CAT 517) and rubber-tired grapple skidder and compare the results to the current method being used (i.e. crawler tractor with cable/winch and a rubber-tired cable skidder).

METHODS

A case study evaluation and production study of two partially mechanized, tree-length logging crews was conducted in the coal-mining region of Wyoming County, West Virginia during the winter of 1999. One crew used the new CAT 517 tracked skidder with a swing-boom grapple, and the second crew used a JD 640 crawler with cable and chokers to perform the same functions of bunching tree-length hardwood stems. After a three week trial period, the productivity of both crews (operating on the same tract and in the same vicinity) was monitored and compared. Both crews were clear cutting a tract consisting of mixed hardwoods (13.8" average DBH) growing on very steep terrain (30-60 % slopes).

The logging operation produced mixed hardwood, log length material including: OSB wood, yellow poplar peelers, grade saw logs, and low-grade tie logs. Contract truckers were used for hauling the products to the various mills. The owner/operator supervised both logging jobs daily, and occasionally operated a dozer building skid roads. The company does not own a maintenance shop for equipment repair, and does not employ a mechanic. The crew is rather young, but most of the crew members have worked in the woods for several years. Data on machine productivity were collected during 10 random full-day field evaluations from February to April (i.e. wet winter logging conditions). Additional data such as average slope, timber density, average DBH of stems harvested, and skidding distance were also obtained. Both crews were operating on the same harvest block that contained similar timber and terrain conditions.

The following is a listing of the in-woods productive and support equipment owned and operated by the two crews observed:

Productive Equipment

1 John Deere 650G Tracked Skidder
1 CAT 517 Tracked Skidder *
1 CAT 525 Rubber-Tired Grapple Skidder *
1 John Deere 640 Rubber-Tired Cable Skidder
1 Prentice 210 KB Loader with CTR Slasher
* New machines being evaluated for this study

Support Equipment

Chevy 1500 Pickup Truck
Bulldozer (JD 750C)
Lowboy Trailer

Crew 1:
Crew 1 (i.e. the new system) used a new CAT 517 tracked skidder with a swing-boom grapple for bunching and a CAT 525 grapple skidder for skidding tree-lengths to the landing. The 3-person crew consisted of one chainsaw operator (to fell, limb, and top the trees), one tracked machine operator to bunch stems, and one grapple skidder operator to skid tree-length to the landing. For comparison purposes, Crew 1 worked separately from Crew 2 (i.e. in a separate part of the sale area), but in very similar timber and terrain conditions. (A loader operator [Prentice 210] at the landing bucked and loaded various products merchandised from the stems that were skidded by both crews.) The crew had a three-week training period to operate the new machines before the comparison study began.

Crew 2:
Crew 2 (i.e. the old method) used a JD 650G tracked machine and the JD640 rubber-tired cable skidder to bunch and skid tree-length hardwood during the study period. This 4-person crew employed one chainsaw operator; a tracked machine operator that skidded and bunched stems to the skid road (using chokers, mainline cable and winch); an extra man (i.e. "gin man") that rode in the cab and set the chokers at the stump (for the JD 650G) and unhooked the chokers at the skid road; and a JD640 cable skidder operator that skidded the bunched stems to the landing for processing.

MACHINE PRODUCTIVITY RESULTS

Bunching

The productive functions for the two tracked machines used for bunching to a skid road were divided into four working categories: bunch trees, travel loaded, drop & position trees, and travel empty. Travel distance and number of trees skidded to the bunch were also collected. The mean elemental and total cycle times (in minutes) are listed in Table 1. (Delay time is also included with the cycle times in a separate column.) The 84 observations (i.e. cycles) of the CAT 517 averaged 4.11 minutes which is 3.3 minutes faster than the JD 650 (based on 36 observations). The most noticeable differences between the two machines is the acquire and drop/position times. In both cases, the mean times for the CAT 517 were less than one-half of the times recorded for the JD 650 machine. The travel times (loaded and empty) for the two machines were similar given the average distance skidded (165 feet for the CAT 517 vs. 211 feet for the JD 650). The swing boom grapple on the CAT 517 was the main operating advantage over the JD 650 tracked machine. During the bunching and positioning functions, the swing grapple made manipulation of the cut stems easy and quick. (Figures 1 and 2 illustrate machine productivity as a function of bunch -skid distance.)

Table 1. Comparison of the elemental and total cycle time means (in 0.01 minutes) for the CAT 517 (Grapple) and JD 650 G (Cable) tracked machines when bunching on steep slopes.

Machine	Bunch Trees	Travel Loaded	Position	Travel Empty	Total Cycle Time	Cycle Time with Delays
CREW 1 CAT 517 (%)	1.59 (39 %)	0.78 (19 %)	0.67 (16 %)	1.07 (26 %)	4.11	5.18
CREW 2 JD 650 G (%)	3.05 (41 %)	0.95 (13 %)	1.79 (24 %)	1.62 (22 %)	7.41	10.56

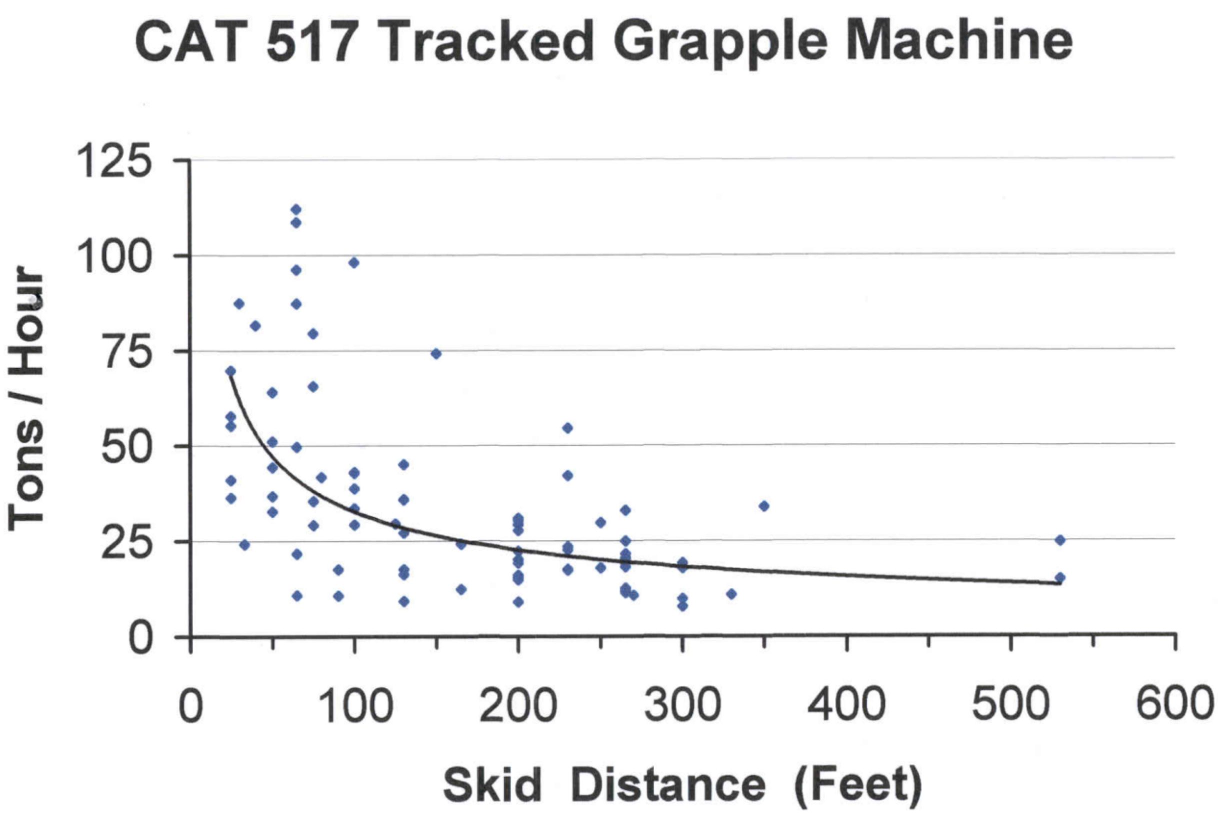

Figure 1: Productivity (tons/hour) vs. Distance when Bunching Tree-Length Stems with the CAT 517 Tracked Grapple Machine.

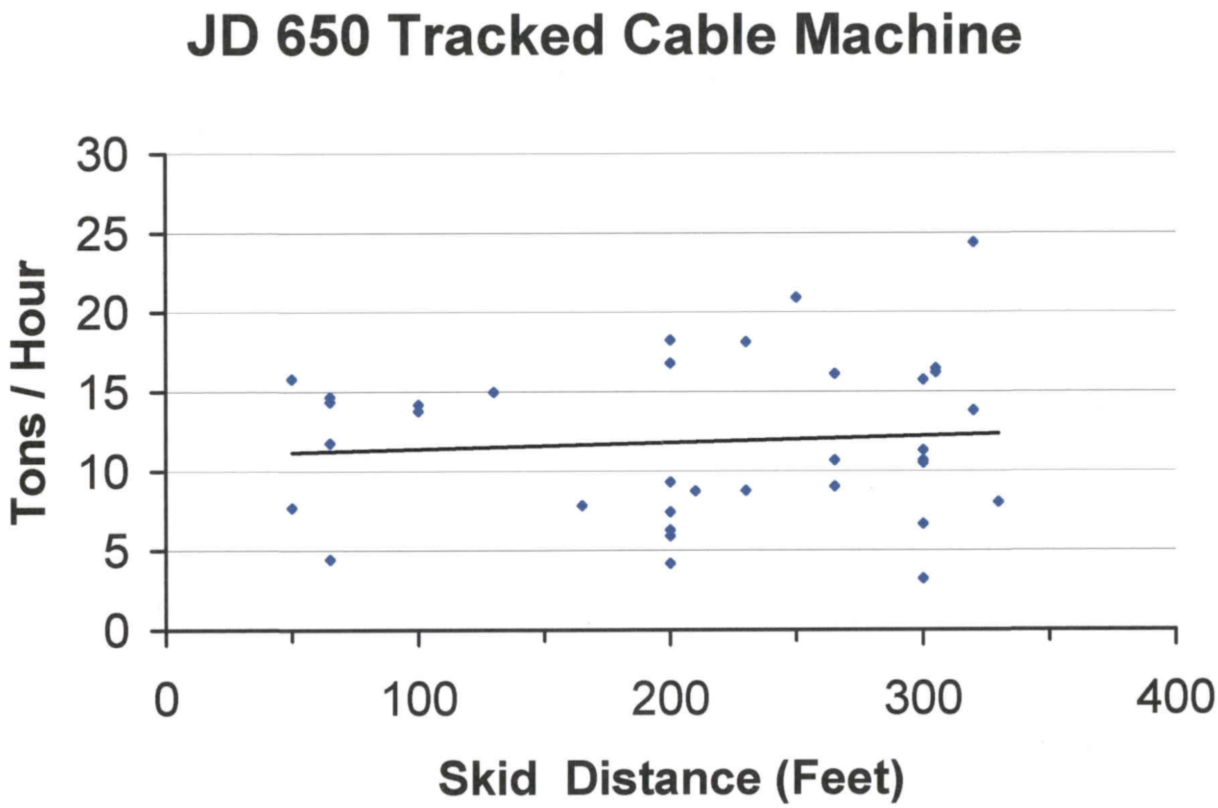

Figure 2: Productivity (tons/hour) vs. Distance when Bunching Tree-Length Stems with the JD 650 G Tracked Cable Machine.

During the course of the study, the DBH (in inches) and merchantable length (in feet) of 175 cut trees were individually measured to determine average stem size and volume. The average stem handled was 13.8 in. at DBH and 50 ft. long resulting in an average volume of 0.976 tons.

When the corresponding production rates were compared, the CAT 517 maintained higher overall productivity. The CAT 517 averaged 36.4 tons per hour compared to 11.8 tons per hour for the JD 650. Unless the stem was large, the CAT 517 typically handled more stems (than the JD650) averaging 1.95 stems or 1.79 tons per cycle. The JD 650 operator normally choked and skidded fewer stems regardless of stem size (i.e. averaging 1.7 stems or 1.41 tons per cycle). Bunching productivity for the JD 650 was reduced because of this, and there did not appear to be any reason why the operator did not bunch more than 1-2 stems per cycle. Tree size did not present a problem for either machine, but the CAT 517 had a definite advantage in manipulating stems during the acquire and drop/position phases.

Observations of both machines were noted on slopes ranging from 30 to 60 percent. The typical operating pattern was to fell trees across the skid road and skid/bunch the stems downhill. When operating on the steeper slopes, the machines worked and traveled on constructed (i.e. bladed) skid roads rather than operating on the side slopes. Occasionally, both machines would back uphill a short distance to acquire a stem or push a short spur road off of the main skid road to reach stems below the road, but this was not the preferred mode of operation. Cycle times increased and productivity was reduced by approximately 50% when skidding or bunching uphill (i.e. 15 tons/hour for the CAT 517).

Frequent delays of the CAT 517 were noted throughout the production study. The most common delays were waiting for the timber cutters to fell and/or top trees, waiting for the skidder to acquire bunched trees, widening the skid road or pushing in spur roads, cleaning and pushing tops and logging debris off the skid road, and long lunch breaks or unscheduled personal breaks during the day (to talk with other crew members).

Skidding

Comparison of the two rubber-tired skidders on the logging job was more difficult. Frequently, weather conditions prevented skidding operations altogether and other problems such as employees not showing up for work and flat tires delayed or slowed skidding. The CAT 525 grapple machine was not observed operating on many days because the wider tires (30.4) and lack of chains made it difficult to negotiate the narrow/steep skid roads on the tract. Consequently, the grapple machine was not used by the contractor when conditions were very wet or the skids long. However, additional data were taken after new tires (24.5) and chains were installed on the CAT 525. The other obvious factor that influences the skidding data is skidding distance. Of the 28 observations recorded for the CAT 525, 17 were on longer skids (> 1000 ft.). Of the 26 observations on the JD 640, only 5 were longer skids (>1000 ft.). Consequently, the average cycle times should be evaluated carefully because of the limited number of observations.

Acquire time for the CAT 525 was 1.07 minutes compared with 4.35 minutes for the JD 640, a savings of over three minutes. Since the skid distances for the two machines were substantially different, no travel comparisons could be made. As noted with the CAT 517/JD 650, no apparent differences in travel loaded and travel empty times were observed after the bunch was acquired. In general, the JD 640 was able to skid larger payloads (5.21 vs. 3.79 tons/turn on the shorter skids) because the choker cable was able to hold more stems than the grapple.

During the study, the grapple configuration on the CAT 525 was also changed which helped to improve the performance of that machine. However, retention of the bunched load was a particular problem for the grapple machine on the longer skids. The CAT 525 frequently lost stems while traveling to the landing because of the many turns and switchbacks encountered on the longer skids. The average number of stems and volume/turn noted below was recorded as the CAT 525 left the stump area, but many of those stems never made it to the landing. Loose and slippery bark on the yellow poplar stems during the spring season was also a factor contributing to the problem of stems slipping out of the drag.

Table 2. Comparison of the total cycle time (in 0.01 minutes) and production rates for the CAT 525 (Grapple) and JD 640 (Cable) rubber-tired skidders.

	CREW 1 CAT 525	[> 1000 ft.]	**CREW 2** JD 640	[> 1000 ft.]
	Short Skids	**Long Skids**	**Short Skids**	**Long Skids**
Distance (feet)	647	4844	870	3750
Cycle Time (minutes)	9.52	34.94	17.90	23.29
Number of Stems/Turn	4.6	4.3	6.4	4.4
Volume/Turn (tons)	3.79	5.17	5.21	3.24
Acquire Time (minutes)	1.07	3.17	4.35	- -
Production (tons/hour)	28.7	8.9	19.5	9.3
Observations	11	17	21	5

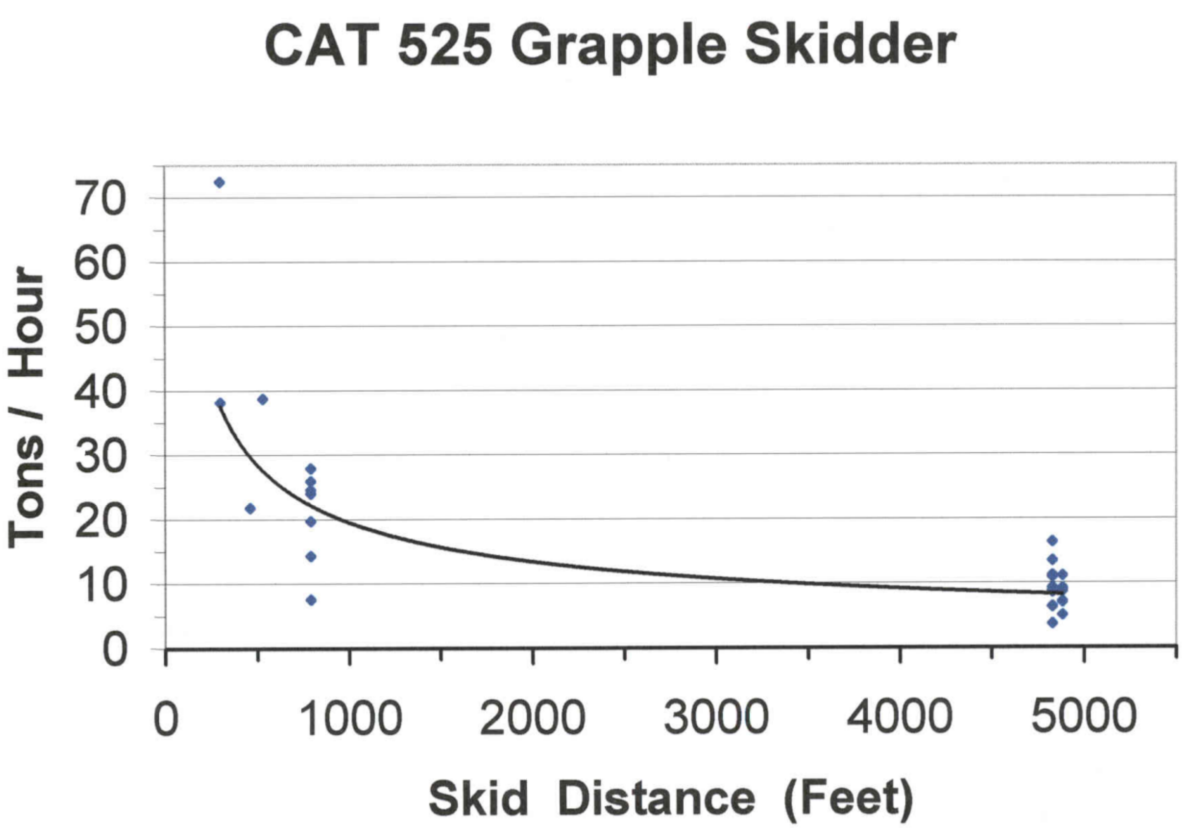

Figure 3. Productivity (tons/hour) vs. Distance when Skidding Tree-Lengths with the CAT 525 Rubber-Tired Grapple Skidder.

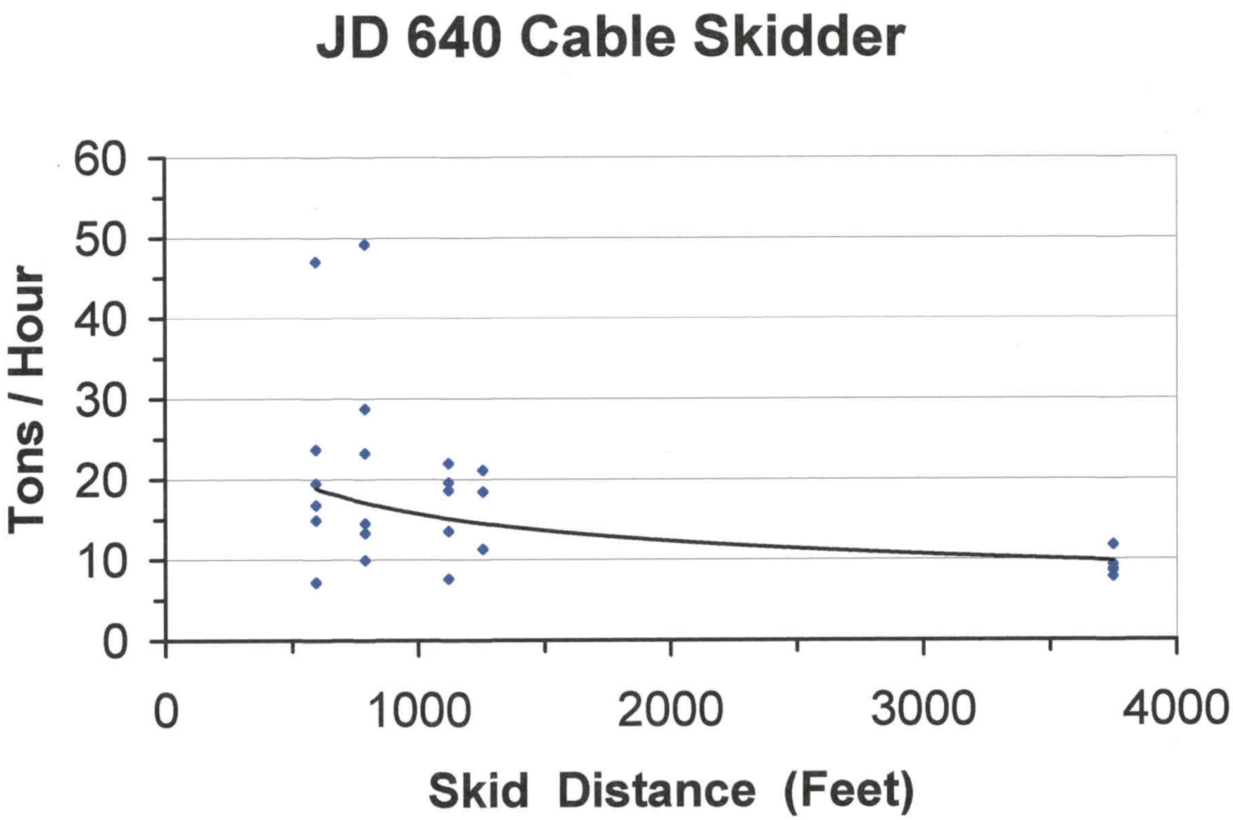

Figure 4. Productivity (tons/hour) vs. Distance when Skidding Tree-Lengths with the JD 640 Rubber-Tired Cable Skidder.

The limited number of machine cycles and different skid distances complicates comparison of production rates for each rubber-tired skidder. For all skidding cycles, the CAT 525 grapple skidder produced at a rate of 15.83 tons per hour, and the JD 640 cable skidder produced 17.51 tons per hour. As shown in Table 2, the CAT 525 significantly out performs the JD 640 on shorter distances (and more gentle slopes), but the JD 640 appears to have an advantage when skidding longer distances (on steep slopes). The graphs (Figures 3 and 4) illustrate the production rates (tons per hour) for each skidder as skidding distance varies. Alternative grapple configurations, more experience using grapples, and operator training related to using grapple skidders on narrow/steep skid roads might help solve this problem. Given the timber and terrain conditions in WV, the narrower, cable skidder may be slightly more productive on the longer skids. However, the CAT 525 operator definitely preferred the convenience of the grapple machine.

Frequent delays of the CAT 525 grapple and JD640 cable skidder were also noted during the production study. The most common delays were difficulty in acquiring a group of stems from the bunch (i.e. stems slipping out of grapple or choker), waiting for the other skidder to pass on the narrow skid trails, getting stuck in mud holes, inability of the skidder to travel uphill when soil conditions were wet, waiting for the truck to finish loading in order to drop off a drag at the landing, and long lunch breaks or unscheduled personal breaks (to talk with other crew members.).

SYSTEM PRODUCTIVITY

Overall system productivity for the whole operation (i.e. combined crews) was evaluated before and after the new crew (i.e. Crew 1) was introduced. This was based primarily on the number of truck loads delivered prior to and during the study period. Number of truckloads and delivered volume for November and December of 1998 were included to establish weekly production rates before the study was initiated. The data on the date, number of truck loads, product type, and volume delivered were provided by the receiving mills. Data on individual machine utilization was also obtained from Service Recorders installed in all the tracked and rubber-tired machines on both logging operations. The individual machines operators (and the contractor) were responsible for keeping up with and supplying the circular recorder forms (i.e. clock output), and the total number of stems skidded by each machine. Over a 26-week period (November 1998 to May 1999), the logging contractor delivered 257 truckloads, totaling 7199 tons, to several different mills. As shown in Figure 5, the volume delivered each week fluctuated widely because of weather conditions and the holidays/hunting season during November and December. Over the 26-week period, the operation averaged 277 tons or 9.9 truckloads per week. For 1999, the lowest weekly production (i.e. 2 truckloads) occurred the third week in January, and the highest volume produced (16 truckloads) was the last week in March.

The number of truckloads delivered each week is closely correlated with in-woods production, but is not always a direct measure of in-woods production on small hardwood logging operations in WV. Generally, the contract trucker's hauling schedule was erratic, and he hauled loads of whatever product was stock piled on the landing. Since the focus of this production study is on the CAT 517/525 machines, comparison of weekly production (combined for the 2 crews) before and after these machines were on the job was evaluated. The weekly production for the 12 weeks before the CAT machines arrived averaged 237 tons (or 8.7 loads) per week. The operation averaged 311 ton (or 10.9 truckloads) per week during the 14 weeks that the CAT machines were operating. Although many factors are involved, this is an increase of 74 tons per week or approximately 3 truck loads per week.

The total truck load production for 1999 is classified by product type below:

Sawlogs	21 %
Peeler Logs	7 %
OSB Wood	59 %
Low Grade Logs	13 %

The data on machine utilization obtained from the service recorders indicates some of the problems observed with individual machine operators and the rest of the crew. After the machine operators realized that the daily service recorder readings indicated how little time they spent working each day, they stopped using the forms and turning in the daily clock readings. Based on the limited data available, the crew is scheduled to work 7.0 hours per day, but only works an average of 343 minutes (or 5.7 hours). Although not representative of a normal work day, the average utilization rates (obtained from the service recorder data) for each machine are as follows:

CAT 517	63 %
JD 650	75 %
CAT 525	59 %
JD 640	65 %

The lower utilization rates for the CAT 517/CAT 525 crew was often due to the inability of the manual chainsaw operator to cut/limb/top sufficient material in advance of the bunching operation.

COMPARISON OF MACHINE COSTS

Since the direct costs of owning and operating all the equipment on the logging operation were not available from the contractor, the costs of the two CAT (517/525) machines were compared with the two John Deere (650/640) machines. The "machine rate" approach was used to estimate the fixed and operating costs of each machine (Miyata, 1980).

For this analysis, many of the cost and operating assumptions were kept the same for an equitable comparison of machine costs for each crew. For example, the following parameters were assumed to be the same for all machines: labor rates; scheduled hours per year; utilization; economic life; salvage value (i.e. % of purchase price); interest and insurance rates; maintenance & repair (%); and fuel and oil price per gallon. The initial purchase price for a new machine, rated horsepower, tire/track costs, and engine/hydraulic oil capacities varied depending on the machine type. The labor rate assigned to the JD 650 includes the machine operator plus the extra "gin man" that sets chokers for the machine operator.

The average production rates (i.e. mean values from the time study) for each machine were used to estimate cost per ton.

The results of the machine rate cost calculations for the four machines on the logging operation are summarized in Table 3. The machine rate methodology only estimates the direct costs of owning and operating a single machine, and does not include other labor, machines, and indirect costs associated with the operation. Hourly fixed [FC] and variable costs [VC] (in $ per Hr.) are shown for each machine. Productivity (in tons/hour) by machine is reported when the machine is productive 100% of the time, then adjusted for machine utilization. The cost per ton (i.e. $ per ton) was determined using the following formula:

Cost / Ton =
(FC + (VC * Utiliz.)) / (100%Production)*Utiliz.)

The total 'machine rate derived' wood cost for the CAT 517/525 machines (Crew 1) was $6.74 per ton and $9.93 per ton for the JD 650/640 machines (Crew 2). The $3.19 per ton difference favored the CAT machines even though the John Deere machines have lower hourly fixed and variable costs. The high bunching capability of the CAT 517 swing boom grapple skidder (i.e. more than three times the productivity of the JD 650) lowered the cost per ton significantly (i.e. almost $4 per ton compared to the JD 650). Because the average (observed) productivity of the CAT 525 grapple skidder was slightly lower, the skidding cost per ton was lower for the JD 640 cable skidder. The actual production rates of the paired John Deere machines were closely balanced, but the logging system would need two CAT 525 skidders to match the productivity of one CAT 517. Since the cost per ton values are based on the production rates observed during this study, these cost figures will vary as individual machine productivity changes for different timber and terrain conditions.

SUMMARY AND CONCLUSIONS

Overall system productivity would be greater if the CAT 517/525 machines were operated by a more motivated and closely supervised crew. Consequently, the study did not demonstrate the full capability of the CAT 517 on this operation. The observed felling productivity (i.e. one timber cutter per crew) could not keep up with the bunching/skidding capability of the CAT 517. A minimum of two timber cutters is needed to match the CAT 517 productivity. Further production gains could also be realized if the operator(s) of either the CAT 517 or JD 650 tracked machines spent more time gathering or grouping stems (at the stump) to increase the number of trees and the volume bunched per cycle. Quite often, the machine operators acquired and skidded only one stem (regardless of stem size).

Even though limited skidding data were observed, the narrower JD 640 cable machine appears to have a productive advantage compared to the wider CAT 525 grapple skidder. On average, the cable skidder operator was able to acquire and retain more stems per drag than the grapple machine. This was a definite productive advantage on the longer skids (of more than 1000 ft.), on steeper slopes, and when negotiating the multiple curves and switchbacks on the skid roads that are characteristic of the mountainous terrain in WV. Retention of stems and higher drag volumes for both the grapple or cable skidders may be improved if the tree butts were oriented in the same direction before bunching.

Table 3. Fixed and Variable Machine Costs ($ / Hour) and Cost per Ton ($/Ton) for Crew 1 (CAT 517/525) and Crew 2 (JD 650/640).

Crew & Machines	**Fixed Cost [$ / Hr.]**	**Var. Cost [$ / Hr.)]**	**Utiliz. [%]**	**100 % Production**	**Crew Production [Tons/Hr.]**	**Cost / Ton [$ / Ton }**
CREW 1						
CAT 517	43.43	25.55	0.70	36.44	25.51	2.40
CAT 525	31.91	19.50	0.65	15.83	10.29	4.33
					TOTAL:	**$ 6.74**
CREW 2						
JD 650 G	40.41	17.42	0.70	11.85	8.30	6.34
JD 640 G	29.84	16.90	0.65	17.51	11.38	3.59
					TOTAL:	**$ 9.93**

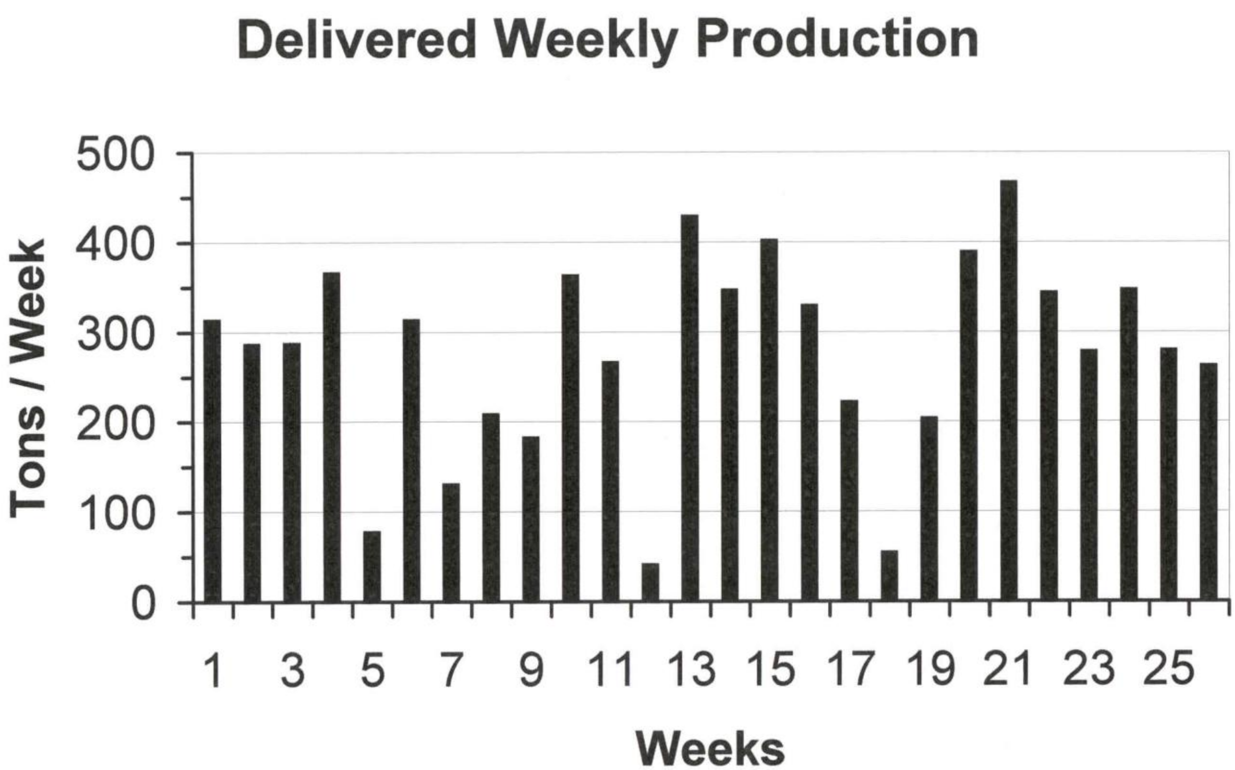

Figure 5. Weekly Production (tons) Delivered by the Logging Operation from November 1998 to May 1999.

The swing boom grapple of CAT 517 is better equipped to orient the butts than the JD 650 tracked machine.

Because of the relatively short time frame of the production study, no apparent differences in skid trail spacing, amount of soil disturbance or method of operation were observed as a result of using the CAT 517 tracked machine. Over time and with additional operator training, wider skid trail spacing and less soil/site disturbance may be realized with the CAT 517 machine.

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An Operational Comparison of Partial Cut and Clearcut Harvesting Methods in Old Cedar-Hemlock Forests in Central British Columbia

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ABSTRACT: Although clearcutting has been a historically dominant harvesting method in British Columbia (representing 95% of the total area harvested annually), forest managers are increasingly recommending the use of alternative silvicultural systems and harvest methods, including various types of partial cutting, to meet ecological and social objectives. In this study we compared harvesting productivity and harvesting costs between treatments in 300-350 year-old Interior Cedar-Hemlock stands. This was achieved through detailed and shift level time studies. Residual stand damage was also assessed and recommendations for improving operational planning/layout and the implementation of clearcut and partial cutting silvicultural systems were made. Ground-based clearcut harvesting was the most cost effective at $11.96/m^3, followed by the cable clearcut using a running skyline system at $16.08/m^3. The group selection treatment had the highest cost at $16.95/m^3, an increase in cost of 42% compared to the ground-based clearcut treatment. The net merchantable volume in the harvested stand ranged from 32% to 49% of the total harvested volume, due to the high proportion of butt and pocket rot. The high amounts of decay and waste had a large effect on the final cost per cubic meter. Residual leave trees damaged by ground-based skidding in the group selection accounted for 9% of the residual stand.

INTRODUCTION

Forest management in British Columbia (BC) is rapidly changing due to increasing emphasis on ecological and social goals that include the management of non-timber resources such as visual quality and wildlife habitat. The use of alternative silvicultural systems, including partial cutting, are being increasingly considered for achieving these management goals. Since clearcutting has been a dominant harvesting method in BC, knowledge and experience with partial cutting is limited for many of BC's forest ecosystems. Also, it has been traditionally widely viewed that the low market value of the Interior Cedar-Hemlock (ICH) stands make it more difficult to practice Partial cut silvicultural systems in these stands (Sinclair 1984). Partial cutting generally is considered to be more expensive than clearcutting (Daigle 1995).

For example, Thibodeau et al. (1996) compared logging productivity and costs of partial cut and clearcut treatments in a second growth ICH stand with an age of 130 years and moderately gentle terrain in northwestern BC, and found that the cost of a ground-based partial cut harvesting system was 1.98 times higher than that of a ground-based harvested clearcut. Layout costs for the partial cut were 1.9 to 2.3 times that of clearcut units due to more intensive timber cruising, layout and marking of internal patch cut boundaries, increased tree marking, and designated skid trail networks (Thibodeau et al. 1996; BCMOF 1996).

Tree marking in partial cuts allows fellers to be free from selecting trees to be felled, thus increasing their productivity (Bennett 1997). Tree marking must take into consideration the safety of the feller through individual tree characteristics (i.e. lean, and distribution of branches), and the characteristics of adjacent trees (Moore 1991). When hand felling, stumps should be close to ground level to minimize hang-ups (Pavel 1999). The primary consideration of the feller is safety (Moore 1991). In decadent western redcedar, felling is dangerous and difficult due to a lack of holding wood and a result of both branches and tops being prone to breakage during falling.

Skidding productivity is affected by weather, skidding distance and slope (Mitchell 2000). The skidding cost per cubic meter, when using a line skidder, a 60 % removal treatment is 1.85 times higher in cost than a conventional clearcut as a result of longer skid distances and less volume delivered to the landing per turn (Thibodeau et al. 1996).

Effective use of the loader is essential to ensure that the landing is clear and safe and that trucks are loaded with a minimum delay (Pavel 1999). The loading cost per cubic meter in partial cuts ranges from 1.31 to 1.46 times greater than in clearcut units as a result of increased non-productive time in the partial cut units (Bennett 1997).

The majority of residual stand damage is located along skid trails where the most harvesting activity occurs (Pavel 1999; Bennett 1997). In ground-based partial cuts, the orientation of harvest units and directional felling play an important role in reducing stand damage (Thibodeau et al. 1996).

The objectives of this study are to 1) compare harvesting productivity and costs between treatments, 2) assess residual stand damage in a partial cut block, and 3) document the current utilization of old western redcedar with high internal defects.

Table 1. Site and stand description.

Harvesting system	Ground-based		Cable
Silvicultural treatment	Group Selection	Clearcut	Clearcut
Treatment size (ha)	8.7	1.1	6.7
Harvested area (ha)	2.1	1.1	6.7
Slope range	0-50 %	0-30 %	30-130 %
(avg.)	(20%)	(15%)	(55%)
Species (%)			
Western red cedar	87	79	90
Subalpine fir	3	10	3
Englemann spruce	10	5	2
Western hemlock	0	6	5
Stems/ha[a]	404.7	424.3	424.3
Avg. DBH (cm)[a]	56.2	53.2	53.2
Avg. ht (m)[a]	36.7	33.5	33.5
Gross vol. (m^3/ha)[a]	1074.6	908.0	908.0
Net. vol. (m^3/ha)[b,c]	349.0	441.6	433.0

[a] Provided by the BC Ministry of Forests (BCMOF) Cruise data.
[b] Low net volume resulted from high decay, waste, and breakage.
[c] The net. volume was calculated from the BCMOF Scale data.

Methods

The research was conducted on sites in the Interior Cedar- Hemlock biogeoclimatic zone (Ketcheson et al. 1991), 35 km west of McBride, BC. The sites were dominated by western redcedar (*Thuja plicata*) with minor components of Engelmann spruce (*Picea engelmanii*), western hemlock (*Tsuga heterophylla*), and subalpine fir (*Abies lasiocarpa*) (Table 1). The stands within the study area had an average age of 300-350 years and high incidence of defect; scaling data indicated combined decay, waste, and breakage total ranging from 51 to 68%. There were three treatments: a group selection and two clearcut blocks. In the group selection treatment the primary goal of the layout crew was to design a skid trail system that would allow for multiple entries while maintaining visual quality.

Two contractors participated in this study; Contractor A harvested the ground-based treatment units (70% retention and 0% retention) using a ground-based harvesting system consisting of hand felling, skidding with rubber-tired and tracked line skidders, manual delimbing/bucking, and loading with a front end wheel loader. Contractor B harvested the cable unit (100% removal) using an adapted running skyline system with a non-slackpulling carriage consisting of hand felling, yarding with a tower yarder, manual delimbing/bucking, and loading with a heel boom log loader. Manual felling was the only method used for all harvest units because of large tree size and steep slopes. Contractor A and B had separate fellers with similar amounts of felling experience (20 years). During felling, snow was present (<20cm) on the site but shovelling was not required for the majority of trees.

There were three methods used to collect time study data on logging operations: shift level, detailed, and activity sampling. A Ranger 3100 data logger was used to time the components of each harvesting process. In activity sampling, sampling intervals were set at 20 seconds to ensure the accuracy of the data as recommended by Olsen and Kellogg (1983).

Harvesting costs were calculated using the Forest Engineering Research Institute of Canada's (FERIC) standard costing methods and were based on local standard contractor rates for workers. A multiple regression analysis was completed for felling and primary transportation elements of the harvesting operation. Systematic transect sampling was used to estimate the damage to residual trees. To determine the utilization of the western redcedar, harvested from this site, three mills were asked to provide a list of their products.

RESULTS AND DISCUSSION

Planning and layout

The layout and planning costs were highest in the group selection (\$2.62/m^3) because of the need to designate removal patches. The recommended skid trails were also marked in both ground-based treatments during the layout phase. The contractors were given the option to modify the location of these skid trails, if necessary. In all treatments pre-existing landings from the construction of the East Twin Forest Service Road were utilized instead of constructing new landings, because the locations of these landings were suitable and resulted in decreased landing construction costs. Layout of the cable-based clearcut incurred higher costs (\$0.68/m^3), than the ground-based clearcut (\$0.53/m^3), due to increased time requirements for layout of skyline roads to ensure sufficient deflection.

Harvesting operations

Felling

Pronounced butt flare in western redcedar in combination with the presence of butt rot, made directional felling difficult and potentially dangerous. In all treatments the cedar was generally felled in a downhill direction as the trees were leaning and weighted by branches to fall in that direction. Breakage occurred in less than 2.0% of the felled timber. In the partial cut, trees were felled towards skid trails unless tree conditions safety or felling constraints made this impossible.

Felling production in the cable clearcut was the highest as a result of the fastest cycle time of 1.97 min./tree. This resulted in a volume production of 359.28m^3 per 8-hour shift. The group selection cycle time (3.13 min./tree) was faster than that of the ground-based clearcut (3.58 min./tree). However, the higher volume per tree, 1.54m^3/tree for the ground-based portion of the clearcut versus 1.22m^3/tree for the group selection treatment, resulted in a larger volume harvested in the ground-based clearcut per cycle. These results indicate that total cycle time, tree size, and decay percentage can have a significant effect on the production.
[1] Total productive time (min.) = 0.040 + 0.020 * Diameter

n = 212 R^2 = 0.513 S.E. of Estimate = 0.604

Primary transport

Skidding

The average skidding distance in the group selection was 284 m, which was 143 m longer than in the clear cut. In the group selection, an additional 1.5 logs were delivered to the landing each turn, but resulted in a longer cycle time. The average total cycle time in the group selection was 2.83 min. greater than the clearcut. In the clearcut and group selection, 0.6% and 1.1% of the total cycle time was spent waiting for the track skidder to clear and develop skid trails. An additional 0.23-min. wait for the feller per cycle was also incurred in the group selection. These delays could have been avoided through better planning by the contractor.

[2] Total productive time (min.) = 8.582- 1.195 * Treatment
+ 0.025 * Distance+ 0.793 * No of logs

n = 136 R^2 = 0.521 S.E. of Estimate = 3.248

Where: Treatment: 0 = Clearcut, 1 = Group selection

Yarding

Figure 1. Pocket and ring rot in the butt of cedar

The yarding was downhill with distances ranging from 35 to 225 meters with an average distance of 125 meters. The unit cost for yarding was 72.5% more expensive than skidding in the group selection and 86.7% higher than skidding in the clearcut. Productive yarding time constitutes 75% of the total cycle time. This is higher than that found in ICH stands near Kitwanga, BC (Pavel 1999), which found that only 55% of the total cycle time was actually productive. Yarder setting change time accounts for 11% of the total cycle time. Approximately 19% of the non-productive time, or 2.52% of the total cycle time, was spent on repairing the haulback drum and general repairs, such as repairing a coolant leak or broken hydraulic line. Equation 3 shows that the number of logs has a greater effect on the total productive time than distance.

Table.2 Summary of total costs. All costs are in $/m^3$.

Harvesting system	Ground-based		Cable
Silvicultural treatment	Group selection	Clearcut	Clearcut
Layout/planning cost	2.62	0.53	0.68
Felling cost	2.01	2.02	1.11
Skidding/yarding cost	4.48	4.14	7.73
Processing and decking cost	6.86	4.29	6.16
Moving cost	0.98	0.98	0.40
Total cost	16.95	11.96	16.08

[3] Total productive time (min.) = 2.002 + 0.027 * Distance
+ 0.639 * No of logs

n = 285 $R^2 = 0.290$ S.E. of Estimate = 1.791

Processing / Decking / Utilization of Western redcedar

Processing for all sites was manually completed using a chainsaw at the landing. The primary consideration of processing was to maximize commercially valuable wood recovery such as saw logs and post and rail wood. The saw logs were required to have a minimum of a 10 cm sound outer shell (distance between outer bark and inner rot) of timber in order to be merchantable. The minimum required length for saw logs was 5m, up to a maximum length of 19 m. The saw logs were processed into dimensional lumber such as 2.5cm x 10cm (1"x4"), 5cm x 7.5cm (2"x3"), and 5cm x 30cm (2"x12") of various lengths, radius edge decking, tongue & groove, channel siding, and rough facia board. The post and rail timber required a 7.5 cm shell. Post and rail timber required a minimum length of 2.5m and a maximum length of 19m. Timber for this product was processed into 7.5cm x 7.5 cm (3"x3") and 10cm x 10cm (4"x4") posts of 2.4 to 3.0m (8 to 10 feet) lengths and 10cm x 10cm (4"x4") and 7.5cm x 7.5cm (3"x3") rails of 2.4 to 4.9m (8 to 16 feet) lengths.

The combined decay, waste, and breakage totals for the ground-based group selection, ground-based clearcut, and cable clearcut treatments were 68%, 51%, and 52%, respectively. These numbers are high as a result of butt and pocket rot being present in the western redcedar (Fig. 1). Butt and pocket rot not only destroy heartwood and sapwood, but also increases the possibility of breakage when felling and skidding/yarding. The bucker made multiple cuts with a chainsaw at 0.75m intervals

Table 3. Summary of stand damage

	Skid trails	Openings	Both
Damage summary			
% of residual stand	6.8	2.5	9.3
No. injuries/ tree	1.4	1.1	1.3
Average size			
Width (cm)	14	9.5	13.1
Length (cm)	42.1	18.7	37.2
Area (cm^2)	659.4	578.3	564
Height [a] (cm)	66.2	12.6	68.3
Percent of total damage [b]			
Stem	84	91	86
Stem and Root	13	9	12
Root	3	0	2

[a] Measured from base of tree to middle of damage
[b] Damage classes: Stem - scarring or gouging stem
Root – scarring or cutting root system
Stem and root - multiple of stem and root damage

to determine where the timber was commercially valuable. In the cable clearcut, the timber was first processed for saw logs and then post and rail wood.

The lowest cost of processing and decking wood ($/m^3$) was the ground-based clearcut. This lower cost may be partially compounded by a lower defect rate per tree and the higher proportion of spruce and subalpine fir in this block. The hemlock, spruce, and subalpine fir generally did not have any decay, thus was faster to process for the bucker. These species were processed for saw logs only. Decking was necessary to sort the timber as it was being sent to mills throughout central and southern British Columbia. Additionally by decking the timber, the landings were kept clear and the safety of bucker was improved. Decking and processing costs were the highest in the group selection because workers and equipment on the landing were waiting for wood to process due to a longer cycle time for wood being skidded to the landing. The cable clearcut had higher costs than the ground-based clearcut largely due to higher equipment costs per hour, although a heel-boom loader showed a greater productivity (m^3/hr) than the front end wheel loader did in the group selection.

According to the activity sampling, primary transportation was not delayed by decking and processing on the landing. In the ground-based treatments, the loader was waiting for timber to sort 49% to 51% of the scheduled operating time. This was also similar for bucking where 39% to 41% of the scheduled operating time was spent waiting for skidded timber to process. To improve loading and bucking efficiency on the landing in the ground-based treatments, we recommend another skidder be employed to reduce the non-productive time. In the cable treatment, the operation was well balanced in its components.

Other harvesting costs

The cost of moving logging equipment by low-bed truck from McBride to the harvest site, a 35km distance, was calculated by dividing the cost of moving by the volume removed. The local rate for moving equipment was $600 per low-bed of equipment. As contractor A harvested both the group selection and ground-based clearcut, the moving cost was shared. Contractor B harvested the cable clearcut block with different equipment and thus new moving costs were incurred.

Skid trail and landing construction costs were calculated by timing the number of hours taken to construct the trail and landings, and the equipment and manpower used to complete the task for each treatment. The group selection treatment required 15 hours of landing and skid trail construction while the ground-based clearcut only required 7.5 hours of landing and skid trail construction. This resulted in a higher cost per cubic meter in the group selection ($2.97/$m^3$) compared to the clearcut ($2.24/$m^3$).

Stand damage

In the group selection treatment 9.25% of the residual stand was damaged during harvesting (Table 3). Stems along the skid trail had the highest incidence of stand damage, 73% of the total stand damage. This damage occurred within 5 meters from the centre of the skid trails. The average width of the skid trails was 5 meters. The remaining 27% of the total stand damage occurred adjacent to the harvest openings, within 5 meters.

CONCLUSION

Tree volume, amount of internal decay, and efficiency of harvesting elements were the most important factors affecting final harvesting cost. Ground-based clearcut harvesting was the most cost effective at $11.96/$m^3$, followed by the cable clearcut at $16.08/$m^3$. The group selection treatment had the highest cost at $16.95/$m^3$, an increase in cost of 42% compared to the ground-based clearcut treatment. This low cost of the ground-based clearcut can be partially attributed to the lower decay waste and breakage of the harvested wood in comparison to the group selection (17% lower). In a group selection, harvest groups should be arranged in a manner that facilitates felling the trees into an open skid trail or other opening, as it is easier and more productive for the feller and skidder. The trees scheduled for removal should be examined for lean and branch orientation, as it will affect the direction and ease of felling. Loading and bucking productivity could be improved in the ground-based treatments by employing another line skidder. Economic feasibility in all three treatment units is dependent on market value. Therefore before harvesting the contractor should ensure that a buyer for the wood to be harvested exists and that the highest commercial volume is being extracted from the timber by processing the timber for use as multiple products.

Stand damage levels in the group selection is 9.25% of the residual stand. Of this damage 73% is located along skid trails and could be decreased if prevention or remediation techniques were utilized, such as straight skid trails and use of rub trees.

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Improving Stability of Low-Volume Forest Roads Using a Lignin-Based Emulsion

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ABSTRACT – Unitol DKG, a lignin-based emulsion used to stabilize road surfaces was tested on a low-volume forest road near Chapman, Alabama. Two replicates of three treatments were applied during October 1999 that included a 3:1 dilution of Unitol DKG, a 6:1 dilution, and pack & grade with no chemical. Also, two control sections were located at each end of the test area. California Bearing Ratio (CBR) and moisture content were measured the following November and March. In addition, soils treated with three different dilutions of the product were subjected to Unconfined Compression (UC) and CBR tests in a lab. Adding the Unitol appeared to bind the soil together. Strength appeared to develop with time in treated road sections. The field CBR's consistently increased from November to March for the chemically stabilized and pack & grade sections. The 3:1 dilution had the best strength performance in the field tests, while the 6:1 dilution was not much different from the control sections. There was not a significant difference in the performance of the various dilutions in the UC tests. The UC tests showed increased plasticity at the lower dilutions. The saturated lab CBR tests showed that the 3:1 dilution retained its cohesiveness under wetted conditions. The lab CBR tests showed higher strength in the weaker dilutions than in the 3:1.

INTRODUCTION

Forest roads are designed to provide access. They must safely carry heavy traffic, provide access during a range of weather conditions, provide service without excessive maintenance, and minimize impacts to water quality. The fundamental problem that forest road designers must address is developing adequate strength in the sub-grade.

Given the economic constraints, the most commonly applied road treatment is periodic addition of surfacing aggregate "as needed." In areas with good sources of rock, aggregate may be relatively inexpensive and readily available. Many regions, however, may not have access to good aggregate and rocking forest roads becomes an expensive option.

An alternative to rocking forest roads is to improve the strength characteristics of the native materials for road construction with the addition of chemical stabilizers. Many materials have been used to increase soil strength, including fly ash, ionic chemicals, lime, and lignin-based products. The performance of these additives is highly variable depending on soil type, climate, and application method.

Unitol DKG[1], a lignin-based emulsion that is derived from a by-product of the tall oil extraction process, may be a viable alternative for enhancing road strength. The by-product is water insoluble and additives are necessary to suspend the product in a water emulsion.

This product was applied at two different dilution rates on two 0.5-mile test sections of a low-volume forest road to improve strength. Application of the product on the test section was performed during October 1999 near Chapman, Butler County, Alabama. The project was a cooperative effort among International Paper Company, Woodland Enterprises, Arizona Chemical, and the Southern Research Station, Auburn, Alabama. Rather than spraying the product onto the road surface and mixing with a grader, a new approach was used where a soil stabilizer machine thoroughly mixed the product with the upper 8-inches of

[1] The use of trade names is for the convenience of the reader and does not imply endorsement by the USDA Forest Service.

road surface. This approach offers the potential for better performance of the road and a greater increase in strength.

PROJECT DESCRIPTION

Test Area

The study was installed on two 0.5-mile sections of a forest road in Butler County, Alabama. Butler County is located in south-central Alabama on the Coastal Plain. The average daily temperature for the county is 65.1°F. Yearly precipitation averages 56.2 inches. Monthly rainfall amounts during the study period are displayed in Figure 1.

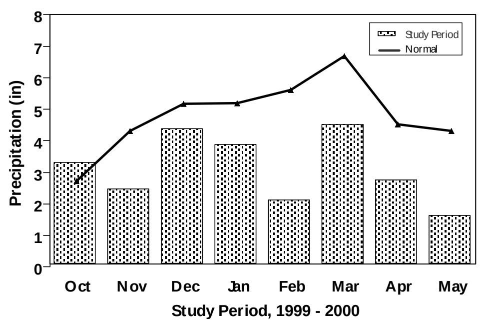


Figure 1. Rainfall amounts for area during study period.

According to the County's soil survey (Soil Survey of Butler County, Alabama, 1993) one test section was located predominately on a Lynchburg soil series and the other on a Luverne (LuB and LuC) soil series. These series had an AASHTO classification of A-2-7 and A-2-4, respectively. The Luverne series was located in areas with slopes ranging from 1 to 8 percent. The Lynchburg soil series was located in areas with 0 to 2 percent slopes. A soil classification summary is shown in Table 1. Procedures from ASTM D 2487-90 and ASTM D 4318-84 were used for soil classification determination.

Table 1. Unified Soil Classification

Soil Type	Liquid Limit	Plastic Limit	Plasticity Index	Group Symbol	Group Class
Lynchburg	27	20	7	SC-SM	A-2-4
Luverne	54	34	20	SM	A-2-7
Sandy loam[1]	58	36	23	SM	A-2-7
Loamy sand[1]	17	NP	17	SC	A-2-4

[1]Lab soil

Treatments and Method of Application

Two replicates of three treatments were installed on two 0.5-mile test sections. One test section was located on flat terrain (Lynchburg) while the other test section contained slopes that ranged from 1 to 8 percent (Luverne). Treatments that were applied included: (1) a 3:1 dilution of water and Unitol, (2) a 6:1 dilution of water and Unitol, and (3) pack & grade with no chemical. Two control sections were located at each end of the first test section. Each treatment replication was installed in a 500-ft test block.

For treatment installation a Caterpillar SS-250 machine was used to till the road surface and apply the chemical. The chemical was transferred through a hose from a tank truck to spray nozzles located near the rear of the tilling drum of the SS-250. After tilling and spraying, the road was graded with a John Deere 770B and then packed with a smooth drum roller. The chemical was applied at different dilution rates, but a constant application rate of 1.125 gal/yd^2.

METHODS

Field California Bearing Ratio (CBR)

CBR is a widely accepted value for expressing soil strength and is defined as the ratio of the stress (psi) at 0.1 inches of penetration to a standard stress of 1000 psi, multiplied by 100. To determine CBR values of treated sections a Dynamic Cone Penetrometer (DCP) was used. The DCP utilizes a cone penetrometer and a 20 lb drop hammer. The hammer is dropped a distance of 22.6 inches, which drives the cone into the soil and the penetration rate measured in mm/blow is recorded. DCP data were converted to CBR values using the formula in Bolander et al. 1995.

For each 500-ft test block, DCP readings were taken at three locations 125-ft apart to a depth of 18-inches. Test points were located in the center of the road and were collected during November 1999 and March 2000.

Field Bulk Density and Moisture Content

To assess bulk density and moisture content of the road surface, two samples were collected within each test block at the time the DCP readings were taken. A soil hammer with 2-inch diameter aluminum rings was used to extract samples from the surface layer at a depth of 2-4-inches.

Moisture content of the sub-grade was determined from samples taken with a Laurd's stick. The Laurd's stick was inserted into the hole left by the bulk density sample. This produced a core sample from a depth of 5-inches and below. The depth of penetration varied from point to point due to the hardness of the sub-grade.

Laboratory Unconfined Compression and CBR Tests

To assess the effect of soil type, chemical dilution, and moisture content on strength properties with the chemical treatment, loamy sand and sandy loam soils were collected from field locations in Lee County, Alabama. These samples were taken to the Soils Lab at the Civil Engineering Department at Auburn University for laboratory CBR and Unconfined Compression Tests.

Proctor tests were performed on both soils to determine optimum moisture content. Optimum moisture is the level of saturation a soil requires for maximum compaction potential. For the sandy loam soil, optimum moisture content was achieved at about 19 percent. The tests performed at optimum were intended to determine the best possible performance of the product.

RESULTS

Field California Bearing Ratio (CBR)

There was a noticeable difference in surface and sub-grade strength within treatments as reflected in the CBR values due to treatment and soil type.

CBR values were calculated for the upper 8-inches of road and for the sub-grade below. The measurements were taken in November and repeated in March (Table 2). The average CBR for the sub-grade on the Lynchburg was 22.7 while for the Luverne it was 9.2. These sub-grade CBR values did not change from November to March. CBR values for the surface sections, however, increased over the 5-month period with the exception of the Control sections.

Table 2. Mean CBR for 0 – 8 inches.

Treatment	Soil Type	November	March
3:1	Lynchburg	27.6	47.5
	Luverne	13.2	20.5
6:1	Lynchburg	25.3	37.4
	Luverne	6.8	13.0
Pack & Grade	Lynchburg	7.4	21.0
	Luverne	5.9	10.7
Control	Lynchburg	17.0	16.3

Laboratory Unconfined Compression and CBR Tests

The laboratory tests of UC and CBR were conducted on representative soil samples rather than actual road material. The lab tests showed the more highly concentrated dilutions of chemical additive increased plasticity, but decreased ultimate strength compared to the control sandy loam (Table 3). UC tests could not be performed on the loamy sand due to insufficient cohesiveness.

Table 3. Mean stress and deformation of sandy loam soil.

Treatment	Mean Stress (psi)	Mean Deformation (inches)
Control	29.62	0.14
3:1	22.98	0.18
5:1	23.17	0.18
7:1	25.43	0.14

Two types of CBR test were run—unsoaked and soaked. The unsoaked tests were compacted at optimum moisture content and tested. The soaked samples were similarly compacted, but then subjected to a 96-hour soak prior to testing. Each dilution was replicated three times. For the sandy loam soil, the 3:1 dilution retained its strength even in saturated conditions. The control and 7:1 dilution had the highest CBR under unsoaked conditions but showed significant reductions in strength with saturation (Table 4). For the loamy sand, the control had the highest CBR for unsoaked and soaked conditions than all other treatments, although it had the largest percent decrease in strength. From the lab tests the 5:1 dilution appeared to perform well. It had the highest CBR value after soaking for the sandy loam soil and about the same CBR value as the 3:1 dilution for the loamy sand with the largest percent increase in strength. However, it appears that adding Unitol to a sandy soils (loamy sands and sands) might not be beneficial since the lab loamy sand with no chemical had the highest CBR value under unsoaked and soaked conditions.

Table 4. Mean CBR values for lab soils.

Treatment	Sandy loam US[1]	Sandy loam S[2]	% Change	Loamy sand US	Loamy sand S	% Change
Control	11.3	4.9	-57	13.9	9.2	-34
3:1	9.4	9.4	0	6.6	7.0	+6
5:1	16.7	10.0	-40	6.1	6.9	+13
7:1	17.5	7.5	-57	5.7	6.0	+5

[1]Unsoaked; [2]Soaked

Bulk Density and Moisture Content

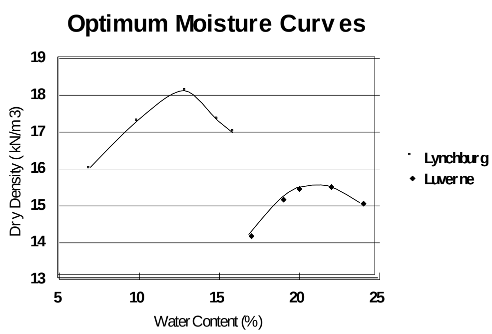
The soil cores collected in the initial post-construction sampling were analyzed for bulk density and moisture content. The results summarized in Table 5 show that the moisture content of the upper layer of the roadway was generally near the Proctor optimum moisture content (Lynchburg ~13%, Luverne ~22). The Lynchburg soils were fairly uniform in moisture content. The Luverne soils, however, were significantly wetter in the sub-grade in all cases but one. In addition, the Luverne soils showed a consistent drying trend in the chemically treated sections.

Post-treatment soil sampling found that the mean bulk density for the Lynchburg test sections was 1.76 g/cm^3 (17.2 kN/m^3). For the Luverne test sections, mean bulk density was 1.58 g/cm^3 (15.5 kN/m^3). These values fall closely on the Proctor curves illustrated in Figure 2, suggesting that the installation achieved maximum compaction.

Table 5. Bulk density and moisture content summary.

Soil Type	Treatment	Road Layer	% MC Nov	% MC Mar	Bulk Density[1] Nov	Bulk Density[1] Mar
LyA[2]	3:1	surface	13.02	11.47	1.78	1.70
LyA		sub-grade	11.28	11.01	-	-
LyA	6:1	surface	12.00	10.35	1.78	1.65
LyA		sub-grade	11.41	12.36	-	-
LyA	PG[3]	surface	18.84	15.77	1.60	1.58
LyA		sub-grade	19.11	14.44	-	-
LyA	Control	surface	17.78	16.67	1.78	1.71
LyA		sub-grade	20.24	17.60	-	-
Lu[4]	3:1	surface	16.67	11.41	1.69	1.57
Lu		sub-grade	20.09	10.71	-	-
Lu	6:1	surface	20.66	7.74	1.56	1.64
Lu		sub-grade	28.26	10.94	-	-
Lu	PG	surface	20.86	14.48	1.67	1.67
Lu		sub-grade	24.46	27.00	-	-

[1]Bulk density is g/cm^3; [2]LyA is Lynchburg soil series
[3]P&G is Pack & Grade; [4]Lu is Luverne soil series (LuB and



LuC)

Figure 2. Proctor curves for two soil types.

Construction Costs

Applications costs were estimated for a grader, soil stabilizer, roller compactor and tank truck. Machine rates for the grader, compactor and tank truck were obtained from the February 2000 Cost Estimating Guide (USDA 2000). The rate for the soil stabilizer was based on a monthly rental rate plus costs for fuel and teeth. Labor rates were based on Davis-Bacon wage rates for heavy equipment operators in Lee County, AL plus 30 percent benefits. Delivered cost of the chemical was $1.00/gal. Applications costs are summarized in Table 6.

Table 6. Machine and chemical costs for application.

Cost Item	
770B Grader w/operator	$58/PMH
Roller compactor w/operator	$52/PMH
CAT SS-250 Soil stabilizer w/operator	$113/PMH
Tanker truck w/operator	$36/PMH
Unitol DKG @ 3:1, 1.5 gal/yd^2	$3,080/mi

The total operating cost was $259/PMH. With a production rate of 1mi/day, assuming 8 SMH/day, the total chemical application cost is $4893/mi. An increased production rate could be achieved by higher travel speeds or a reduced amount of treated soil. By tilling to a shallower depth a smaller, lower cost soil stabilizer could possibly be used. However, the application cost is more sensitive to chemical quantity than to production rate, since chemical cost is 63 percent of the total application cost. For example, increasing the production rate by 25 percent (1.25 mi/day) decreases the cost by 7 percent ($4530/mi). However, using a 5:1 dilution rate reduces the cost by 20 percent ($3866/mi).

CONCLUSIONS

The incorporation of Unitol into the road surface appeared to enhance strength as indicated by the field CBR values. The 3:1 dilution rate exhibited a higher strength for both soil types than the 6:1, pack and grade and control treatments. Surface strength also increased over time though part of this was due to a settling effect. Laboratory CBR tests showed that under soaked conditions for the sandy loam soil the 3:1 dilution managed to retain its cohesiveness. However, the 5:1 dilution had a slightly higher soaked CBR value than the 3:1 dilution, though the 5:1 weakened with soaking. Laboratory CBR values for the loamy sand soil were highest for the control under unsoaked and soaked conditions but the control had the only decrease in strength (-34%) after soaking.

There was a general drying trend in moisture content of the surface layer for both soil types and all treatments during the 5-month period. The change in moisture content from November to March indicates that the pack and grade and control treatments were wetter in the surface layer than the chemically treated sections for both soil types. This suggests that the chemical could have acted as a barrier and shed the water rather than allowing it to penetrate through the surface.

Moisture content of the sub-grade did not increase during the 5-month period, even for the pack and grade and control treatments. For the Lynchburg soil type sub-grade moisture content was fairly constant in the chemically treated sections. The Luverne soil type displayed a drying trend in the sub-grade for the chemically treated sections.

Post-treatment bulk densities indicated that maximum compaction was achieved on both soil types during the application since these values are near those on the Proctor curves that correspond to maximum density at optimum moisture.

It is important to understand and control moisture content during the application of this chemical. If the soil becomes too wet it will be impossible to achieve maximum density during the compaction process. It would be beneficial to obtain Proctor information for the soils of interest prior to application.

Soil type and their engineering properties are also important factors to consider. The Lynchburg soil, which had a plasticity index of 7, responded better to the chemical than the Luverne soil type, which had a plasticity index of 20. A county soil survey should be obtained prior to application.

Transportation planning will be required for cost-effective use of lignin-emulsion. Roads that will be critical for use in upcoming winter months need to be identified since the greatest benefit is achieved by maintaining access on these critical roads during wet weather.

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Effect of Load Distribution and Trailer Geometry on the Gradeability of Short Log Tractor-Trailer Combinations

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ABSTRACT - The use of cut-to-length systems has increased the use of short log tractor and trailers in the western United States and elsewhere. The equations for uphill gradeability for a loaded short log tractor and trailer are derived and compared to a loaded long log pole trailer. A sensitivity analysis shows the gradeability of the short log tractor and trailer is highly affected by the load distribution and is also affected by the angle of the reach between the tractor and trailer.

INTRODUCTION

Roads in the western United States are often in mountainous terrain. The road systems have been developed considering the log truck with pole trailer. The use of cut-to-length systems has increased the use of short log tractor and trailers in the western United States and elsewhere. In this paper, equations for uphill gradeability of a short log tractor and trailer in loaded configurations are derived. The purpose of these equations is to allow the user to analyze the limits of truck performance under a variety of loading and road conditions.

MODEL

The basic model for developing the gradeability equations is the short log tractor and trailer combination. The short log tractor and trailer is a log truck that has a straight front bunk for loading short logs and a trailer attached by a hitch point (Figure 1). When performance of the loaded short log tractor and trailer is evaluated, the reach from the trailer is assumed to function as transferring tangential (parallel to the road) and normal (perpendicular to the road) forces depending upon angle of the reach. Connections between the tractor and trailer are assumed pinned.

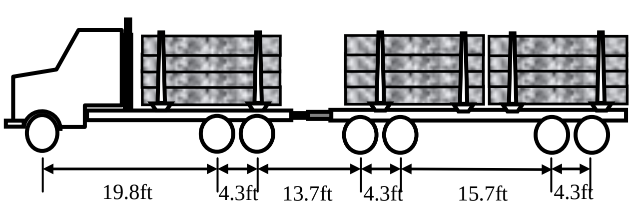

Figure 1. Configuration of a short log tractor and trailer

Maximum Gradeability

The following equations were derived to predict maximum gradeability (P) for loaded log trucks in tractor-trailer configurations:

$$P = 100 \cdot \tan\theta \qquad \text{[Eq.1]}$$

$$\tan\theta = \frac{\left[\dfrac{L \cdot f}{1 + f \cdot \tan\alpha} \times (y'_2 + x_2 \cdot \tan\alpha) + W \cdot x_1 - \dfrac{x_3 \cdot f \cdot (W + L)}{\mu}\right]}{\left[\dfrac{x_3 \cdot (W + L)}{\mu} - \dfrac{L}{1 + f \cdot \tan\alpha} \times (y'_2 + x_2 \cdot \tan\alpha) - W \cdot y_1\right]} \qquad \text{[Eq.2]}$$

where, *P* is the percent slope, representing the limit of gradeability and other terms are as defined in Table 1.

Table 1. Nomenclature for a short log tractor and trailer geometry and load distribution as used in Figure 2 and the gradeability equations, with sample values.

Symbol	Description	Sample Value
W	Weight of tractor plus short log load	35,000 lb
L	Weight of trailer plus log load	45,000 lb
X_1	Distance from front axle to center of gravity of tractor plus short log load	15.0 ft
X_2	Distance from front axle to end of stinger	30.0 ft
X_3	Wheel-base of tractor	22.0 ft
X_4	Distance between center of trailer tandem and center of gravity of the trailer plus log load	10.0 ft
X_5	Distance between center of trailer tandem and reach	30.0 ft
X_6	Wheel-base of trailer	20.0 ft
Y_1	Height to center of gravity of tractor plus short log load	3.5 ft
Y'_2	Height to stinger or front bunk	4.0 ft
Y_2	Height to attached point of reach at trailer	4.0 ft
Y_4	Height to center of gravity of loaded trailer	7.0 ft
N_F, N_D, N_{TF}, N_{TR}	are the respective normal components of the axle loads	

T_V,T_H	are the normal and parallel forces transferred to the tractor from the trailer	
f	coefficient of rolling resistance	0.02
μ	coefficient of traction	0.4
α	is angle of the reach from the trailer	0°

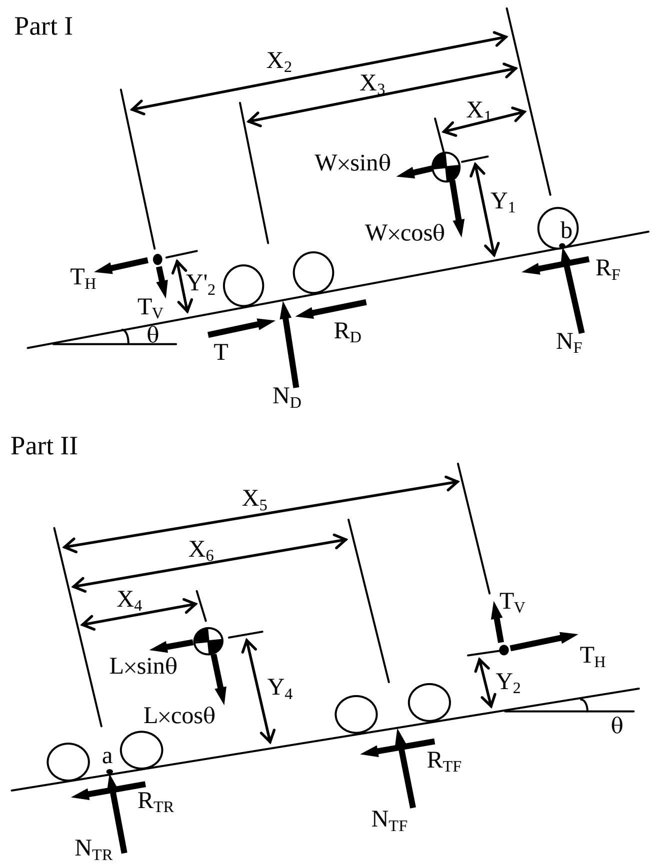

Figure 2. Geometry of a tractor with a straight front bunk (part I) and trailer (part II) for sample calculations. Nomenclature is defined in Table 1.

This function was derived by summing forces normal and parallel to the road surface and summing moments. The sums were then set equal to zero (Eq.3,4,6,7). For the trailer, the moments were summed about the rear tandem (Eq.5). For the tractor, the moments were summed about the front wheels (Eq.8). Maximum usable thrust was calculated as the weight on the drive axles multiplied by the coefficient of traction (Eq.9). Force parallel to the road surface, T_H, was assumed to be transmitted to the tractor through the reach from the trailer and force normal to the road surface, T_V, was assumed to determined by the relation of T_H and the angle of the reach (Eq.10). This provided eight equations with eight unknowns. This system of equations was solved simultaneously to yield the equations listed above.

For the trailer,

$$\sum F_Y = 0; \quad T_V = L \cdot \cos\theta - N_{TR} - N_{TF} \qquad \text{[Eq.3]}$$

$$\sum F_X = 0; \quad T_H = L \cdot \sin\theta + f \cdot N_{TR} + f \cdot N_{TF} \qquad \text{[Eq.4]}$$

$$\sum M_a = 0; \quad \mathrm{L} \cdot \cos\theta \cdot x_4 + T_H \cdot y_2 - T_V \cdot x_5 - L \cdot \sin\theta \cdot y_4 - N_{TF} \cdot x_6 = 0 \qquad \text{[Eq.5]}$$

For the tractor,

$$\sum F_Y = 0; \quad T_V = N_D + N_F - W \cdot \cos\theta \qquad \text{[Eq.6]}$$

$$\sum F_X = 0; \quad T = T_H + f \cdot N_{TR} + f \cdot N_{TF} + W \cdot \sin\theta \qquad \text{[Eq.7]}$$

$$\sum M_b = 0; \quad N_D \cdot x_3 - T_V \cdot x_2 - T_H \cdot y'_2 - W \cdot \sin\theta \cdot y_1 - W \cdot \cos\theta \cdot x_1 = 0 \qquad \text{[Eq.8]}$$

For the boundary conditions,

$$T = \mu \cdot N_D \qquad \text{[Eq.9]}$$

$$\tan\alpha = \frac{T_V}{T_H} \qquad \text{[Eq.10]}$$

Once we know the gradeability of a log truck, we can also estimate normal forces at each axle (Eq. 13,14,15,16) as well as normal and parallel forces transferred to the tractor from the trailer (Eq.11,12).

$$T_H = \frac{L \cdot f \cdot \cos\theta + L \cdot \sin\theta}{f \cdot \tan\alpha + 1} \qquad \text{[Eq.11]}$$

$$T_V = T_H \cdot \tan\alpha \qquad \text{[Eq.12]}$$

$$N_D = \frac{f \cdot W \cdot \cos\theta + T_H + W \cdot \sin\theta + T_V \cdot f}{\mu} \qquad \text{[Eq.13]}$$

$$N_F = \frac{T - f \cdot N_D - T_H - W \cdot \sin\theta}{f}, \quad \textit{where} \quad T = \mu \cdot N_D \qquad \text{[Eq.14]}$$

$$N_{TF} = \frac{L \cdot \cos\theta \cdot x_4 + T_H \cdot y_2 - L \cdot \sin\theta \cdot y_4 - T_V \cdot x_5}{x_6} \qquad \text{[Eq.15]}$$

$$N_{TR} = \frac{T_H - f \cdot N_{TF} - L \cdot \sin\theta}{f} \qquad \text{[Eq.16]}$$

APPLICATIONS

Given the vehicle illustrated in Figure 2, and the associated data in Table 1, the equations presented in this paper can be used to determine the maximum hill climbing ability of loaded log trucks. For the example in which the coefficient of traction is assumed to be 0.4 and the coefficient of rolling resistance is assumed to be 0.02, the maximum grade is 10.8%, when the reach from the trailer is parallel to the ground.

Figure 3 illustrates the effect of different values of the coefficient of traction on gradeability for the loaded truck and trailer noted above. Figure 3 also illustrates some observed ranges for coefficients of traction for three surfaces that might be encountered on log hauling roads. Figure 4 shows the change of gradeability with respect to W and L, weights of tractor plus short log load and trailer plus its log load, respectively.

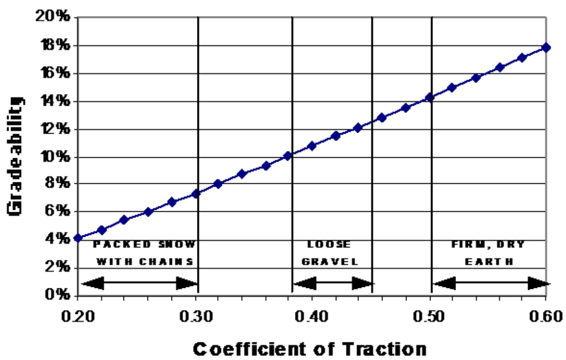

Figure 3. Change of gradeability with respect to coefficient of traction for the short log truck and trailer with sample values

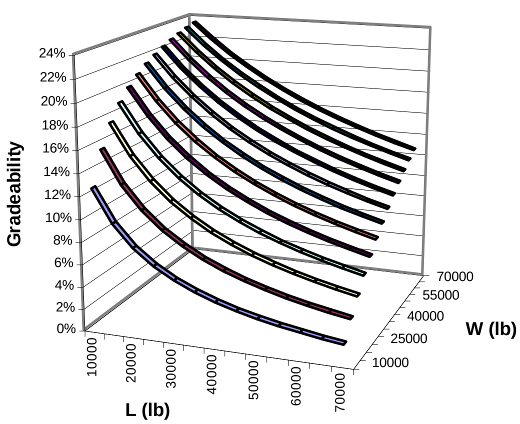

Figure 4. Change of gradeability with respect to weight of tractor and trailer with loads for the example truck with $\mu = 0.4$

Figure 5 illustrates the gradeability of a log truck is proportional to the angle of the reach from the trailer. It illustrates the effect of the angle of the reach on a normal force at the drive axles, which in turn affects the amount of potential thrust of the tractor. A negative value of the angle in Figure 5 means the location of the trailer hitch point is lower than that of the trailer reach, which has negative effect on gradeability.

The results were compared with the estimated gradeability of a log truck with a pole trailer. The equations derived by Sessions et al.(1986) were used. Figure 6 describes the gradeability of a short log tractor and trailer is less than that of a log truck with a pole trailer because of a lower proportion of the total weight on the driving axles.

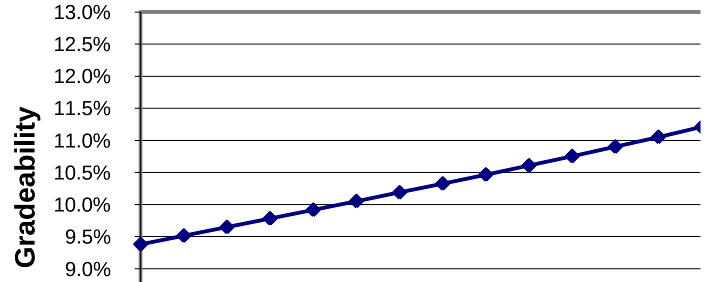

Figure 5. Effect of the reach angle on gradeability for the short log truck and trailer with sample values (μ = 0.4)

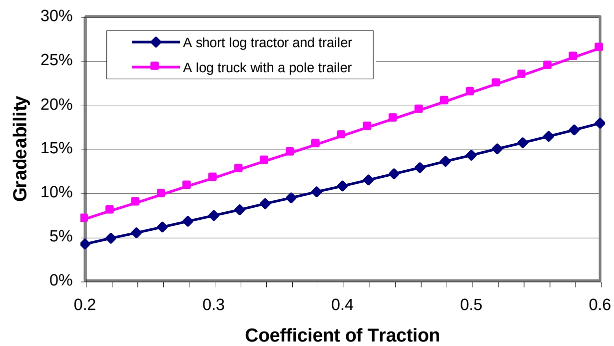

Figure 6. Comparison of gradeability between a typical log truck with a pole trailer and a short log tractor and trailer with sample values (μ = 0.4)

CONCLUDING COMMENTS

The equations presented can be useful in predicting short log tractor and trailer uphill gradeability in nonturning motion under conditions of constant velocity. Similar relationships can be derived the down hill gradeability considering maximum gradeability limited by engine brakes for sustained grades (powered axles) or a combination of engine brakes and service brakes.

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LOW-VOLUME ROADS, BEST MANAGEMENT PRACTICES: A Field Guide for US Agency for International Development

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ABSTRACT - Low-Volume Road Engineering, A BEST MANAGEMENT PRACTICES Field Guide for USDA, Forest Service, International Programs and the U.S. Agency for International Development (USAID), by Gordon Keller and James Sherar was an original development funded by USAID/Honduras in support of their Forestry Development Program (FDP) and their National Forestry School (ESNACIFOR). It has since been revised and expanded to be consistent with and complement the training manual titled "Minimum Impact Low-Volume Roads". This Best Management Practices Field Guide is intended to provide an overview of the key planning, location, design, construction, and maintenance aspects of roads that can cause adverse environmental impacts and list key ways to prevent those impacts. It is intended to present key "DO's and DON'Ts" in roads activities. These fundamental practices apply to roads worldwide and for a wide range of road uses and standards.

Introduction

Rural low-volume roads, farm-to-market access roads, forest haul roads and skid trails, etc. are necessary parts of any transportation system to serve the general public in rural areas, as well as help forest management and resource extraction. At the same time, roads and disturbed areas can produce significant amounts of sediment and can be one of the greatest adverse impacts on local water quality. They can produce significant erosion, can cause gullies, can impact groundwater, wildlife, and vegetation and can degrade scenic values. Roads are necessary but they must be constructed and maintained in such a way that environmental impacts are minimized. A well planned, located, designed and constructed road will have minimum adverse impacts and will be cost effective in the long term with minimum maintenance and repair costs.

Controlling erosion and protecting or improving water quality are essential to the quality of life, the health of the forest ecosystem, and to the long-term sustainability of forest resources. Forests play a vital role in producing, purifying and maintaining clean water.

The "Best Management Practices" (BMPs)" presented herein are a compilation of ideas and techniques which can be used in road construction to minimize or eliminate most of the potential impacts from these operations. The objectives of these Best Management Practices (BMPs) are to:

* Protect water quality
* Maintain natural channels and stream flow
* Minimize ground and drainage channel disturbance
* Control road surface water
* Control erosion
* Implement needed slope stabilization measures
* Stabilize the roadway driving surface, and
* Produce a safe, cost effective and practical road design

The scope of this manual is to develop recommended BMPs for low standard roads. The information is also applicable to most rural roads with other uses, such as logging, and is partially applicable to higher standard roads, although this was not the emphasis of this manual. Soil and water quality issues related to temperature, nutrients, chemical pollution, debris, quantity of flow, etc. are also beyond the scope of this manual, although there are many varied benefits from the application of these practices.

Each topic in this manual contains a problem statement that presents concerns, advantages and potential impacts for that issue. Information on the proper or most desirable way to plan, locate, design, construct and maintain roads, skid roads and landings are presented, along with figures and tables where helpful. Finally, PRACTICES TO AVOID are listed to discourage poor and undesirable practices.

This manual offers the Best Management Practices associated with the various aspects of roads and logging operations. The information presented in this manual should become an integral part of transportation planning and rural road design by applicable roads agencies.

These BMPs are applicable to road construction practices in most field situations. However, BMPS may be modified for site-specific conditions with guidance from experienced engineers, foresters, or other resource professionals. Modifications should be researched, designed and documented and must provide for equal or greater water quality protection before used.

Some important aspects of low-volume road design that are addressed in this manual include:

- **Minimizing road width and area of disturbance.**
- **Minimizing alteration of natural drainage patterns.**
- **Providing adequate surface drainage.**
- **Avoiding problems such as wet and unstable areas.**
- **Staying an adequate distance from creeks and minimizing the number of drainage crossings.**
- **Minimizing the number of "connections" between roads and watercourses, and minimizing "diversion potential".**
- **Designing creek and river crossings with adequate capacity and bank erosion protection.**
- **Having a stable, structurally sound road surface and using subsurface drainage where needed.**
- **Reducing erosion by providing good ground cover on cuts, fills, and any exposed or disturbed areas.**
- **Using stable cut and fill slope angles.**
- **Using slope stabilization measures, structures, and drainage as needed.**
- **Applying special techniques when crossing meadows, riparian areas, and when controlling gullies.**
- **Providing thorough periodic road maintenance.**
- **Closing or obliterating roads when not in use or no longer needed.**

The following is a Table of Contents of the Field Guide:

Chapter 3:Roads Issues and Special Applications

Excerpts from Chapter 3, Roads Issues and Special Applications are included as examples of content and format. Chapter 3 includes various aspects of road planning and special applications. Streamside Management Zones (SMZs) are emphasized to help insure water quality protection.

Streamside Management Zones

Streamside Management Zones (SMZs) are those areas adjacent to natural drainages and watercourses that require special consideration during forestry operations. These SMZs are important zones for protecting water quality by filtering sedimentation that may occur from road construction and logging activities. Harvesting activities must be planned and designed to minimize ground-disturbing activities.

Logging activities should not be eliminated in SMZs, but should be minimized and modified to insure that stream channels and stream banks are protected from disturbance. The width of the SMZ will vary with the natural ground slope on each side of the stream and with the erodible aspects of the soils. Steeper ground slopes will increase the possibility of sediment reaching the stream. TABLE 2.1 gives a recommended minimum width of the SMZ.

TABLE 2.1:
Recommended Minimum Widths for SMZ
Slope Distance

Width of SMZ	Ground Slope
10 m	0 - 20 %
20 m	21 - 40 %
30 m	41 - 60 %
40 m	60% +

Each chapter of the manual contains a list of practices to avoid as an easy reference.

X - PRACTICES TO AVOID
* **Keep logging debris out of lakes and streams**
* **Avoid using logging equipment within the SMZ**
* **Avoid road and landing construction within the SMZ**
* **Avoid contamination from fuels and oils on forest soils**

Chapter 3 also includes general guidelines for timber harvesting, log landings, and skid roads and skid trails. Examples of the bullet statements for skid roads and skid trails and the "Practices to Avoid" sections are included.

Skid Roads and Skid Trails

Skidding should be conducted in such a way that soil disturbance is minimized.
* Locate main skid trails before felling operations begin
* Locate skid roads to follow the contour of the natural terrain with natural breaks in grade
* Winch logs from areas of steep slopes or from SMZs
* Locate skid roads and trails in such a way that water is not concentrated onto the log landing
* Cover skid roads and trails with logging slash after operations cease to minimize erosion from exposed soils
* Construct skid roads on grades of 15% or less except for short distances (20 meters) where 30% pitches are acceptable

X -PRACTICES TO AVOID
* **Avoid contamination from fuel and oils on forest soils**
* **Do not locate landings and skid roads within the SMZ**
* **Do not use stream channels as skid trails**
* **Avoid skid road construction on steep grades**
* **Do not operate skidding equipment within the SMZ**
* **Avoid wet weather logging**

Chapter 4: Low-Volume Roads

Chapter 4 contains material on the location and design and maintenance aspects of low-volume forest roads. Access roads create more potential for soil erosion than any other activity that occurs during timber harvesting. A well planned, located, constructed and maintained road system is essential for forest management activities. Proper planning and design of the road system will minimize the impacts to water quality that are normally associated with forest roads. Poorly planned road systems have high maintenance and repair costs and contribute to excessive erosion.

Maintenance

Much of the work and interest has been in road repair and maintenance of low-volume forest roads. These roads must be maintained during active operations and after operations have been completed to insure that the drainage structures are functioning properly. Natural occurrences of rains cause cut slope failures that block ditches, cause water flow on the road surface, and can erode the surface and fill slope. Debris moves down natural channels during heavy rains and blocks drainage structures, causing water to overtop the road and erode the fill. Routine maintenance during logging operations (Active) will keep the road serviceable, keep drainages clean and will reduce log haul costs.

Road Planning

* Use topographic maps, photos, soils information, etc.
* Consider both short term and long-term access needs
* Limit the total area disturbed by minimizing the number, width, and length of roads
* Use existing roads only if they serve the long-term needs of the area and can be reconstructed to provide adequate drainage and safety
* Minimize the number of stream crossings needed

Road Location

* Use topographic control points and physical features (saddles, rock outcrops, stream crossings, slides, spring areas) to locate the road
* Locate roads outside of wet areas and SMZs except at stream crossings
* Locate roads high on the topography to avoid steep drainages
* Locate roads to follow the natural terrain by rolling the grade
* Locate roads, switchbacks and landings on bench areas and on flatter terrain.

Road Design and Construction

* Use minimum road standards needed for safety and traffic use
* Remove merchantable timber from the road Right-of-way before excavation.
* Windrow slash, tops, unmerchantable trees and stumps removed from the right-of-way at the toe of the fill slope before excavation

Outslope road surface 2-5% for road grades less than 10% on stable soils, using rolling dips for drainage structures
* Inslope or crown road surface for road grades in excess of 10%. Use ditches and provide cross drainage with pipes or rolling dips.
* Construct roads with grades of 12% of less, using short pitches to 15% where necessary
* Locate Roads with a minimum curve radius of 13 meters
* Construct roads with breaks in grade

Road Costs
* Steep side slopes increase the cost of road construction
* Stream crossings increase the cost of the road
- Steep grades increase long-term maintenance costs of the road

X - PRACTICES TO AVOID

- **Avoid road construction on steep side slopes**
- **Avoid construction during periods of wet weather**
- **Avoid steep road grades**
- **Avoid vertical cut slopes on ditched roads**
- **Avoid very flat areas**
- **Avoid locating roads within the SMZ, except at crossings**
- **Avoid wet and spring areas, slide areas**

Chapters 5-14:

Chapters 5- 10 include recommended practices for design and installation of drainage structures for low-volume roads. In many parts of the world, drainage design principles are severely lacking and this became an emphasis of this manual and much of the training that has been provided.

Chapters 11-14 include recommended practices for slope and gully stabilization, erosion control and roadway materials. Many field practices are illustrated which give the user good general guidelines for stabilizing soils in most low-volume road applications.

Summary

This manual was originally written in Spanish in cooperation with US AID/Honduras and is being translated into English for use in English speaking parts of the world. The authors wish to thank and acknowledge all who have contributed to this work.

MACHINE AND LABOR TIMES REQUIRED TO IMPLEMENT KENTUCKY'S SKID TRAIL EROSION CONTROL AND REVEGETATION BMPS

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ABSTRACT This paper describes a study designed to determine average labor and machine times required to implement erosion control and revegetation best management practices (BMPs) for skid trails in Kentucky. Labor and machine activities were recorded for 14,400 feet of skid trail on 10 nonindustrial private logging sites. Reshaping activities such as filling ruts, berm removal, and water bar construction (the most typical reverse grade structure used for water diversion) were recorded using time-motion study techniques and continuous filming with a digital video camera. Labor activities for revegetation such as seeding and application of fertilizer were timed with a standard chronograph. The average total machine time for retirement activities per 1000 feet was 51 minutes for sites using dozers and 52 minutes for sites using skidders. A total of 133 water bars were measured and timed and the average delay-free cycle time for dozer constructed water bars was 1 minute 28 seconds (n=112) and 3 minutes 32 seconds for wheel skidder construction (n = 21). The average amount of labor time required to seed 1000 feet of skid trail was 23 minutes (n = 5). Linear regression was used to establish relationships between machine and labor time and a number of site variables such as slope percent, cut and fill parameters, and machine variables such as horsepower and machine type.

INTRODUCTION

It would be difficult to overstate the importance of using erosion control measures on haul roads, skid trails and log landings and yet their implementation costs are not well defined. Since the passage of the Clean Water Act in the 70's, considerable research has been conducted to determine the costs of state and federally sponsored erosion control programs. However, the majority of these derive overall harvesting costs using cost estimates of individual practices obtained from surveys of logging and forestry professionals (Lickwar et al. 1992, Schaffer et al. 1998, Ellefson et al. 1985). Hewitt et al. (1998) used work study techniques and an 8mm video camera to measure the construction times of 191 water bars. The resulting multiple linear regression model was able to account for only 21% of the observed variation in water bar construction time. Using $65 as a base hourly rate for dozer operation and a mean construction time of 2 minutes and 19 seconds, they determined that the average waterbar cost $2.68.

This paper presents a portion of the results of a study focused on determining the costs associated with skid trail retirement BMPs. Specifically on machine and labor times, and material costs used on active logging sites in Kentucky to remove berms, fill ruts, construct water bars, and revegetate skid trail. Since these practices are used by all logging operations installing BMPs, it is important that costs associated with these practices are well understood. These costs are not only beneficial to loggers but must be well understood by all parties involved in timber sales.

METHODS

Ten contract logging operations were identified for study by industrial foresters, forestry consultants, and loggers in Kentucky. Geographic location and tract acreage were recorded for each site. Crew information including weekly volume (as reported by the logger) machine operator experience (with logging, BMPs, equipment used, and whether or not the operator had completed the Kentucky Master Logger Program), average crew size and wage, and workers compensation insurance rates were recorded. Equipment information including make, model, horse power, and engine hours of logging equipment used were also determined.

Skid trail condition prior to retirement

Using systematic random sampling, points along primary skid trails to be retired were established at 75 foot intervals. At each point, a level line was established across the width of the trail using a laser level. Vertical and horizontal measurements (XY coordinates) were taken from the level line at each significant change in contour of the trail surface using a leveling rod (vertical) and a loggers tape (horizontal). After the profile was manipulated to account for in-sloping and out-sloping, trail width, average rut depth, depth of the deepest rut, and average cross-sectional profile of the retired skid trail were calculated. Cut and fill calculations were then used on the trail profile to estimate the volume of earth needed to be moved to smooth the trail surface.

Machine and labor activities

All operations concerned with reshaping and water bar construction were filmed continuously with an eight millimeter digital video recorder with automatic time stamping. When revegetation activities such as seeding or application of fertilizer or lime were conducted, labor times and amount and cost of materials were recorded as well as the length of skid trail to which the materials were applied. Differences in total machine time among regions and machine types were evaluated using analysis of variance tests. Simple linear regression was used to detect relationships among total machine time, operator experience, machine horsepower, total volume of earth moved, and total length of skid trail retired. Linear regression was also used to evaluate relationships among seeding time, total length retired, and pounds per acre used.

Post retirement measurements of water bars and skid trail

Table 1: Observed machine times and site cha-

		site characteristics				observed machine [1] (min)					machine times per 1000 feet[3] (min)			
	site #	length retired (ft)	trail width (ft)	% Soil moisture	% slope	reshape	water bar	(n)	travel[2]	total	reshape	wb	travel	total
dozer	2	684	13	10%	15%	28	12	(10)	7	47	41	18	9	68
	3	878	16	18%	26%	15	14	(8)	4	33	17	16	5	38
	5	2194	17	10%	11%	69	12	(15)	26	108	31	6	12	49
	8	1125	16	12%	27%	51	16	(8)	5	72	44	15	4	64
	9	936	17	13%	26%	14	34	(17)	0	48	15	36	0	51
	10	3127	17	11%	23%	106	26	(22)	3	135	34	8	1	43
	avg.	**1491**	**16**	**13%**	**22%**	**47**	**19**		**7**	**74**	**30**	**16**	**5**	**52**
	st dev	**963**	**1**	**3%**	**7%**	**36**	**9**		**9**	**40**	**12**	**11**	**5**	**12**
skidder	4	580	16	11%	17%	5	41	(10)	8	54	9	71	14	94
	6	935	19	11%	23%	12	23	(8)	2	37	13	25	2	39
	7	1148	15	25%	14%	10	9	(3)	3	22	9	8	2	19
	avg.	**888**	**17**	**15%**	**18%**	**9**	**25**		**4**	**38**	**10**	**35**	**6**	**51**
	st dev	**287**	**2**	**8%**	**4%**	**4**	**16**		**3**	**16**	**2**	**33**	**7**	**39**

[1]Machine time refers to the amount of time the machine was operated to complete a particular task (engine hours). [2]On site travel time to and from location of retirement area. No machine delay was recorded and all operator delay resulted from interaction with the researcher and as such is not included in total ma-time. [3]Machine times per 1000 feet are calculated by multiplying 1000 times the ratio of time to total length

After all machine operations were completed, individual water bar dimensions were measured. The volume of material in each water bar was geometrically estimated using surface heights and angle information. Soil was sampled from each water bar to determine volumetric soil moisture.

Reshaping and water bar construction cycle elements

Cycle elements were recorded for each site to the nearest second using the time stamp on the video recording. Rut and berm removal and other activities not directly related to water bar construction were analyzed separately and classified as reshaping. Reshaping cycle elements were identified as positioning, moving earth, or moving brush. Each of these three were recorded in forward and reverse for a total of six distinct actions. Water bar construction was divided into positioning, main and auxiliary movements of earth, and travel to the next water bar. Again, each of these were recorded in forward and reverse for a total of 8 distinct actions. Main movements were defined as those which produced a perceptible and measurable change in water bar volume or shape. Auxiliary movements were defined as those having no perceptible change in the structure. Other machine time elements not specific to reshaping or water bar construction were also recorded including machine and operator delay and machine travel to and from the retirement work areas. Differences in delay-free water bar construction time among regions and machine types were evaluated with analysis of variance tests. Simple linear regression was used to detect relationships among water bar construction time, operator experience, machine horsepower, water bar volume, and the number of forward and reverse movements used to construct each water bar.

RESULTS

Data were collected on ten sites in 4 physiographic regions of Kentucky. Five sites in the Cumberland Plateau physiographic region and 2 in the Eastern Pennyroyal used bulldozers for retirement operations while the remaining 3 sites were located in the Western Pennyroyal region and used wheeled skidders. The machine times and site characteristics for nine of the ten sites are presented in Table 1. Data from one of the sites was not included for total machine and revegetation time due to interaction with the researcher that interfered with data collection.

There were no statistically significant ($p < 0.05$) differences found among regions or machine types for total machine time or its components per 1000 feet of skid trail retired. Linear regression for dozer operators revealed significant positive relationships between total machine time and total length retired (Figure 1) as well as a significant positive relationship between total machine time and total volume of earth moved ($r^2 = 0.89$, $p = 0.0028$). No such relationships were found for skidder sites. Operator experience and machine horsepower were also evaluated against total machine time using linear regression but no significant relationships were found for dozer or skidder sites.

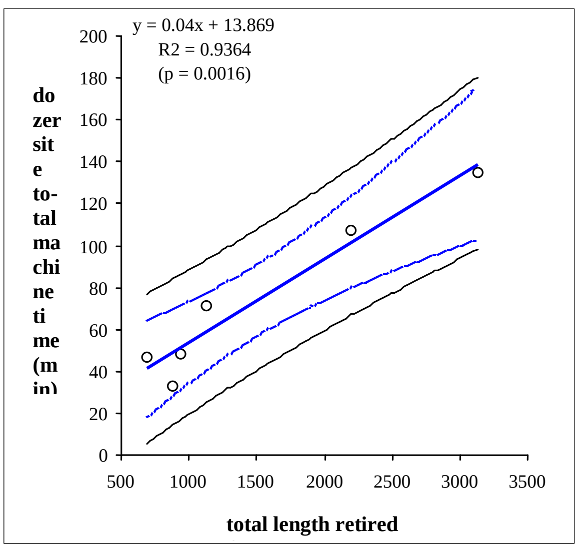

Figure 1 Total machine time (includes reshape, water bar, and travel time) vs total length of skid trail retired (n = 6). Clos- pair of lines to the regression line is the confidence interval band while the outer set of lines contains the prediction interval band at 95%.

A total of 133 water bars, 112 built with dozers and 21 built with skidders, were filmed during construction and then measured as previously described. Analysis of variance of cycle times revealed no significant difference between the Eastern Pennyroyal and Cumberland Plateau regions while the Western Pennyroyal region (all skidder sites) was significantly different from the other two. For this reason further analysis of cycle time was conducted by machine type. There was a signify

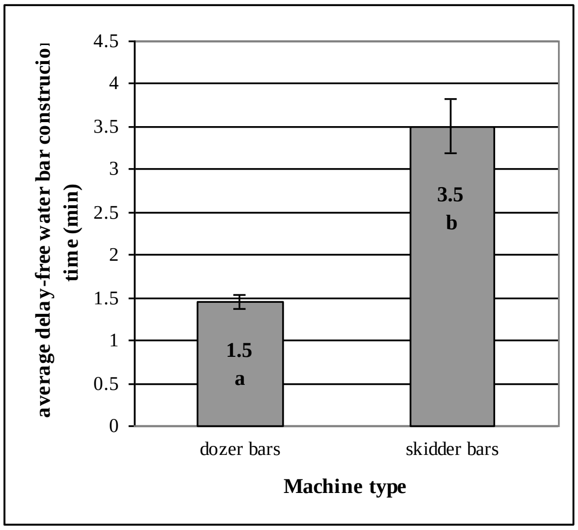

Figure 2 Average water bar construction delay-free cycle time by machine type. Columns with different letters are significantly different ($p < 0.0001$). N = 112 for dozer bars and n = 21 for skidder bars.

cant difference ($p < 0.0001$) between the average dozer bar cycle time of 1.5 minutes and the average skidder bar cycle time of 3.5 minutes (Figure 2).

Linear regression of the factors recorded for each water bar against construction time indicates that the number of forward and reverse movements was the only significant factor with an r^2 of 0.59 ($p < 0.0001$) for dozer bars and an of $r^2 = 0.78$ ($p < 0.0001$) for skidder bars.

It was possible to record revegetation activities on 4 of the sites with the average time of 27 minutes per 1000 feet with a range of 20 to 41 minutes. Hand seeders were used on all four sites.

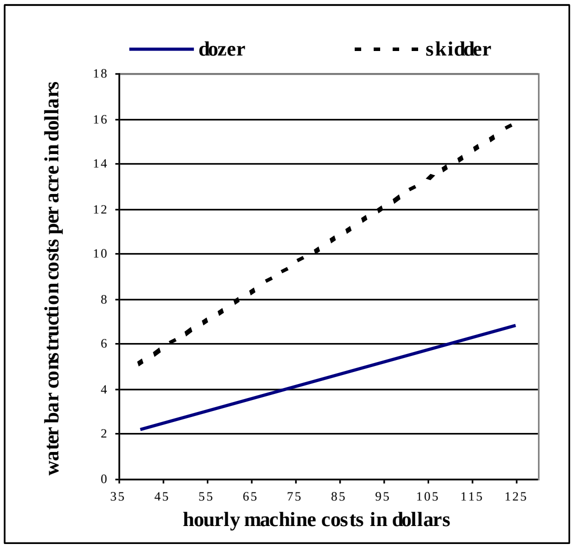

Figure 3 Water bar construction costs by machine type. Calculations are based on Kentucky averages of 3.5 crew members per firm, 303 mbf harvested per year per logger, 2.7 mbf per acre, 17 percent slope on skid trails, 1 mile of retireable skid trail per 45 acres of harvested area, and water bar construction times of 1.5 minutes and 3.5 minutes for dozers and skidders respectively.

DISCUSSION

While a limited number of sites were incorporated in this study the operations were typical of those used in Kentucky and we believe that the machine and labor times can be used to establish reasonable estimates of BMP implementation. Data from Kentucky Master Logger surveys indicate that, on average, logging firms are composed of 3.5 loggers harvesting 303,030 board feet (Doyle scale) per crew member per year. Using the state harvest average of 2700 board feet per acre, a typical firm cuts 393 acres per year. Queary found that logging jobs in Kentucky will average one mile of retireable skid trail for every 45 acres harvested. Using the data derived from this study, a logger can expect to spend 51 minutes of machine time per 1000 feet of skid trail. Therefore, a typical crew would use 39 hours of machine time per year. At $65 per machine hour the estimated cost is $2,546 per year on reshaping, water bar construction, and travel. At 27 minutes per 1000 feet of skid trail to seed, a typical firm will spend 21 hours per year seeding. Using a 50% workers compensation rate and an $8 per hour wage, a firm spends $248 per year seeding. Participants used approximately 72 lbs per acre of grass seed. With an average trail width of 14 feet, an average logger will spend $690 dollars per year in seed (plus labor to purchase and transport the seed to the logging site). In total, a typical logger has $2,546 in machine time, $248 in labor time, and $690 in materials for a total of $3,484 per year to retire skid trail. That is $8.87 per acre (@ 393 acres per year) or $3.28 per thousand (@ 1.06 million board feet per year). Using the contract prices reported by study participants, skid trail retirement reduces gross revenue by 1.9% to 2.5% with an average of 2.1%.

The average total machine time per 1000 feet in Table 1 is roughly the same for each machine type. This can be explained by observing that sites that used dozers spent more time reshaping than installing water bars while those that used skidders spent more time building water bars. Skidders, designed to pull rather than dig, have to back up several skidder lengths to gather enough soil to build a sound water bar. Hence reshaping occurs to a certain degree during water bar construction. It is also important to note that all of the skidder sites were in the Western Pennyroyal region of Kentucky which is less difficult terrain than the eastern half of the state. Average rut depth could also be an important factor in the amount of reshape time required. The Cumberland plateau averaged 12.2 inches, a significant difference from the Western and Eastern Pennyroyal regions which averaged 8.2 and 8.6 inches ($p = 0.0042$). If water bar construction is considered separately in terms of total number of water bars installed per year and using the previously presented averages, the cost difference between the two machines is more obvious (Figure 3). In this example, water bar construction costs about $5 per acre when the skidder hourly cost is $40 per hour and the dozer hourly cost is $95 per hour.

Another important consideration in calculating skid trail retirement costs is whether retirement activities are conducted during or outside of the scheduled work week. If conducted during the work week, then the dollars per hour each crew member generates is used in place of machine or labor cost per hour. Only two of the ten sites included in this study conducted retirement activities outside the scheduled work week.

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Utilization and Cost for Animal Logging Operations

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ABSTRACT - Forest harvesting with animals is a labor-intensive operation. Due to the development of efficient machines and high volume demands from the forest products industry, mechanization of logging developed very fast, leaving behind the traditional horse and mule logging. It is expensive to use machines on smaller woodlots, which require frequent moves if mechanically logged, so small logging systems using animals may be more cost effective. Highly sensitive areas such as around public recreation may be logged effectively with minimal disruption using animal crews. In this study, work sampling was used for five animal logging operations in Alabama to measure productive and non-productive time elements, to determine utilization with respect to operators, functions (felling and processing of trees, skidding, and loading and/or forwarding of logs), animals, and machines. Animals (horses and mules) were utilized less than 50 percent of the scheduled time. There appears to be an opportunity to reduce cost of log production by increasing scheduled work hours and utilization of machines and animals. Average onboard truck logging cost was estimated to be $28.12 per cord for the five crews.

INTRODUCTION

Logging in the United States began more than 200 years ago. The need for more lumber increased due to growing villages and later the booming towns of the eastern seaboard (Creighton, 1997). For a logging operation to be successful today, and in the future, it must produce the highest-value products in a safe, economical, steady-paced operation. Dykstra and Heinrich (1996) emphasized that proper forest harvesting operations must meet economic, silvicultural, environmental, and social objectives. Regardless of the size of a harvesting area or size of trees, a harvesting operation must be well organized.

Before the invention of the railways and automobiles, animal power was the main source of land transportation. Waterson (1994) pointed out that in the past, horses were one of the main sources of timber extraction. After the potential for higher outputs and cost reduction from mechanization was realized, horses were restricted to areas where machines had difficulty such as steep and broken ground.

In general, a logging operation can be divided into activities such as tree felling, limbing, bucking, bunching, skidding or forwarding, loading, and hauling to mills. Heinrich (1983) identified three levels of logging operations: 1) labor intensive, 2) intermediate technology, and 3) fully mechanized. Timber harvesting with animals is a labor intensive type of logging. Utilization of manpower, machines, and/or animals is a key factor to increasing overall system productivity and reducing cost of harvesting per unit of timber. Available literature reports very little information on the utilization of animal logging components and cost of log production particularly when machines are combined with animals.

In Alabama most of the horse and mule loggers are located in the northern half of the state. These are hilly areas with oak-hickory and mixed pine-hardwood forests typically owned by non-industrial private forest (NIPF) landowners in small tracts. Most of these landowners do not want mechanical skidders on their land (Toms et. al. 1998). This indicates the potential for horse and mule logging in these small tracts of timber and in terrain with slopes. A typical horse logger is shown in Figure 1.

Figure 1. Animal logger with horse

OBJECTIVE

The goal of this study was to determine utilization, productivity, and costs within animal logging operations with respect to operators, functions (felling and processing of trees, skidding of logs, and loading and/or forwarding), animals, and machines.

METHODOLOGY

Field data were collected in the summer and fall 1999. Animal logging crews working in Alabama selected for this study were: 1) horses with forwarder (H/FWD), 2) mules with forwarder (M/FWD), 3) horses with side loading truck (H/SLT), 4) horses with knuckleboom loader (H/KBL), and 5) horse with long stick cable loader trucks (H/LSCLT). All were involved in partial cuts and used cut-to-length (CTL) saw logs and pulpwood. The functions observed were: 1) manual chainsaw felling and processing of trees, 2) animal skidding, and 3) loading and/or forwarding with forwarders, side loading trucks, knuckleboom loader, or long stick cable loader trucks.

Utilization

The proportion of time involved in each activity was obtained by taking a work sample of operators, functions, and animals/machines (Miyata et. al. 1981). Observations were recorded at five-minute intervals. Work activities varied slightly from crew to crew depending upon the management goals, crewmembers, and animals/machines used. Crewmembers often performed multiple functions. For instance, operators who primarily ran chainsaws might spend time skidding with horses. For each observation, activities for each operator, animal, and machine were recorded indicating whether the activity involved productive with the primary task, productive with a secondary task, servicing, repairing, or idle times. Utilization was defined as the ratio of productive time to total time. Estimation of utilization, which was calculated as binomial variables, used least squares regression analysis.

Cost

Ownership, operating, and labor costs were established from personal interviews with owners and crewmembers during the collection of field data using machine rate calculation methods discussed by Miyata (1986). Where possible, common cost factors were used for all crews. Eight percent annual interest rate was used for the alternative rate along with straight-line depreciation. The owners suggested an annual cost of 5 percent for insurance. Workman's compensation in Alabama for these operations was $3.00 per cord, and Social Security (FICA) and Federal Unemployment Insurance (FUTA) were 9.65 percent of labor cost.

RESULTS

General

For the five crews, the average scheduled hours per day ranged from 5.25 to 7.03 hours (excluding lunch breaks) (Table 3). Crew size ranged from one to five. The horse with knuckleboom loader operation had only one person who performed all tasks as compared to the mules with forwarder crew that had five persons. The other three animal operations had usually three persons. Many times, crew size varied for these operations from day to day. The horses with long stick cable loader truck crew used only one horse everyday while the other four animal operations had two horses/mules skidding logs. Generally, animal loggers worked less than 30 miles from their homes. With the exception of the mules with forwarder crew, who left their animals overnight in a fenced area near the logging site, crews moved their horses to the logging site each morning and home at the end of each workday.

Utilization

Animal logging operations were divided into three main functions: 1) felling and processing of trees, 2) skidding of logs, and 3) loading and/or forwarding. Utilization was calculated for operators, crews, functions, and animals/machines.

Table 1. Utilization and ownership status for individual operators of five animal logging operations

Operator (Ownership status)	Utilization (%)
Horses with forwarder crews	
Chainsaw operator (owner)	71***
Animal operator (family member)	57***
Forwarder operator (family member)	75^{NS}
Mules with forwarder crews	
Chainsaw operator (crew member)	43***
Assistant to chainsaw operator (crew member)	23***
Animal operator 1 (crew member)	40***
Animal operator 2 (crew member)	40***
Forwarder operator (Crew member)	68^{NS}
Horses with side loading truck crews	
Chainsaw operator (owner)	51***
Animal operator 1 (owner)	46***
Animal operator 2 (owner)	48***
Horses with knuckleboom loader crews	
Multifunction operator (owner)	68^{NS}
Horse with long stick cable loader trucks crews	
Chainsaw operator (owner)	79^{NS}
LSCL truck operator (owner)	100***
Assistant to LSCL truck operator (crew member)	64^{NS}
Average	58

^{NS} Not significantly different from average
*** Significantly different at 99% confidence interval

Utilization of operators

Altogether 15 operators were involved in the five animal logging operations. Table 1 gives the utilization of each operator. Operator productive time might include only his primary task but usually incorporated secondary tasks also. The productive time percentage contributed by both forwarder operators, chainsaw operators in long stick cable loader truck and horse with knuckleboom loader crews, and assistant to long stick cable loader truck were not significantly different from that of the chainsaw operator in horse with forwarder operation. Utilization of the long stick cable loader truck operator was significantly higher and the other nine operators were significantly lower. The long stick cable loader truck operator had 100 percent utilization because he spent much of his time driving outside of the woods area and when he was in the woods he was observed only being productive. When ownership status was compared, owners and family members were found to work significantly more than non - owners (Figure 2).

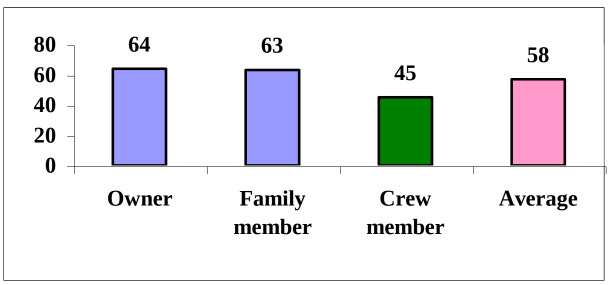

Figure 2. Utilization by ownership status (%)

Comparison of overall crew utilization

Crew utilization was determined by summing all productive time observations and dividing by total observations of all crewmembers. Utilization for the five animal operations were compared, and it was found that there was no significant difference among the knuckleboom loader, the long stick cable loader truck, and horses with forwarder operations. Mules with forwarder and horses with side loading truck operations had significantly lower utilization (Figure 3). The long stick cable loader truck crew had highest overall utilization of 75 percent.

Tree felling and processing function

Utilization for felling and processing was calculated as the ratio of productive time to the total observations of the felling and processing function. This utilization was compared among crews and found to be similar for all crews except the mules with forwarder crew, which was significantly lower (Figure 4).

Log skidding function

Log skidding utilization was defined as the proportion of skidding observations spent doing productive activities. When comparing the five animal logging operations, there was no significant difference between skidding with mules or horses with forwarder crews or horses with long stick cable loader truck crews. However, skidding with horses with side loading trucks or knuckleboom loaders had significantly higher utilization (Figure 5).

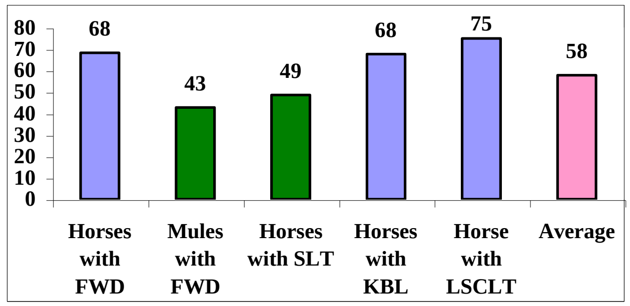

Figure 3. Utilization for five animal logging operations (%)

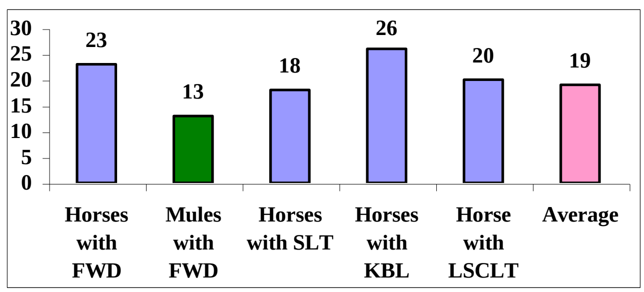

Figure 4. Utilization of felling and processing function in five animal logging operations

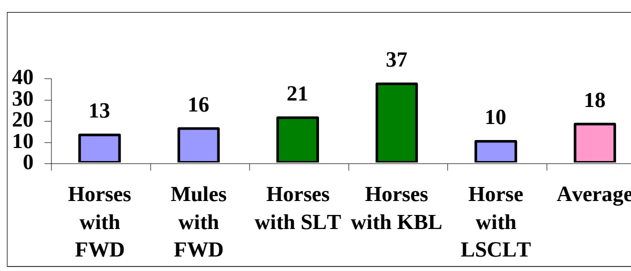

Figure 5. Utilization of log skidding function (%)

Log loading and forwarding function

When loaders or forwarders were examined, utilization was calculated as the ratio of productive time to total observations of that function. Utilization was compared for the five operations (Figure 6). Loading and/or forwarding for the horses with long stick cable loader truck operation was significantly higher than the horses with forwarder operation. Utilization for the other crews were significantly lower.

Utilization of animals and machines

Just as observations were made of operators, animals and machines were observed. Hand tools such as chainsaw and axes were not reported.

Utilization of horses and mules were calculated as the ratio of productive time observations to the total observations of animals. Figure 7 compares the ten animals in the study. The two horses used in horses with forwarder crew were used equally as were the horses used with the knuckleboom loader crew and the mules in the mules with forwarder crew. Only the horses with side loading truck crew were used a disproportional amount of time. On average, animals were utilized 22 percent of the work day.

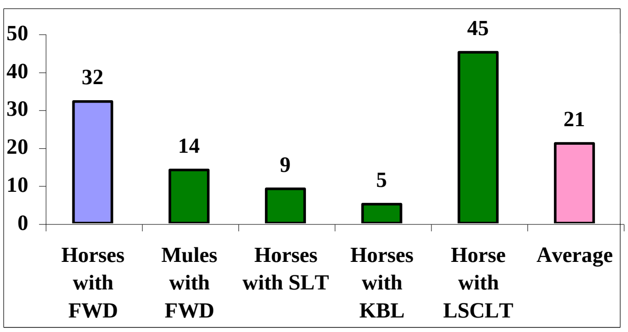

Figure 6. Utilization for loading and/or forwarding function (%)

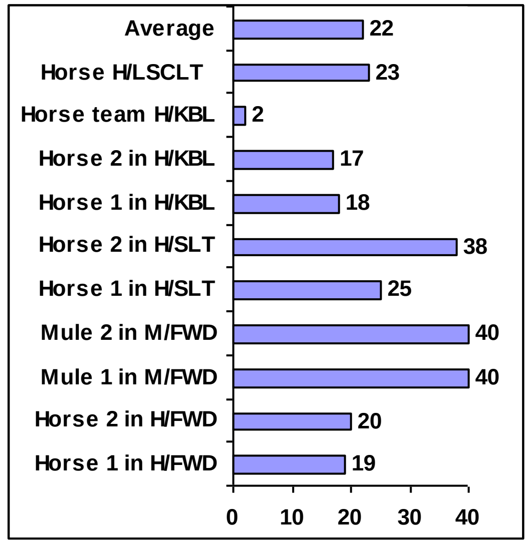

Figure 7. Utilization of animals (%)

When utilization of machines was compared, the forwarders had the highest utilization – 74 percent with horses and 68 percent with mules (Figure 8). The side loading truck and one of the trucks with long stick cable loader were used 24 percent. The knuckleboom loader was used the least. The other long stick cable loader truck was loaded immediately when it returned to the woods causing it to have 100 percent utilization.

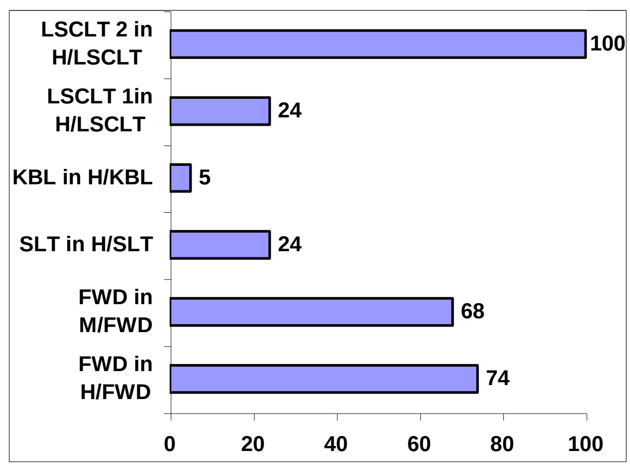

Figure 8. Utilization of loading and forwarding equipment (%)

COST AND PRODUCTIVITY

Fixed and variable costs were calculated for productive equipment like horses or mules, forwarders, side loading truck, knuckleboom loader, and long stick cable loader trucks. Animal accessories like harnesses also had fixed costs. Support equipment included pickup trucks and van for transporting animals. One crew had a dedicated office and a part time bookkeeper. Labor cost was based on an average rate of $10.09 per hour. Table 2 shows that fixed costs vary greatly by level of mechanization. Variable costs were more consistent. Labor cost was directly affected by the number of employees.

Cost for horses or mules ranged from $1,750 to $3,000 with an expected economic life of 12 to 15 years (Mules were more expensive than horses). Two sets of harnesses with tongs and chains were estimated to be $1,300 with an economic life of five years. Each crew had two sets of harnesses and 3 to 4 tongs.

The horses with forwarder crew had purchased a used forwarder for $28,000, a new pickup truck for $16,000, a van to carry the horses for $25,000, and had two Belgian horses for $5,000. The mules with forwarder crew purchased a new forwarder for $112,000, a pickup truck for $16,000, a van to transport crews for $25,000, and four mules for $21,000. This operation had an office and part time office assistant. The horses with side loading truck crew had a used side loading truck for $3,412, a used van to transport horses for $3,750, and two Belgian horses for $3,750. The horses with knuckleboom crew had purchased two horses for $5,000, a used knuckleboom loader for $5,000, and a used van to carry horses for $5,000. The horses with long stick cable loader crew purchased two long stick cable loader trucks for $15,000 each, two horses for $5,000, and a used pickup truck for $2,500.
Table 3 summarizes productivity and costs for the five crews. Daily production of logs ranged from 5.5 to 25 cords and from 0.78 to 4.41 cords per schedule hour (SMH). The mules with forwarder crew having 5 operators produced the most in both categories followed closely by the long stick cable loader crew. Not surprisingly, the one-man horse with knuckleboom loader crew was the least productive. When summarized by man-hour production, the long stick cable loader truck crew was more productive than the mules with forwarder and the side loading truck crew was the least productive. When paired with hourly costs given in Table 2, the lowest costs were with the long stick cable loader crew ($19.30 per cord) and highest with the side loading truck crew ($36.12 per cord). Average cost per cord for the five crews was $28.12 per cord for wood onboard truck.

CONCLUSION

Owners and family members performed productive work more than non-owners from this study of five animal logging operations. Utilization of horses or mules averaged about 22 percent as compared to machines that averaged 44 percent. Forwarders, the most expensive piece of equipment, had highest utilization. Operators for these mostly manual crews performed productively 58 percent of the time. Due to the low levels of utilization, it appears that productivity could be improved on these animal logging operations by working more of the scheduled workday. Also, this study showed that all five animal logging operations were working less than the normal 8-hour days (6.21 hours). By increasing daily scheduled work hours, cost of log production could be reduced by reducing fixed hourly costs.

It was found that the horses with side loading truck crew had the lowest hourly capital investment but highest unit cost for log production. The horses with long stick cable loader truck crew that had a moderate capital investment produced logs at the lowest cost rate. The next lowest logging cost was for the horses with knuckleboom loader crew. This study indicates that for animal logging operations high capital investments may not result in low costs for log production.

Table 2. Cost summary for five animal logging crews

Animal logging operations	Fixed ($/SMH)	Variable ($/SMH)	Labor ($/SMH)	Total ($/SMH)
Horses with FWD	10.37	9.70	33.18	53.25
Mules with FWD	31.74	14.94	61.90	108.58
Horses with SLT	2.52	5.37	33.18	41.07
Horses with KBL	2.66	5.00	11.06	18.72
Horse with LSCL truck	7.74	11.23	33.18	52.15

Table 3. Productivity and cost from five animal logging operations in Alabama

Animal logging operations	Crew members	Average scheduled work hours per day	Average daily log production (Cords)	Log production per schedule hour (Cords)	Cords per man - hour	Cost per cord ($)
Horses with FWD	3	6.83	13.20	1.93	0.64	30.55
Mules with FWD	5	5.67	25.00	4.41	0.88	27.62
Horses with SLT	3	5.25	6.50	1.24	0.41	36.12

Horses with KBL	1	7.03	5.50	0.78	0.78	27.00
Horse with LSCL truck	3	6.25	20.00	3.20	1.07	19.30
Average	3	6.21	14.04	2.31	0.76	28.12

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Appalachian Hardwood Logging Systems; Managing Change for Effective BMP Implementation

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Abstract - As the forest resources of the Appalachian region are utilized more intensely, public scrutiny of forest operations has become more common. Public trust is necessary to maintain the minimally regulated practice of forestry. Maintaining effective BMPs, and resulting clean water, on harvesting jobs is paramount to ensuring public trust.

Effective BMP implementation for timber harvesting operations is dependent on logging plans and appropriate logging system selection. Utilization of specialized logging systems can result in lower costs and environmental impacts when compared to one size fits all, a crescent wrench approach to, timber-harvesting tools. Logging planning is essential to successful implementation of specialized logging systems and effective implementation of BMPs. Logging contractors and mill owners have and, in the future, will develop specialized logging systems in order to enjoy the competitive advantages of using the right harvesting tool for the job.

Introduction

Logging systems, or tools to harvest timber, have evolved in design and function to be responsive to different harvesting conditions. As harvesting conditions change, so too have these tools to harvest timber. Today, this evolution in logging systems results in a wide variety of specialized harvesting tools, each designed to specifically be effective in particular conditions. As the public acceptance of harvesting's environmental impacts has decreased, logging systems have evolved to create less of an impact. As the utilization of the Appalachian timber resource has pushed harvesting on increasingly difficult sites, logging systems have evolved to be effective in challenging timber and terrain. This evolution has resulted in a logging system toolbox, each tool being particularly effective and suited to a set of conditions. The harvesting application of logging systems means applying the right tools to the right set of conditions for which it is most effective. Proper harvesting application of logging systems can result in both cost effectiveness and minimal adverse impact to the forest environment. Improper application of a logging system usually results in increased harvesting costs and/or undesirable environmental impacts. BMP implementation to mitigate harvesting impacts is dependent on the applied logging system. The environmental impacts of improper logging system applications cannot usually be cost effectively mitigated through BMP implementation, particularly on the more challenging timber and terrain.

One of the current limitations in applied Appalachian logging systems is the lack of awareness of the alternative systems that are available, and the conditions in which they are particularly suited. This paper attempts to raise this awareness by presenting both descriptions and applications of various logging systems currently being used in the Appalachian mountain region.

Another limitation to Appalachian logging system applications is the inability to plan and schedule for specific systems. This paper provides some guidance on methods and techniques that are necessary to successfully implement specialized logging systems.

Logging System Descriptions

1. **Animal** Horses, mules, etc to pull logs or carts suspending logs. Animal weight, number of animals, and specie of animal vary to provide varying skidding capacities.
2. **Tracks** Use of track laying tractors to pull logs or arches suspending logs. Tracks may be hard as in dozers with rails or soft as in KMC with torsion bar suspension. Tracked systems may have winches, grapples, or swing boom grapples. Track length, width and grouser patterns vary for differing weight and horsepower classes.
3. **Skidder** Use of rubber tired articulated tractors with integral arch to pull logs. Skidders may have winches, grapples, both, or swing boom grapples. Tire width and grouser pattern can vary for differing weight and horsepower classes.
4. **Shovel** Use of hydraulic excavator based loader / shovel to bail logs. Reach, track length, width and grouser patterns vary for

differing weight and horsepower classes. May be combined with processing heads, grapple saws, felling heads, grapples, excavation buckets, live or dead heels and quick connections to transform into a multi-function machine.

5. **Forwarders** Use of rubber tired tractors equipped with log bunks and loader to transport logs free of the ground. Number of axles, tires, weight capacity, loader size vary for differing weight and horsepower classes.
6. **Cable** Use of a cable yarder and carriage to yard logs either one end suspended or completely suspended by wire rope. A yarder is logging equipment combining winch drum and steel spars or towers. Cable yarders may be mounted on tracks, truck, trailer, or sled. Tower height, number of winches, line size, line length vary by horsepower and weight class. A carriage is the device which moves in and out from the yarder to the timber and accommodates chokers or a grapple for hooking logs. Carriage characteristics are non slack pulling or manual, mechanical, motorized slack pulling; radio, cycle, or mechanically controlled; single or multiple span.
7. **Helicopter** Use of helicopters to vertically lift timber from the stump and fly fully suspended to the landing. Helicopters used in logging have primarily different lifting capacities.

Logging System Selection

The proper selection of a logging system involves consideration of many different conditions. Factors such as slope, terrain shape, yarding distance, weather, soils, tree size, volume per acre, size of tract, cost of road construction, cost of logging, and productivity goals. The following table lists the logging systems and the various characteristics of each systems niche. The niche, or place, for a logging system is the application where the harvesting costs and the environmental impacts are minimal, when compared to other logging systems. The following table and narratives describe each of the logging systems niche.

Table 1. Logging System Application.

Logging System	Weather Sensitivity	Terrain Slope %	External Yarding Distance	Average Tree size	Volume per acre	Volume per tract	Cost of road	Terrain Shape & length
Animal	Moderate	<20%	<500 ft	Small	Low	Small	Low	Flat short
Tracks	Moderate	<40%	<800 ft	Large	Common	Small	Low	Moderate short
Skidder	High	<35%	<1500 ft	Medium	Common	Medium	Med	Flat + common
Shovel	Low	<45%	<400 ft	Medium	Common+ Clear cut	Small	Low	Moderate broken
Forwarder	High	<30%	<2500 ft	Medium	Low	Large	High	Gentle long
Cable	Low	Any	<1500 ft	Medium	Common+	Medium	High	Steep Concave long
Helicopter	Low	Any	<6000 ft	Large	High Sawtimber	Large	High	Any

Logging System Application Narrative

Animal Using animals to skid timber is best applied in flat terrain, close to existing roads, and which is in a publicly sensitive location. The sensitivity may be a recreation site, a trail, a road or residential viewshed. The system is limited by the weight of the animals and their ability to exert pull, and in general can be used in up to 20 inch timber on favorable slopes. Because of the low productivity and low move costs, small tracts can be harvested economically.

Tracks Tracks are best used where short steeper slopes prohibits overland rubber tired skidding. Because of the slower travel speeds, yarding distance is limited and roads should either be existing or inexpensive to construct. Soft tracks, or high-speed torsion bar suspended tracks, can extend the efficient skidding distance and operate on somewhat steeper slopes than traditional hard tracks.

Swing boom grapple tracked machines can be effective in larger timber on steeper slopes at short distances, and can be used on wetter sites, or in moderately inclement weather.

Skidder Rubber tired skidders have application in the broadest range of logging conditions of any logging system. This is why skidders are the conventional logging system in Virginia. Skidders are a flat ground system, but with winches can be effectively used on flat - moderate slopes. Skidding is the default logging system selection except when: logging is necessary in inclement weather, or whenever skidding distances are longer than ~1500 feet due to the cost of road construction, or when a dozed road is necessary for the skidder to operate on because slope is excessive. Under these conditions other logging systems should be considered. Tire widths can be increased to operate overland on steeper slopes and on wetter sites.

Shovel Shovel logging is limited to clear cutting (or close to it) due to the necessity to pick up and swing the timber towards the road (bail). Shovels can work in adverse weather, in wet areas, and on steeper slopes due to the fact that they are not dependent on tractive effort to move the timber. Shovels are best applied in common + timber volumes clear cut per acre, logging in adverse weather and or on steeper slopes, where yarding distance is generally less than 400 feet, and roads are either existing or inexpensive to build due to the shorter yarding distance.

Forwarder Forwarders are best applied where longer yarding distances in fairly gentle terrain is needed to avoid expensive truck road construction, or where the volume to be harvested per acre is low and does not justify truck road construction. Scattered pieces can be picked up and forwarded. It is suited to larger tracts with existing trails which can be used as is without the need for truck road construction, and the need to yard longer distances, 1500+ feet.

Cable Cable logging systems are best applied where, due to excessive slope, ground based systems require excavated skid roads to operate, when harvesting in adverse weather is necessary, or where compaction due to ground based systems is unacceptable. Logging uphill up to 1500 feet is most efficient, however downhill and cross canyon cable systems can also be used effectively. Terrain features control the landing, cable corridor pattern, and the acres which can be harvested from a setting. There must be a sufficient volume of timber on each setting to make it economically efficient. As a result higher than common timber volumes and value are generally needed.

Helicopter Helicopter logging is best applied when road costs are high, large volumes must be moved in a short period (salvage or keep the mill running), sawtimber only is planned for harvest, harvest in adverse weather is needed, or when the landowners objectives want to minimize the environmental impacts of harvesting. This harvesting option, due to the expense, should be considered when other options are unsatisfactory. Maximum flight distances should be less than 6000 ft to maintain an average of 2500 ft or less. Flight paths can be uphill or downhill, but are limited by power lines, roads, houses and other improvements. Maximum log size is limited by the lift capacity of the helicopter used. Helicopter logging will stop when visual contact between the pilot and ground crew cannot be maintained (fog), or when the wind is >30 mph, or when icing conditions (jet intake 30 – 34 f) are present. Due to the high productivity, 80 – 100 mbf/day, extensive landing and trucking support is required.

Swing Systems Swing systems are combinations of logging systems to move the timber from stump to a full service landing. They may or may not involve a swing landing, which is a concentration point between the logging systems employed. The combination of logging systems allows each system to operate in the terrain that it is most efficient on. For example, since tracks can operate on steeper slopes than skidders yet are limited in the distance to which they can pull, combining tracks with a grapple skidder allows for logging on steeper slopes at greater distance than either tracks or skidders alone. If the distance is even greater, combining tracks with a forwarder would be efficient. Another good option for steeper slopes at longer distances is a shovel – skidder swing, however it is applicable to only clear cutting operations. The following table lists some swing systems that have good application.

Table 2. Common Swing System Applications.

Swing System	**Application**
Tracks to skidder	Short steep slopes to flat ridge or flat bottom
Shovel to skidder	Short steeper slopes to flat ridge or flat bottom
Skidder to forwarder	Moderately steep slopes to long flat ridge or bottom
Skidder to cable	Flat slopes/ bottom to steep slopes (up a cliff/ across a river)
Cable to skidder	Steep slope to moderately steep ridge

Logging System Planning

Historically, Appalachian logging systems have evolved mainly through a need to harvest on the widest variety of timber and terrain, usually with little emphasis on the environmental impacts. This "one size fits all" emphasis has resulted in the conventional logging system of the Appalachians being the dozer – cable skidder combination.

No matter if the distance is short or long, the terrain flat or steep, the timber small or large, the rubber tired cable skidder combined with building roads to work from is the one logging system that can, usually, get the timber out. Unfortunately, this crescent wrench approach is not the most cost effective or environmentally friendly in a large number of harvesting applications. The aesthetics of stacked skid roads on the side of a mountain, the grade on the skid roads, safety of ground based equipment on steep slopes, and the stream crossings needed are some of the more prominent issues with the crescent wrench application in the Appalachian Mountains. However, while this system is not the most effective, it is also the one that requires the least planning. This lack of logging planning is both the reason why the dozer - cable skidder is the most applied system, and the single biggest impediment to the success of more effective systems.

The successful implementation of any specialized logging system is dependent upon harvest planning. With a specialized logging system, it is possible to do a better job in particular conditions. The key to logging planning is to be able to keep the specialized logging system working in its particular niche. If the logging system is applied in conditions that it is not suited, then harvesting costs and environmental impacts will likely be high. An example would be the application of mechanical felling. It is well known that mechanical felling can be safer, more productive, and less expensive than manual falling. However there are certain slope and tree size limitations to mechanical falling equipment. If a logger buys a mechanical faller, but can only use it 50% of the time because the tracts are too steep or the timber to big, then the costs are effectively doubled, and the risk of accident due to pushing the machine on slopes beyond its effective working range to increase utilization is high, and productivity suffers. So the key is, yes mechanical falling is better than manual falling, <u>in it's niche</u>. Keeping the specialized tool in its niche is what logging planning is all about. It is knowing well ahead of the scheduled harvest what logging system is needed, and if there is enough of it to keep it utilized. Logging Plans are done at different scales, to serve different purposes, and are typically referred to as **Strategic** and **Tactical** logging plans.

<u>Strategic Logging Plans</u> involve large areas, on numerous tracts, are based heavily on topographic maps with fieldwork to verify only critical items. A paper logging plan is designed, showing landing locations, road locations, logging systems and yarding patterns. This paper plan is then reviewed in the woods to verify questionable locations, such as access points and major road locations, and adjusted accordingly. In this fashion, different logging systems can be evaluated for their environmental impacts and cost of harvesting. An example of such evaluations could be comparing the conventional cable skidder to cable logging on steep ground. The results of this comparison would typically be that the impacts and costs of building extensive skid road networks for the skidder would create more impacts and cost more than cable logging. In addition, the capacity of the cable system would be identified, such as how much uphill, sidehill, and downhill yarding is required? How far will the cable system need to yard? What type of carrier should the yarder be on in order negotiate the landing settings? What size lines should the yarder run and how tall a tower is needed? After enough strategic logging planning is done, representing the variety of timber and terrain being harvested, patterns develop which lead to logging system equipment selection. This is the purpose of strategic logging plans, to identify logging system needs and to develop strategies for harvesting, i.e. the road needs to be at the top whenever possible, and when the slope is such that extensive skid road networks are needed, cable logging should be utilized. Strategic logging plans also allow the evaluation of the extent of the logging system needs, and an appropriate means to procure the logging system. For example, if plans indicate that 40% of the tracts to be harvested need cable systems, then a contractor has enough work to specialize in this type of logging.

<u>Tactical Logging Plans</u> involve specific tracts, with specific logging systems, and are field verified to the extent that the plan can be implemented as designed with acceptable environmental impacts, and within the harvesting cost budgeted for the tract. This is the plan that the selected logging contractor can take to the woods, with their particular equipment, and build the roads where shown, and log with the patterns shown, at the cost that has been planned. Having an accurate logging plan allows the contractor to schedule the work so as to be efficient and avoid unknown surprises. As logging system specialization occurs, this will typically mean that tracts will need to be subdivided for the logging contractor which has the system to fit the timber and terrain. This could mean reserving a strip of selective harvest along a residential development for a horse logging contractor (or small selective cut contractor), while the remainder of the tract is reserved for a fully mechanized high production clear cutting contractor. In the mountains it will mean separating the tract between the specialized cable logger from a conventional skidder logger. By tactically identifying each logging systems niche, and planning to fit the specialized system to the timber and terrain, a reduction in both the harvesting costs and environmental impacts can be achieved.

Conclusion

The increasing utilization of the Appalachian forest resources has caused public scrutiny of harvesting practices. Effective BMP implementation, and insuring clean water, is essential to maintaining the public trust with increased utilization. Proper specialized logging system application is critical to effective BMP implementation. Success of specialized logging system implementation is dependent on logging plans in system selection, system application, and scheduling. Proper implementation of specialized logging systems is a way to increase cost effectiveness and reduce environmental impacts. The Appalachian Forest Products Industry will continue to implement specialized logging systems in order to enjoy the competitive advantages of using the right harvesting tool in the proper application. Maintaining a non-regulatory practice of forestry will depend on the timing and progress made with these efforts.

Alternative Skid Trail Retirement Options for Steep Terrain Logging

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ABSTRACT

In winter 1999-2000 trials of deep tillage and recontouring of skid trails were implemented on three sites in northeastern Kentucky, USA to examine their potential as skid trail retirement options. While effective, current Best Management Practices (BMPs) for trail retirement do not address two potential benefits of retirement: recovery of normal hill slope hydrology and amelioration of soil compaction. Subsoiling and recontouring both significantly reduced soil compaction compared to the control. Preliminary data from runoff sampling indicated none of the treatments were similar to the undisturbed hillside, but recontoured treatments had surface runoff 77% of the control and sediment yield 41% of the control. Subsoil treatments results for sediment yield and runoff volume were between the control and recontour treatments. Production levels from research application of deep tillage showed that the cost could be competitive with conventional BMPs. The recontouring treatment was three to five times the cost of conventional BMPs. General application of deep tillage and site-specific application of recontouring may be cost neutral or reduce net cost of BMPs if treatments increase tree growth or significantly improve water quality.

INTRODUCTION

In the Appalachians, ground-based logging on the steep terrain results in a network of bladed trails on hillsides. These trails are a primary source of erosion and commonly cover from 10-25% of the harvest area (Stuart and Carr 1991; Miller and Sirois 1986; Kochenderfer 1977). The Best Management Practices (BMPs) for trail retirement following the harvest are installation of cross drainage and establishment of vegetative cover. There are two limitations to conventional BMPs: 1) the areas with soil damage (erosion, compaction, destruction of surface soil) continue to accumulate with successive stand entries and 2) the trails disrupt the normal hillslope surface and subsurface water flow leading to increased long-term erosion and potential changes in watershed hydrology.

Addressing these limitations, may provide opportunities for alternative methods for trail retirement including the restoration of the hillslope to the original profile or deep tillage of the trail running surface. While a tracked excavator was the obvious choice for recovery of the fill slope, choices for deep tillage of the trail surface are varied (Andrus and Froehlich 1983). The goals for tillage on these trails include: 1) ameliorate soil compaction, 2) increase infiltration, 3) enhance germination and growth of ground cover and tree growth, 4) avoid acceleration of erosion through trail surface disturbance, and 5) maintain or enhance trail surface drainage.

The entire study was designed to evaluate seedling growth and soil water, surface water and sediment movement across the profile of trails treated with water bars and revegetation (control), recontouring and revegetation (recontour), and subsoiling and revegetation (subsoil). Here we report on the implementation of the recontouring and subsoiling, soil conditions immediately following implementation, and preliminary data from water volume and quality measurements.

METHODS

The research sites were located in northeastern Kentucky, USA in the Cumberland Plateau Physiographic Province. The Cumberland Plateau is characterized by short, steep sloped hills with relatively narrow ridges. The area is generally considered part of the Appalachian region. Two of the sites, Moore Branch and Road Branch were within 3 miles of the other and had similar soil texture (sandy loam). The Fuller Branch site was about 25 miles away and had loamy soils.

For subsoiling applications we chose the Tilth Self-Drafting Winged Subsoiler (subsoiler). Characteristics of the subsoiler were described by Andrus and Froehlich (1983), and its application was described in Andrus and Froehlich (1983), Davis (1990), De Long et al. (1990) and Hogervorst and Adams (1994).

Trials of the subsoiler were completed on trail segments on side hills and ridge tops on the three research sites. The prime mover or tractor was a Caterpillar D6R XL. University of Kentucky staff operated the tractor with the subsoiler. The operator was an experienced tractor operator

but had no previous experience with the subsoiler. The manufacturer provided support for subsoiler operation during the study.
The subsoiling was completed in early December 1999 about one week after 25-mm of rainfall. Light rain fell (12-mm) after the completion of the Fuller Branch Site and before starting operations on the Road Branch and Moore Branch sites. Soils were dry in spite of the rain since extreme drought conditions prevailed for the area throughout the summer and fall 1999. We hired a local contractor with a Caterpillar E120B to complete the fill slope recovery and re-contour on sections of side slope roads. Recontouring occurred during moist soil conditions in late February 2000. We took continuous timing measurements on the subsoiler from video recordings. The excavator was videotaped on three of the six trail sections. To maintain a complete randomized block design for the experiment, the excavator walked over the subsoiled plots to get to the recontour plots. The excavator compacted surface soil in subsoiled treatments about 3-cm under the track. Scrap lumber was placed every 60-80-cm perpendicular to the trail to distribute the weight of the excavator more evenly across the trail. Soil was compacted about 7-10-cm under the lumber.
Following the application of the treatments we took penetrometer readings in the inner track, middle, and outer track locations at three systematic locations in the treated plot. Readings were taken with a Rimik recording penetrometer with a 130-mm^2 cone according to ASEA Standard: ASAE S313.2 (ASAE 1989). Slopes of the resistance profiles were computed using ordinary least squares. In some control locations the penetrometer could not be inserted because the soil strength exceeded the capacity of the penetrometer. For those locations we estimated the slope using a regression developed from bulk density, soil moisture, and clay content (R^2=0.29). The slopes were modeled using ANOVA with a complete randomized block design.
In Spring 2000 we planted each of the treatments with 20 eastern white pine and 20 tulip poplar bareroot (1-0) seedlings. For three treatments on each site and an undisturbed reference location we installed TDR probes for soil moisture data above the trail, on the trail surface, and below the trail and runoff collection plots on the trail surface. Runoff data presented here were collected from June to August 2000.

RESULTS

Soil

Recontour and subsoil treatments were significant in reducing soil strength on the trail running surface (P=0.0001). Recontour and subsoil treatments were significantly different from the control (P<0.05), but the recontour treatment was not significantly different from subsoil treatments. Figure 1 shows the mean slopes for each of the sites and treatments. The control on the Fuller Branch site was significantly less compact than the other two controls.

Water and sediment

Preliminary analyses revealed that the recontour treatments had the lowest volume runoff and the lowest sediment runoff (Table 1). None of the treatments were similar to the undisturbed hillslope (reference).

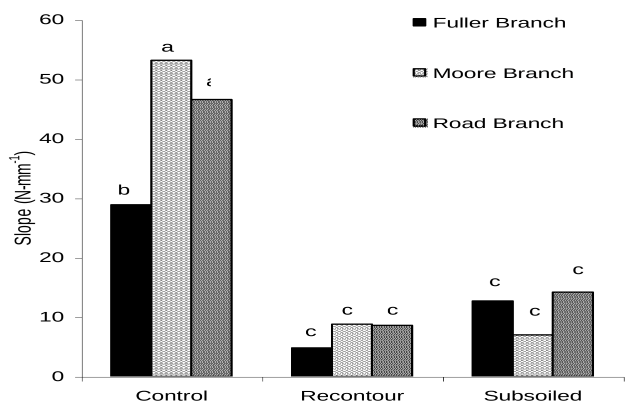

Figure 1. Slopes of the penetrometer profile for control, recontour, and subsoiled treatments for each site. Letters represent significant differences at P<0.05.

Table 1. Summary of preliminary runoff and sediment data. Letters indicate significant diffences at P<0.05.

	Runoff volume (L m^{-2})	Sediment (g m^{-2})
Subsoil	8.5 a	31.40 ab
Recontour	5.9 b	14.18 b
Control	7.6 ab	34.74 a
Reference	0.04 c	0.06 c

Production

The timing data for the subsoiled trail sections are presented in Table 2. Delay times were large due in part to an inexperienced operator. Most frequently delays were caused when the operator tried to avoid creating soil disturbance and to avoid damaging standing trees. Some delays were produced when the operator attempted to minimize damage to the subsoiler and minimize disturbance by not moving large rocks with the subsoiler. Delays for maneuvering, avoiding stumps, and debris comprised over 78% of the total productive delay time. The operator often received instruction about how to deal these problems increasing the length of the delay.

Travel time to the location was not included in the subsoiling data since a) we were using the dolly mounted configuration which required backing down some trails and b) machine speed was reduced to minimize damage to the experimental plots prior to treatment.

Delay free production ranged from 0.59 to 2.31 km-hr^{-1} and production including productive delays only ranged from 0.42 to 1.75 km-hr^{-1} (Table 3). A treatment width of 4-m (the width of the trail running surface) yielded production with productive delays 0.17-0.70 ha-hr^{-1}. For ridges and benches the actual treated width could be up to 50% wider (Andrus and Froehlich 1983).

Table 2. Subsoiler production and delay times (seconds) for each site and trail segment

	Site Road				Moore		Fuller		
Trail segment	1	2	3	4	1	2	1	2	3
Length (m)	197	182	33	42	26	57	64	321	318
Productive time (sec)	530	283	144	256	73	102	170	767	535
Delay (sec)									
Stump	108	88	0	37	0	0	0	26	192
Tree	89	12	0	0	49	0	0	0	0
Debris	49	21	29	37	0	0	0	0	225
Rock	20	0	0	0	0	0	0	0	13
Maneuver	0	56	27	0	0	0	46	212	0
Waterbar	0	0	0	0	0	0	0	146	0
Other	0	0	45	0	0	15	130	1188	302
Total	266	177	101	74	49	15	176	1572	732

Table 3. Subsoiler production estimates and mean production in kilometers per hour and hectares per hour for each trail segment.

Site	Trail seg.	Length (m)	Production (delay free) Km-hr^{-1}	Production (delay free) Ha-hr^{-1}	Production (productive delays) Km-hr^{-1}	Production (productive delays) Ha-hr^{-1}
Road	1	197	1.34	0.54	0.89	0.36
Road	2	182	2.31	0.93	1.42	0.57
Road	3	33	0.82	0.33	0.48	0.19
Road	4	42	0.59	0.24	0.42	0.17
Moore	1	26	1.29	0.51	0.77	0.31
Moore	2	57	2.01	0.80	1.75	0.70
Fuller	1	64	1.35	0.54	0.67	0.27
Fuller	2	322	1.51	0.60	0.49	0.20
Fuller	3	318	2.14	0.86	0.90	0.36
Mean			1.48	0.59	0.87	0.35

The recontouring treatments took from 18 to 25 minutes for each 25-m plot. No significant delays were experienced during the completion of any of the six plots. The contractor we employed indicated that his production including travel out would be 0.1-km-hr^{-1} on sites similar to the research sites. Using the same 4-m width for the trail surface yielded production rate of 0.04 ha-hr^{-1}. Using the distance from the inside of the cut slope to base of the fill slope (6-m), the production increases to 0.06 ha-hr^{-1}. The local contractor rate for this size machine was about $120 per hour yielding a cost of $1200 per kilometer of trail or $3000 per hectare (4-m wide trail).

DISCUSSION

Both treatments significantly reduced compaction. Recontouring had an advantage in this regard since the penetrometer sampled an upper layer of the soil profile. In the subsoil and control treatments the penetrometer sampled subsoil that was at least 0.5-m below the original soil surface. The result was considerably higher rock content in addition to penetrometer resistance. In addition the penetrometer results of the subsoil treatments were probably affected by excavator traffic following the subsoil treatment. The importance of the differences won't be known until tree growth, infiltration, and runoff data are collected from these treatments.

Recorded production of the subsoiler was slower than production speeds previously recorded because the operator had only one day of training prior to the trial and was relying on instructions from the manufacturer and the researchers. Using one pass to clear slash and the second pass to subsoil De Long et al. (1990) recorded production of 0.29 ha-hr^{-1}.

The most recent published costs are from Davis (1990) of $160 per hour for both crawler tractor and subsoiler. Delong et al. (1990) predicted ownership and operating costs for the subsoiler at $5.88 (Canadian) per hour. Subsoiler costs may differ slightly in the Appalachians due to operator proficiency and local terrain and soil conditions. Local contractor rates for a 180 Hp crawler tractor at the time of the study ranged from $150 to $200 per machine hour. Rates quoted to us may have been inflated because contractors did not have a good sense of how the tractor would be used and the amount of downtime that would be experienced. In De Long et al. (1990) the first pass was used to clear slash from the subsoiled areas and took 60% of the productive time. Total productivity would be sensitive to slash cover on the trails. In the Appalachians fellers and skidders combined have considerable control over how much slash is on the trails following harvest. Using a rate of $175 hr^{-1} for the prime mover and subsoiler, the average productivity of subsoiling from this study (0.35-ha-hr^{-1}), and a first pass that consumes 0.5-ha-hr^{-1}, the treatment cost equals $850-$ha^{-1}$. Doubling the productivity of the subsoiling but with the slash removal production at 0.5-ha-hr^{-1} decreases costs to $600-$ha^{-1}$.

While much of the value of these two techniques has yet to be determined by tree growth and runoff results, the costs estimated are not that different from present retirement costs. Assuming that 1 water bar would be installed every 18-m which relates to an average trail slope of 15% (Stringer et al. 1997), the cost of recontouring equals conventional retirement at $21.60 per waterbar. At the low (0.17-ha-hr^{-1}) and high (0.70-ha-hr^{-1}) productivity levels from the subsoiler (0.50-ha-hr^{-1} for the first pass), the cost of subsoiling equals conventional retirement at $9.92 and $4.31 per waterbar, respectively. From survey results Shaffer et al. (1998) found average waterbar costs at $15 each. A production study gave the cost per water bar at this density $3.34 per waterbar (Hewitt et al. 1998).

The ability to put a larger dozer on the harvest for tillage should have production benefits in all phases of retirement. Most loggers that have dozers have smaller dozers since their primary function is bunching and skidding and not earth moving. In addition the cost of assigning a productive machine to a retirement task is probably somewhat higher than the machine rate or even the contractor rate for a comparably sized dozer. Both recontouring and subsoiling are likely to increase the success of revegetation through seedbed preparation and may allow increased mechanization of seeding, mulching, and fertilizing through equipping the prime mover with bulk spreaders. A limiting factor for both recontouring and subsoiling would be the area treated at one location. Small harvests with only a few hectares to treat would drive up the costs per hectare because of transport costs and poor machine utilization.

Current investments in trail retirement through BMPs may represent an under investment in retirement to ameliorate soil damage or planning to reduce area impacted. Stewart et al. (1988) showed that several methods used to decrease the compacted area in harvests of forests in the Pacific Northwest, including tillage, yielded positive returns. In hardwood forests our understanding of the growth losses due to trails is extremely limited and such a comparison would be difficult. Adding the cost of amelioration to the cost of ground-based harvesting in this steep terrain likely represents the true opportunity for aerial logging systems or other ground-based systems that minimize trail density and trail slope.

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CONES – A COMPUTER BASED MULTIPLE CRITERIA DECISION SUPPORT TOOL FOR TIMBER HARVEST PLANNING IN STEEP TERRAIN

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ABSTRACT – This paper presents the conceptual basis of a mobile spatial decision support system (SDSS) for improved timber harvest planning in mature stands in steep terrain. The expected utility of a decision alternative (combination of harvesting system, location of skyline trails, silvicultural prescription) in a given stand is calculated from partial utilities with regard to efficiency of the harvesting system [cost/m^3], expected damage to residual stand,and advance regeneration and stability of the residual stand employing an additive utility model based on the Analytic Hierarchy Process (AHP). Input to the decision model is calculated with quantitative models for system productivity and damage probabilities.

INTRODUCTION

In recent years several international cooperations and resolutions (e.g. Ministerial Conferences for the Protection of European Forests 1998, 1999) have pinpointed the importance of functional sustainable forests. In Central European mountain forests a close-to-nature forestry based on natural woodland communities aiming at heterogenizing rather than homogenizing forest structure by means of small-scale silvicultural treatment strategies such as single stem selection systems or group selection systems is considered an appropriate means (Mayer and Ott 1991).

From Austria’s appr. 3.5 mill. hectares of forest approximately 25% are situated on slopes with an inclination of more than 60%. Timber harvesting operations under such steep terrain conditions rely on cable yarding systems which have proven to be an adequate hauling means. However, to cover the costs of installation (i.e. fixed cost) harvest intensities usually are high with substantial extracted timber volumes per stand entry. Therefore a "classic" and widely applied approach to minimize harvesting costs are strip cuts or clear cuts where the harvested timber concentrates on relatively small scales. This approach usually requires subsequent expensive artificial regeneration and furthermore often misses to meet the requirements of other societal needs beyond timber production such as protecting infrastructure and settlements from natural hazards like avalanches, mud flow and torrents, or providing sustained yield of high quality water resources, and preventing fragile mountain sites from soil erosion.

Thus, to arrive at an overall best compromise solution the local forest manager has to consider the trade-off of short-term minimal harvesting costs against expected long-term benefits from longer regeneration periods and continuous cover at a site. Essentially decision making about harvesting and natural regeneration of forest stands in steep terrain with cable yarding system requires the careful consideration of 3 sub-processes: (i) the design of an appropriate silvicultural treatment strategy (type of silvicultural treatment, intensity of entry), (ii) the selection of the appropriate timber harvesting system (uphill/downhill, whole tree, whole stem, etc.) , (iii) the optimal location (i.e. sequence) of the skyline trails.

Silvicultural treatment strategy, harvest system as well as location of skyline trails can be considered as decision variables. Within a multiple-purpose setting the efficiency of the applied timber harvesting system (i.e. cost/m^3 harvested timber), the damage to the residual stand and to advance tree regeneration, and the prolonged functioning of the remaining stand (i.e. stability against snow breakage and wind-throw, continuous forest cover etc.) are the variables to be optimized. Decision making about natural stand regeneration and timber harvesting at the operational level always includes spatial considerations. For instance, skyline trails rely on suitable supports and landings. Limits regarding the maximal extraction distance of a harvesting system impose constraints with regard to the sequence of skyline trails. Thus, it is obvious that a proper analysis of the expected impacts of a timber harvest operation relies on spatial information.

Considering the complexity of this task neither intuitive nor schematic solutions are appropriate planning approaches. For such problems a formal decision analysis is strongly recommended. According to Keeney and Raiffa (1993) four phases of decision analysis can be distinguished; (1) structuring the decision problem, (2) assessing the impacts of each possible solution, (3) determining the preferences of the decision maker, and (4) comparing the decision alternatives. This process might be too complex to be solved when entirely based on the cognitive capabilities of the human mind. For such unstructured decision problems decision support systems (DSS) can provide valuable help.

The aim of this paper is to present the design and conceptual basis of a mobile spatial decision support system (SDSS) for timber harvest planning at the stand level in steep terrain.

SDSS ARCHITECTURE AND COMPONENTS

In general terms, SDSS are computer-based systems for integrating data base management systems with analytical models, graphic display, tabular reporting capabilities and the expert knowledge of decision makers to assist in solving specific problems. As DSS are based on formalized knowledge, their application in the decision making process facilitates decisions that are reproducable and as rational as possible. Moreover, through the use of DSS the way the decision maker arrives a solution is automatically documented and, thus, the process of decision making can be evaluated (Vacik and Lexer 2001).

Among others, Densham (1991) suggests, that SDSS have the following distinguishing major characteristics:

1. they are designed to solve ill-structured problems,
2. they have a user-interface that is both powerful and easy to use,
3. they enable the user to combine data and models/methods in a flexible manner,
4. they help the user to evaluate the decision space
5. they provide mechanisms for the input, storage, spatial analysis and query of spatial data
6. provide output in spatial forms (e.g. maps)

Based on these considerations the core structure of the decision support tool CONES comprises four components: (1) the information base (implemented in Oracle™) containing all available information about the stands to be harvested either from direct stand inventory or generated by models, (2) the tool box (containing implementations of multi criteria analysis methodology and spatial analysis methods), (3) the DSS-generator where the decision model (i.e. the sequence of algorithms which is used to evaluate the decision alternatives) is embedded, and (4) a graphical user-interface. Within CONES, ArcView™ 3.2 is employed for input and analysis of spatially explicit information such as location of skyline trails or advance regeneration. The standard graphical user-interface of ArcView™ 3.2 was modified by custom-made Avenue code to develop an application on top of ArcView™.

The decision model

A decision alternative consists of (a) harvesting system, (b) the location of at least one skyline trail, and (c) the prescribed silvicultural treatment (i.e. which trees are to be cut). For demonstration the overall utility of a decision alternative conceptually consists of partial utilities regarding the economic feasibility of the operation, minimized damage to the residual stand and to advance tree regeneration, and from the expected utility with regard to the mechanical stability of the residual stand (Figure 1).

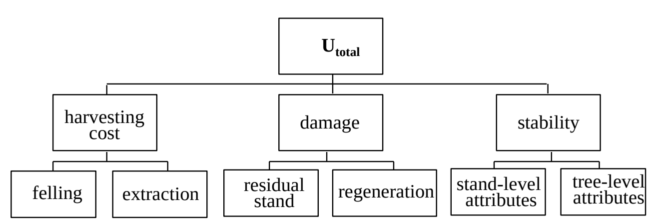

Figure 1. Example for the hierarchical structure of partial objectives to evaluate the overall utility of decision alernatives.

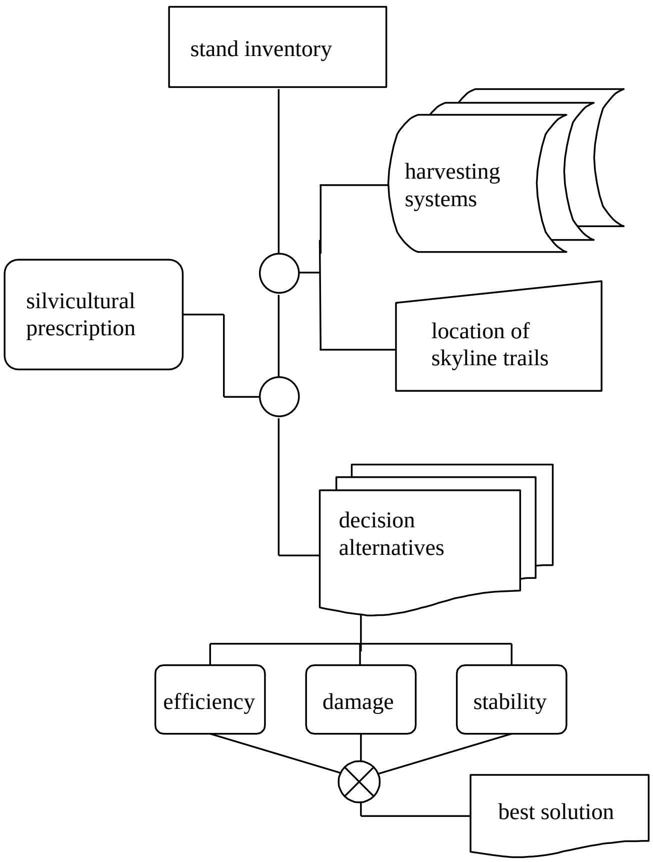

Figure 2. Schematic representation of the decision model within CONES.

The evaluation of the economic feasibility of an alternative will be based on the total harvesting cost per m^3 harvested timber and the returns from the harvested timber assortments. In case of a silvicultural strategy which is based on selective harvesting one decisive aspect in steep terrain is the economic feasibility of the future stand entries due to the installation costs of skyline systems. Thus, in the decision model of CONES the effect of an alternative on future operations will be taken into account as a decision constraint by calculating the expected costs of the next stand entry assuming that the same skyline trails will be used.

To calculate the input required for the decision model (compare Figure 2) productivity models for a set of harvesting systems as well as predictive models for the damage to the residual stand and to advance regeneration expected from a particular combination of silvicultural prescription and harvesting system are needed.

Productivity models

Quantitative productivity models for timber harvesting in steep terrain are rare in scientific literature. In addition the use of published models is often hampered due to the following reasons: (a) varying time study concepts of published material, (b) for practical reasons the set of predictor variables in such models should be restricted to few easily obtainable site and stand attributes (Stampfer 1999). With CONES productivity models for felling and timber extraction will be used. Productivity of felling is mainly determined by tree volume, branchiness of the harvested trees and harvesting intensity. The total cost of extraction will be calculated from estimates of installation costs (fixed costs) and from variable extraction costs. Estimation of installation cost will be based on operation data from the Austrian Federal Forests (öbf AG) and will consider the harvesting system, direction of extraction (uphill, downhill), length of skyline and number of required intermediate supports. According to (Stampfer and Daxner 1998) the productivity of a cable yarding system mainly depends on mean tree volume, the distance of lateral yarding and the overall extraction distance, as well as the harvesting intensity.

Stand and regeneration damage models

For spatial units (i.e. pixels) within a stand defined by (a) distance from the skyline, and (b) extraction distance the probability of a particular damage class regarding the residual stand as well as eventually existing advance regeneration will be estimated by logistic regression (eq. 1).

$$P = \frac{1}{1 + \exp(-b_0 \cdot \sum a_i X_{stand(i)} + \sum b_i \cdot X_{site(i)}} \qquad (1)$$

P = probability of damage to the residual stand/advance regeneration by area unit (pixel)
a_i , b_i = empirical coefficients
$X_{site(i)}$ = site variables
$X_{stand(i)}$ = stand variables

For skidder-based harvesting systems Ostrofsky et al. (1986) and Nichols et al. (1993) presented examples for quantitative damage modelling in northern hardwoods in the United States. They identified distance from the skid trails and basal area of the harvested stand as the major determinants for damage probability to the residual stand. To our knowledge for cable yarding systems such models are still missing. Based on practical experience in Austria potential predictor variables in models for damage to the residual stand are the mean harvested tree volume, the lateral yarding distance, stand density and slope inclination. Modelling the expected damage from skyline yarding to advance regeneration is a novel approach within CONES.

Assessment approach

To quantitatively evaluate the overall utility of decision alternatives (i.e. combinations of harvesting system, location of skyline trails, silvicultural prescription) in case that more than one possible solution exists an approach that borrows from multiple-attribute utility theory (MAUT) will be adopted. In CONES the overall utility of a decision alternative is composed of partial utilities based on total harvesting costs, on damage to the residual stand and advance regeneration, and on mechanical stability of the residual stand. It is obvious that the evaluation process has to be based on quantitative (e.g., harvesting cost) as well as on qualitative (e.g., stability of residual stand) decision criteria. For such situations Lexer et al. (2000) and Vacik and Lexer (2001) demonstrate the use of an additive utility function for the aggregation of partial utilities which in turn are derived from preferences for the decision alternatives with respect to decision criteria. Preferences for decision alternatives as well as weights of involved partial objectives are calculated with Saaty´s eigenvalue method as applied in the Analytic Hierarchy Process (AHP) (Saaty 1977).

DISCUSSION

To enhance decision making about silvicultural treatment of mature mountain forests in steep terrain it is essential to integrate the design of the silvicultural treatment plan and the choice of the harvesting system and the operational planning of timber harvesting. To fully understand the consequences of a particular operation beyond harvesting costs forest managers need reliable a priori estimates of expected damages to residual stand, advance regeneration as well as on other attributes related to functional sustainable forests. The decision support tool CONES aims at providing this information based on stand inventory data and quantitative models for harvesting system productivity and damage probability. Moreover, to allow for a consistent comparison of decision alternatives CONES provides a multiple-criteria evaluation. Though decision support systems are not meant to provide a ready decision, tools like CONES have the potential to improve decision making on site considerable.

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Calculating Utilization Rates for Rubber Tired Grapple Skidders in the Southern United States

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ABSTRACT - Utilization rate is an important factor in calculating machine rates for forest harvesting machines. Machine rates allow an evaluation of harvesting system costs and facilitate comparisons between different systems and machines. There are many factors that affect utilization rate. These include mechanical delays, non-mechanical delays, operational lost time, and personnel time. As a result utilization rate can be highly variable and difficult to accurately estimate without detailed information. This paper reports on an ongoing study to measure the utilization rates for forest harvesting machines in the southern US, specifically rubber tired grapple skidders. Electronic service recorders were mounted on four grapple skidders on a harvesting operation in east central Alabama. To date, 44 working days have been monitored for three of the skidders and 19 for the fourth machine. The average utilization rate ranged from 76.5 percent to 64.8 percent.

INTRODUCTION

Accurate machine productive time has a variety of uses for machine owners, managers and researchers. The data can be used to account for and charge for machine use. Maintenance and service scheduling and documenting can be kept more accurately.

Service recorders are the traditional means of measuring productive machine hours. There are several drawbacks to service recorders. They generally can only record for 24 to 48 hours and the charts must be changed manually. Data interpretation is also time consuming and can be tedious. Until recently there were very few commercially available alternatives. The Yellow Activity Monitoring System (YAMS) (Thompson, in press) is a commercially available electronic service recorder and software package that replaces the traditional service recorder.

YAMS has made possible the opportunity to monitor multiple machines for long periods of time with minimal labor. For research purposes, YAMS allows long term data capture that can be used to gain a better understanding and measure of machine usage and utilization rate.

Utilization rate is the ratio of Productive Machine Hours (PMH) to Scheduled Machine Hours (SMH) (Rolston, 1972). Utilization rate is used in the calculation of machine rates. Machine rate is a cost analysis method used to calculate a machine's average cost over it's lifetime (Matthews, 1942). Harvesting contractors and forest managers can use machine rates to more accurately compare machines and systems and address issues affecting their productivity. For a machine rate to be reliable it must be based on accurate data. Machine utilization rate is a value inherent to all machines, but one that is rarely calculated or reported. This paper reports on an ongoing study to measure the long term utilization rate for forest harvesting machines. The intent of the study is to monitor a wide range of forest machines working in different forest types and conditions. This paper is focused on current results for rubber tired grapple skidders.

MATERIALS AND METHODS

The Yellow Activity Monitoring System (YAMS) consists of a activity recorder, data gatherer and a data storage and analysis software package. The activity recorder can be permanently or temporarily mounted in any machine. It stores machine vibrations electronically and can hold 114 hours of machine activity. The intensity and frequency of the vibrations are recorded and the sensitivity can be adjusted to filter out "noise". The data gatherer is used to download machine data from the activity recorders in the field. The data gatherer has the capacity to download as many as 16 activity recorders while in the field. The YAMS software allows the storage and analysis of data for multiple machines. Reports can be printed for single or multiple machines over short or long periods of time. The software allows scheduled hours to be set for each machine and automatically calculates a wide range of machine statistics.

For this study four YAMS activity recorders were mounted on four rubber-tired grapple skidders working on an in-woods chipping operation in east central Alabama. The machines were a Caterpillar 518, Timberjack 450C, Timberjack 460, and a Timberjack 660. The three Timberjack machines were the primary skidding machines, while the Caterpillar was used mainly for short skids, and cleaning the landing area.

The activity recorders should be mounted vertically on a wall of the machine and are downloaded via the bottom of the recorder. This limits the number of available places for mounting the recorders in the cabs of modern skidders. Double sided tape was first used to mount the recorders and later we switched to Velcro to allow for more mounting options (for example on carpeted interior walls). Based on information provided by the contractor scheduled hours were set for 8 am to 5 pm daily for each machine Monday through Friday.

RESULTS AND DISCUSSION

Data Collection

Data collection began in the second week of January 2001 and is ongoing at the writing of this paper. The data from the recorders was downloaded weekly and entered into the YAMS software. The data gatherer proved to be very easy to use and convenient for downloading in the field. Downloading time per machine was very quick, averaging less than a minute for a week's data. Each machine's data was downloaded as they approached or left the landing. Total time to download all machines was generally less than 30 minutes.

The activity recorders proved to be reliable overall. Some instances of lost data did occur due to battery problems. If an error occurred with an activity recorder it could not be diagnosed until the data had been downloaded back at the office. Other sources of lost data occurred as a result of mounting problems. For example, one activity recorder fell from it's mounting and the operator placed it in a cushioned compartment to keep it from getting damaged thus stopping the recorder was vibrating.

Data Analysis

Summary results are presented in Table 1. The Caterpillar 518 and the Timberjack 450C and 460 were monitored for 44 consecutive working days. The Timberjack 660 was monitored for 19 working days. Missed days on the Timberjack 660 were due to errors with the activity recorder. During the 44 day observation period the operation was shut down due to the weather on only two occasions. Mechanical availability was not calculated for the machines due to the lack of data on daily service time. Work missed for major mechanical delays is accounted for.

Table 1: Utilization rates (percent) and productive machine hours for four rubber tired grapple skidders working in an in-woods chipping operation in east central Alabama.

	Cat 518	***TJ 450C***	***TJ 460***	***TJ 660***
No. Days	44	44	44	19
Avg Util	65.61	64.75	76.52	70.65
Max Util	94.77	91.44	96.44	90.0
Min Util	0	0	0	0
Std dev	26.22	26.14	22.56	26.72
Avg. Hrs	6.71	6.58	8.11	7.81
Max Hrs	9.32	9.03	10.37	9.88
Min Hrs	0	0	0	0
Std dev	2.57	2.55	2.14	2.74

The Caterpillar 518 had an average utilization rate of 65.61 percent and averaged 6.71 hours per day. On 37 of the 44 monitored days (84 percent) the machine worked outside of the scheduled hours. The average time per day outside of scheduled hours was 0.66 hours with a maximum of 1.37 hrs. The machine missed two days due to mechanical delays.

The average daily utilization rate for the Timberjack 450C was 64.75 percent with an average daily working time of 6.58 hrs. On 36 of the 44 days (82 percent) of monitoring the machine worked outside of the scheduled hours of 8am to 5pm. The average time per day spent outside of scheduled hours was 0.59 hrs with a maximum of 1.06 hrs. The machine had no lost days due to mechanical delays, but did have two lost days due to personnel time (operator unavailability).

The Timberjack 460 had the highest calculated utilization rate of 76.52 percent. The average daily working time was 8.11 hrs with a maximum of 10.37 hrs. The machine worked outside of scheduled hours 40 out of the 44 days (91 percent) with an average time per day of 0.73 hrs and a maximum of 1.85 hrs. The machine had no lost days due to operator unavailability or mechanical delays.

Average daily utilization rate for the Timberjack 660 was 70.65 percent with 19 days of observation as compared to 44 for the three other machines. Average daily working time was 7.81 hrs with a maximum of 9.88 hrs. On 18 of the 19 monitored days (95 percent) the machine worked outside of the scheduled machine hours. The average daily working time outside of scheduled time was 1.34 hours with a maximum of 1.85 hrs. No days were lost due to operator unavailability or mechanical delays. The machine did experience some lost days due to mechanical delays, but they occurred during the time no activity was recorded due to errors with the activity recorder.

Brinker et al (1989) suggest utilization rates for grapple skidders of 60 and 65 percent based on machine power. The higher utilization rate of 65 percent was suggested for machines of lower power ratings 70 - 90 hp (52 – 67 kw) and the lower utilization rate of 60 percent was suggested for machines with power ratings of 91 hp (68 kw) or above. To date two of the observed machines in this study have averaged 10 and 16 percent higher average daily utilization rates than the maximum suggested 65 percent. The other two machines in the study averaged the maximum suggested utilization rate of 65 percent. All machines in the study have power rating above 68 kilowatts. The Caterpillar 518 has a power rating of 97 kw and the Timberjack 450C, 460, and 660 have power ratings of 130, 130, and 160 kw respectively. In this situation calculated utilization rates are higher for the more powerful and newer machines.

The scheduled hours were set from 8 am to 5pm based on information provided by the contractor. The data show that the machines worked outside of the scheduled hours a majority of the time with average times ranging from a minimum of 0.59 hrs to 1.34 hrs per day. The calculated utilization rate could be higher than that reported here if the scheduled hours were adjusted to fit the average work day.

CONCLUSIONS

The use of Yellow Activity Monitoring System electronic activity recorders allows the long-term collection and calculation of utilization rates for forest harvesting machines. Four rubber tired grapple skidders working on an in-woods chipping operation in east central Alabama were monitored. Calculated utilization rates ranged from 64.75 to 76.52 percent for the four machines. These rates are equal to or above the figures suggested in the literature for grapple skidders. Is this due to the nature of the operation? Would grapple skidders working in a predominantly sawlog harvesting operation have lower average utilization rates? Future plans call for machines working in these types of operations to be studied. This study is ongoing at the writing of this paper.

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IMPROVED HARVESTING VIABILITY THROUGH INCREASED VALUE RECOVERY

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ABSTRACT - Poor markets for pulp and lumber have significantly reduced raw material prices in the Appalachian area of southeastern USA. At the time of harvest it is possible to focus on two key factors that will help improve the viability of harvesting; (a) reduced logging costs through increasing system efficiency and (b) increasing value recovery from a given timber resource.

Improving system efficiency can reduce logging costs and allow for increased contractor profitably. Setting cut and haul rates according to key productivity variables, system capability evaluation, and machine matching may also provide solutions to harvesting non-uniform stands. Increasing value recovery involves optimizing the financial return of the timber harvested. This is achieved by market selection, quality grading, bucking accuracy and inventory control. This paper discusses the problems and possible improvements to current practices for logging contractors and companies in the Appalachian area.

INTRODUCTION

The main timber producing states in the Appalachians include Maryland, Ohio, Pennsylvania, and West Virginia (Figure 1).

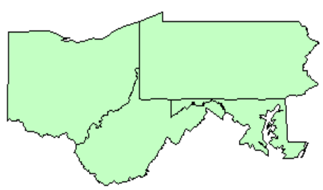

Figure 1. Appalachian Hardwood States

These states have a combined-forested acreage of 53.2 million acres. In 1999 these states produced 3.93 billion board feet of sawtimber. Species harvested include red oak, white oak, yellow poplar, hickory, ash, maple, walnut, beech, and cherry (World Almanac of Facts, 2001).

Current prices for hardwood sawtimber can range from $300 per thousand board feet (MBF) for red oak to $3,000 per MBF for black cherry. In peak months black cherry veneer can sell for as much as $7,000 per MBF and red oak $1,400 per MBF (*pers com* Scronce 2001). Prices for hardwood pulp can be a low as $18-$22/ton.

Altering harvesting systems in this region, for example integrating modern steep terrain harvesting systems or conversion to cut-to-length logging equipment, is often limited by the lack of capital, and uncertainty of both labor and product markets. This leaves three basic ways to increase profitability without increasing the capital cost.

First, the operation can attempt to produce the same amount of output at a reduced cost. However, due to the continual increase of stumpage, equipment, labor, insurance and fuel costs, it is difficult to reduce the cost of the operation. Second, the operation can attempt to produce more output with the same amount of equipment and manpower. This can only be achieved through increased operational efficiency of the current harvesting systems. Finally, the operation can try to obtain more money for each unit of output that is produced. With stumpage values of this magnitude it is easy to see the importance of proper merchandising for all products.

The concept of maximizing value recovery means that these three improvements cannot be considered in isolation. That means improving logging efficiency cannot be to the detriment of the value of the timber harvested. Vise versa, the additional cost associated with harvesting to increase the value of the timber extracted should not be greater than the value returned for that increase.

This paper outlines the key principles and considerations for implementing these two concepts with a focus on the Appalachian region of the eastern USA.

VALUE RECOVERY

Despite the increasing use of mechanized systems, most timber harvesting in the Appalachians is performed with manual logging systems. While the functions of felling, delimbing, and skidding all affect the end value of a log, processing and merchandising by far have the most impact on the end value.

The most feasible method of increasing the profitability of an operation is obtaining additional money for the products being produced. Highest value can be influenced by a number of factors, including species, diameter, defect, and quality. Proper merchandising can ensure that after all other processes have been performed the full value of a log will be realized. Individuals responsible for merchandising should have knowledge related to local market specifications and demands.

There are four key areas to focus on for the improvement of ensuring maximum value recovery from the timber resource at the harvest site:

- Accurate bucking
- Accurate quality grading
- Optimizing stem value
- Inventory management

Accurate bucking

Bucking the stems into logs is typically carried out manually with a chainsaw or in the Appalachian region with a sawbuck operated from a trailer mounted loader.

Little emphasis is placed on bucking accuracy. There is often a penalty involved in supplying undersize logs but certainly there is no reward for extra length. Typical over-run on sawlogs is 6 to 8 inches. However 6 inches of a 24inch diameter sawlog can represent $2ft^3$ of timber, worth up to $20 for higher value timber species.

The accumulation of this overrun can literally add up to hundreds of dollars a day on a typical operation. Bucking accuracy can readily be improved when using a chainsaw. However, operating a sawbuck limits accuracy. Encouraging operators to cut to an exact length as opposed to cutting to a 'zone' will reduce the loss of this timber for which neither the land-owner nor the logger is compensated.

Figure 2: Typical trailer mounted loader and saw buck set-up.

Grading and optimizing stem value

Grading is a critical step in the process of obtaining the maximum value from a stem. In Appalachian hardwoods the difference in value between one grade of log and the next higher grade can be very significant.

To the detriment of accurate log grading, there has been a strong push to improve system efficiency by mechanization of all tasks on the landing. This has complemented the drive to improve safety by removing people from the ground into machines. However there is a great need to study the opportunity of introducing 'quality grading and bucking' into Appalachian systems. Other studies in single species harvests have shown that often 10 to 15% of the value is lost in either inaccurate grading or non-optimal bucking.

Improved technology is becoming available to aid the logger in optimizing the value from each stem. Proper grade is often difficult to determine because of the large number of parameters involved including large end diameter, small end diameter, knots, number of clear faces and sweep. New hand-held computerized caliper systems provide for computer optimized bucking strategies and automated inventory management (Figure 3).

Figure 3. Using a handheld computer to determine the highest value cutting solution for a log.

Inventory Management

A commonly overlooked way of increasing the value of a log is ensuring that it is delivered to the proper location. As the trees are brought to the processing area and bucked into logs it is important to ensure that they have been put into the correct pile for transportation. Logs that are intentionally used to fill out a load of another product do not realize their full value.

Figure 4. Sending products to the proper destination increases the likelihood of obtaining the highest value

For example, a single cherry log that is approximately 12 inches in diameter and 12 feet long weighs roughly 500 pounds. If this log is used to fill out a load of Oriented Strand Board wood, the logger will receive $5.50 and the landowner will receive $1.00 (assuming $22.00 per ton delivered to the mill and $4.00 per ton stumpage for OSB). However the same log as sawtimber returns $88 to the logger and $59 to the landowner (assuming $3,000 per MBF delivered and $2000 per MBF to the landowner and 8.5 tons per MBF). To further illustrate the point, consider the additional value that the log would have if it were of veneer quality. If delivered prices for veneer were $5,000 per MBF the log would be worth $147 to the logger, which is almost double the value of a grade log and almost 300 times that of a piece as OSB.

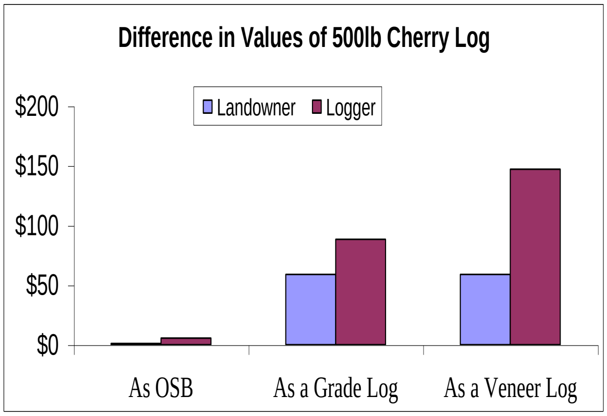

Figure 5. Values of a Cherry log depending on delivery

Another method of increasing the value of hardwood logs that is often overlooked is the timing of harvest. Hardwood markets fluctuate like any other market. Prices for high-grade sawtimber can range from $300 per MBF to $3,000 per MBF and veneer can sell for as much as $7,000 per MBF in peak months (*pers com* Scronce, 2001). In months that productive capacity is high, prices drop due to oversupply. While it is not possible for individuals to predict future prices it is possible to exploit trends in the market. In the Appalachians timber prices tend to be lowest in the months between March and August. In September prices begin to increase and are at they're highest in the months between December and February (Scronce, 2001).

Improved saw timber recovery

A study carried out in West Virginia showed that approximately 8 tons per acre was being left on site after harvest (Grushecky *et al*, 1995). In addition to improved bucking and optimizing, a conservative estimate of 10% increase can be calculated.

The magnitude of additional profit that could be realized by increasing the yield of sawtimber by 10% is illustrated with the following example. If an acre of mountain hardwood timberland has 100 tons of merchantable volume, approximately 60% will be pulpwood material and the remaining 40% sawtimber. Therefore the volume of pulpwood would be 60 tons (total value of $1,320 at $22 per ton) and sawtimber would be 4,700 feet (assuming 8.5 tons per thousand board feet). If the average delivered price is $1000 per thousand board feet, the per acre sawtimber value will be $4,700.

By recovering an additional 10% of sawlog material the value per acre increases to $5,110, an increase of $470 per acre ($6,430 including pulp). Figure 6 shows annual profits possible from recovering an additional 10% of sawlog volume at various production rates.

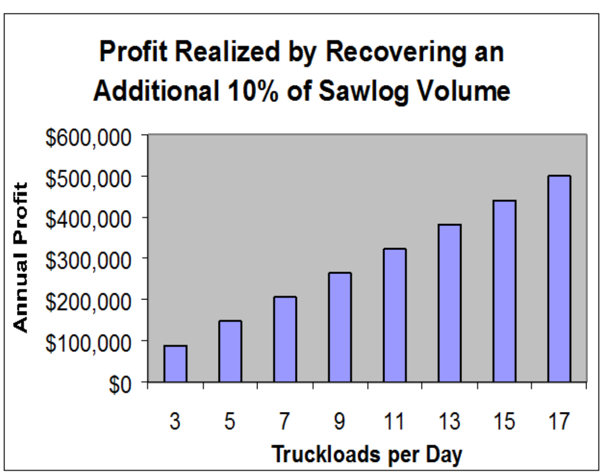

Figure 6. Annual profit from gaining 10% sawlog volume

SYSTEM EFFICIENCY

As mentioned in the introduction, forestry companies should realize that increasing value recovery also typically increases true harvesting cost. This can be in the form of a slight decrease in loader productivity for increased bucking accuracy, some under-loaded trucks to avoid loading higher value products to 'round-off' the load, additional labor required to improve grading or capital expense to purchase computerized optimizing equipment.

A Canadian study showed that sorting can increase costs anywhere from 4.2% in cut to length with a single grip harvester to 14.5% in a full tree harvesting system. However the extra additional value recovered may offset these costs (Gingras, 1996).

Encouraging the logger to extract additional residual but merchantable hardwood from a stand will decrease the average piece size. A recent productivity study on skidders showed the influence on productivity as average piece size changes (Figure 7). Increasing the amount of timber recovered from the site decreases the productivity and hence will increase the harvesting cost (Visser and Stampfer, 2000).

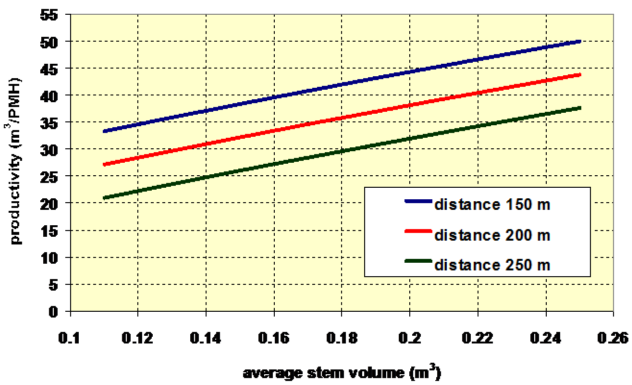

Figure 7: Skidder productivity shown to be dependent on both average piece size and extraction distance.

CONCLUSION

Though much of the material in this report relies on assumption, the level of opportunity that is possible by correctly merchandising material is evident. By recovering the full volume of each stem and then merchandising for highest value, an operation has a better chance of capitalizing on the costs associated with harvesting. With the increasing cost of materials necessary to operate, and rising stumpage prices, proper merchandising may become one of the most cost effective methods available for loggers and landowners to increase profitability.

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A COMPUTER-BASED TIME STUDY SYSTEM FOR TIMBER HARVESTING OPERATIONS

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ABSTRACT - A computer-based time study system was developed for timber harvesting operations. Object-oriented techniques were used to model and design the whole system. The front-end of the system sits on the MS Windows CE and the back-end is supported by MS Access database. The system consists of three major components – handheld system, data transfer interface, and data storage. The design module is on the handheld, which is used to design harvesting functions and variables for different types of machines, and to edit tree species in the study sites. The data collection module also resided in a HP handheld that is used to collect time, motion, and other data for harvesting machines in the woods. The interface module of data transfer is used to transfer field data from handheld to desktop PC. This module on desktop PC also allows the user to manipulate and export the field data.

INTRODUCTION

Time study is "a set of procedures for determining the amount of time required, under certain standard conditions of measurement, for tasks involving some human, machine, or combined activity" (Mundel and Danner 1994). Time study has traditionally been conducted using stopwatches and hand recording since the beginning of 20th century (Howard 1989), and is still used as a common method to collect the production and cost data for logging machines.

Through the years time study has been conducted in different ways. Early in its existence, stopwatches and paper were used to measure and record times. This method usually required two people working together. One operated the stopwatch and the other recorded the times and other measurements about the site and volume of timber being removed from the forest. This method is probably the most common method used in logging production. However, such traditional time studies can be very tedious, expensive, and error prone (Olsen and Kellogg 1983) and are being replaced by computer-based time study methods (Howard and Gasson 1991). Another method that has been introduced to time studies is the video camera. It captures exactly what is happening so time measurement is not required. Information about the site or volume of timber is still needed so another person is required to collect it.

With the evolution of technologies, new techniques have been introduced into time studies of forest operations. A DOS-based handheld time study system was developed with the advantages of the ability to modify the time design "on the fly" and the economy of keystrokes (Howard and Gasson 1991). Designing, editing, and preparation of the time study had to be done on the base computer and the edited data saved in a plain text file in this system. The design driver had to be downloaded to a handheld prior to use. Using the built in clock in the computer, the observer can use the program to collect times while entering the site and volume information simultaneously.

An effort has also been made for automated time study of felling and skidding (McDonald 1999, McDonald and Rummer 2000). It used the Global Positioning Systems (GPS) for tracking machine movements and switches for monitoring machine's functions. The system was successful in providing gross time study data, but less so in providing detailed elemental times. Their results also indicated that sequencing of tree cuts with felling cycles was subject to errors. Apparently, an accurate, user-friendly, portable time study tool for logging operations is needed.

OBJECTIVES

The objectives of this study are to:

(1) develop a handheld time study system with MS Windows-based graphical user interface (GUI) for timber harvesting operations,
(2) adapt a relational database as the backend for time and factor data storage in the system, and
(3) build an interface module for time and factor data communication between PC and HPC using ActiveX Data Object (ADO).

SYSTEM STRUCTURE

This time study system consists of three major parts: handheld system, GUI on desktop PC, and data storage (Figure 1). The handheld system is the major component used to edit species, design harvesting functions and variables, and collect site, elemental time, and variable data. The GUI component on desktop provides the interfaces and functions that allow the user to transfer data between handheld PC and desktop PC, and to manipulate and export the data for later analysis. The data storage component is a typical relational database containing tables of time study data.

The handheld system was written with Microsoft VB CE, which runs under Microsoft Windows CE environment. It contains two modules – design and collect (Figure 2). Framework design was essential to promote full exploration of the advantages of computer-based time studies over traditional manual methods and had to conform to the well-established design principles (Gibson and Rodenberg 1975, Howard and Gasson 1991). The design module in this system has the functionalities that can allow the design work to be done on either PC or handheld. Species design provides the user with the option to enter or edit tree species to be used in study site. Harvesting functions refer to the procedures or steps involved in a work cycle of a harvesting machine. For example, chainsaw felling may have functions – walk to tree, acquire, and fell. The system allows the users to define their own functions for a specific machine. Harvesting factors are the variables that affect harvesting operations and elemental times. For example, DBH and height of the tree, and distance between harvested trees are the variables for chainsaw felling in addition to site effect. Once the time study design is done, the collect module can be invoked and retrieves the information entered in the design module. Supporting help files used html-based architecture are also provided for this handheld time study system.

The data transfer interface module was written with MS VB V6.0 under MS Windows 98 or NT environment. ADO CE application programming interface (API) was employed via a dynamic link library (DLL) – adofiltr.dll. This DLL contains two functions, DesktopToDevice() and DeviceToDesktop() that are used to transfer data or copy tables. It runs on desktop PC, not the handheld. The desktop initiates and controls the transfer process. The key requirement for this transfer process is to have the same table schemas on both desktop and handheld. ADO CE data transfer feature has a solid set of tools for transferring data. While the manual method for copying tables does not offer the controllability that would be needed by most applications, the programmatic method does. This feature especially provides the functionality to transfer complete tables between devices rather than synchronizing individual records.

A relational data model was used for holding harvesting functions, variables, and time study data in the system, which was implemented based on the entity-relationship (ER) model (Figure 3). Basically there are five data entities in the model - harvesting functions, variables, site, species, and felling/skidding/forwarding/yarding. Each entity has its own attributes. For example, the harvesting functions entity has function ID and name, and machine type attributes. Entities are related using relationships such as "has" and "contains" in the model. Cycle number, machine type, function start, stop, elapsed time, and associated harvesting variables are automatically recorded. Harvesting functions, variable factors, and species are stored in separate data tables in the design module, which are identified by their primary keys and harvesting machine types. In the collect module, harvesting functions and variables can be queried and retrieved for a specific machine type on which another data table is created for storing functions, variables, and elemental times. Species information is also retrieved for data entry. The site data table contains general information such as site number, name, location, slope, and weather about the logging site. Site number is used as a foreign key to associate site information with other data tables created in collect module.

APPLICATION

Design Species

To begin the design of species, the user needs to click the "Design|Species" menu. A dialog window will be displayed for editing species that will be used in the time and motion study (Figure 4a). Hit the "New" button, then simply type species name in the "Species Name" box, and hit the "Add" button and this species will be added to species list in the database. The system also allows the user to navigate the species list entered via "First, Previous, ..." buttons. While the user navigates to a specific species in the list, she/he can click the "Delete" button to delete the current species record.

Design Harvesting Functions

In order to design harvesting functions, the user must select "harvesting machine" first, which is displayed on the left side of the screen (Figure 4b). Function name is entered in the "Function Name" box, and then hit "Add". This harvesting function will be added into the database for the type of harvesting machine the user specified. Meanwhile, the "Function No." box displays the function number with a prefix of harvesting machine type. Similarly, the user is allowed to navigate or delete the harvesting functions entered earlier.

Design Harvesting Variables

Harvesting variables can be entered or designed in the design module (Figure 4c). The same procedures for designing harvesting functions need to be followed to design the harvesting variables.

Collect Site Information

By clicking the "Collect|Site Info" menu, a dialog window will pop out for collecting site information (Figure 4d). To record information for a new site, click "New" on the form. Enter the data fields on the form. Notice that there are three required fields - site name, site slope, and study date. Then click "Add" and the new site information will be added to the database. The site number will automatically be increased and recorded when you add a new site. The "Site No." will be retrieved later when you start to collect time study data and will be saved together with these data.

Collect Elemental Times and Variable Data

Collecting elemental times and variable data is the ultimate objective of time studies. A dialog window will pop up for collecting harvesting elemental times and variables by clicking the "Collect|Harvesting" menu (Figure 4e). All the useful information entered under the design module can be retrieved and employed here.

Elemental times and variables are saved in a database table whose data structure is created based on the parameters entered in the design section. To create such a table, click the "Create Table" button located on the bottom of the form. If the table does not exist, a new one will be created. Otherwise, the system will inform the user that either the table exists or the table's data structure is not consistent with the current data, and suggest that the user create a new one.

In order to associate the site information with the time study data, a site number in the "Site No." combo box must be selected. To record elemental time for a function, select the function from the "Function" list box by simply clicking this function. Hit "Start" when this function starts and hit the "Record Time" button once the function ends. Repeat the above procedures for any other functions in the list. To record a value for a variable, select the variable in the "Variable" list box using the same procedures used for selecting a function. Then, the user can simply type a value in the text box beside the "Record Value" button, then click this button. The value for the selected variable is recorded. Repeat the procedures for other harvesting variables.

Another option is provided to enter the variable's value. If the handheld does not have a keyboard or the user does not like to use the keyboard on the handheld, she/he can use the "Species" combo box to select a species by clicking the species required if the variable is tree species. If the variable is numeric, the user can click "Get Number" button, a data input form will pop out. They can easily click number buttons and the "Enter" button to get the required number.

Once the recording is done for the current work cycle, click "Next Cycle" button. That will also save the current work cycle data to the database whether or not the user precedes to the next work cycle. The unit of elemental time is recorded in seconds that is converted to minutes when the user exports the data for analysis. Units for harvesting variables can be defined by the user.

DISCUSSIONS

Many improvements have been made since time study was first introduced. From stopwatches to video cameras and now to handheld computers, changes have been and continue to be made for the better. The Windows CE-based handheld time study system developed in this study provides a user-friendly interface and more flexible functionalities to collect time study data of forest operations. The system can design the species, harvesting functions, and variables in either the office or in the woods. Touch screen or numeric data entry on handheld computers also provide an efficient means of data collection. With the integration of the data transfer interface, this system can improve time study work greatly and make the task easier, more efficient, and more accurate.

Although the system is intentionally designed for elemental time studies, it can be used for gross and work sampling time studies. Furthermore, it can also be used for all types of logging machines.

A statistical analysis module should be added to the system. This will provide statistics such as sample size of time studies.

HP Jornada 680 is the development prototype of this time study system. However, this system is compatible and can be run on any handheld computers such as Juniper Allegro, Palm and Pocket PCs with Windows CE operating systems.

The system was successfully used in a pretest time study and provided accurate and satisfactory data. Extensive applications of this system will be conducted in a research project at West Virginia University.

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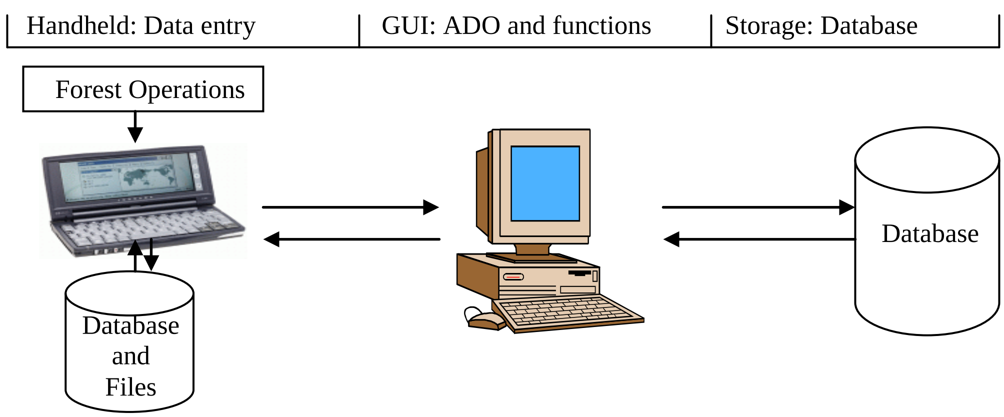

Figure 1. Architecture of the time study system.

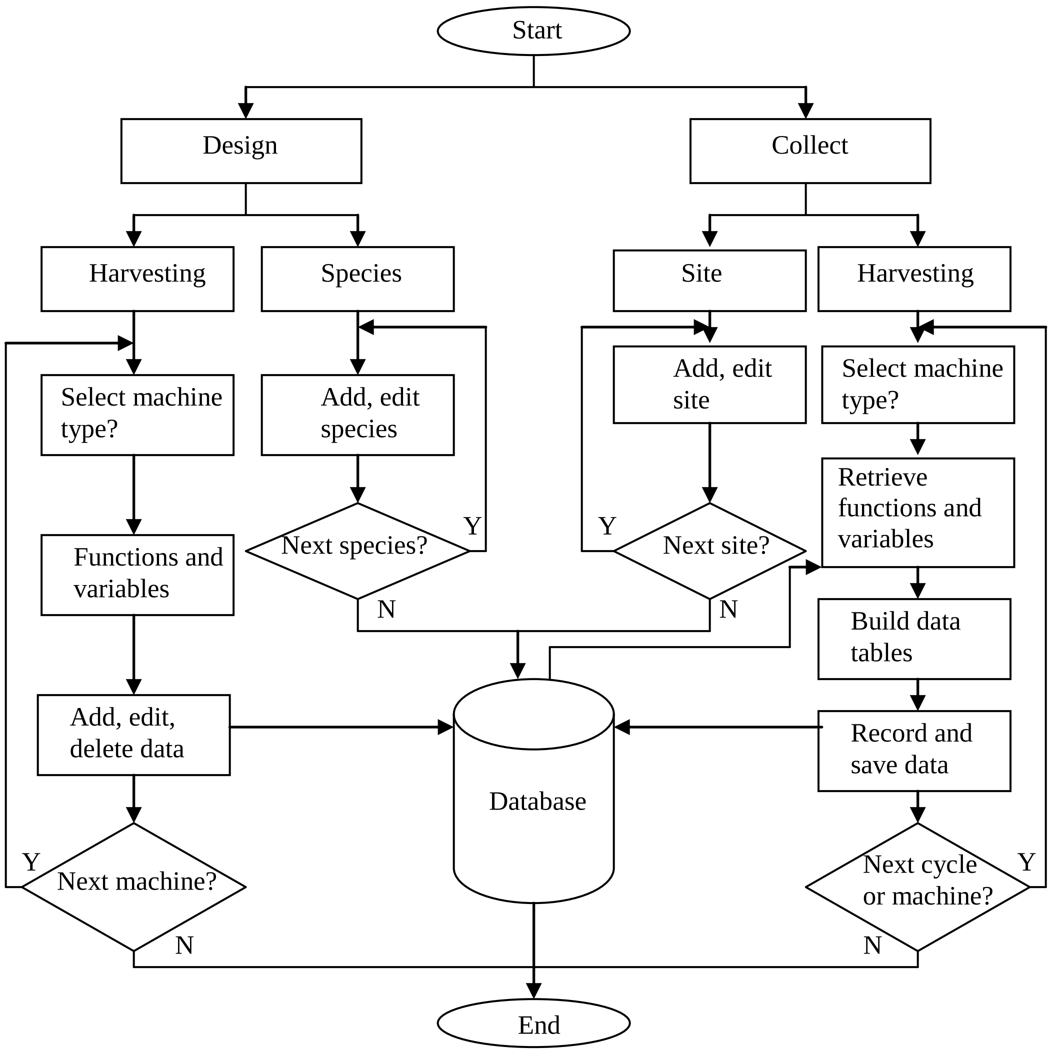

Figure 2. Flowchart of handheld-based time study system.

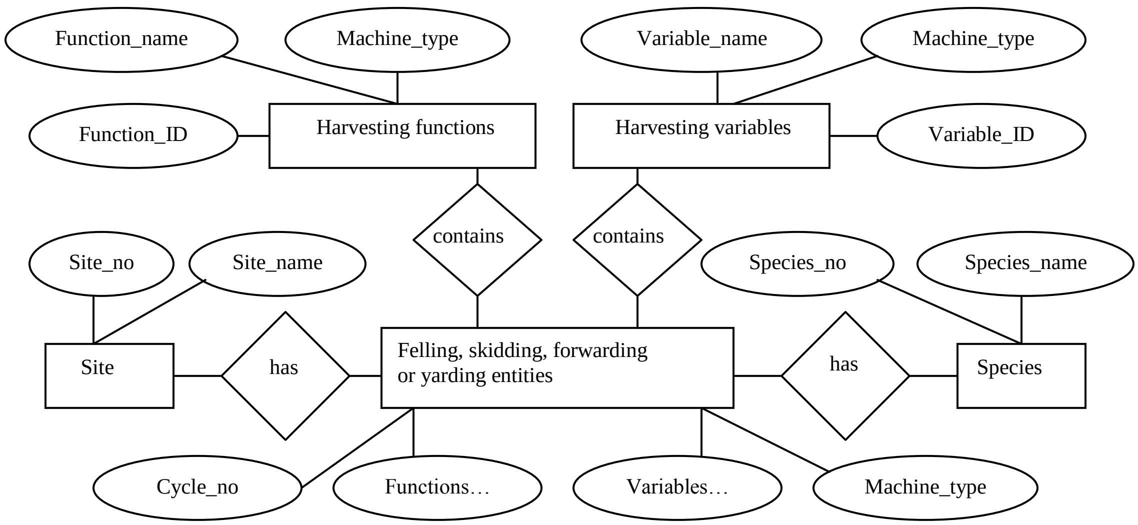

Figure 3. ER data model of the time study system.

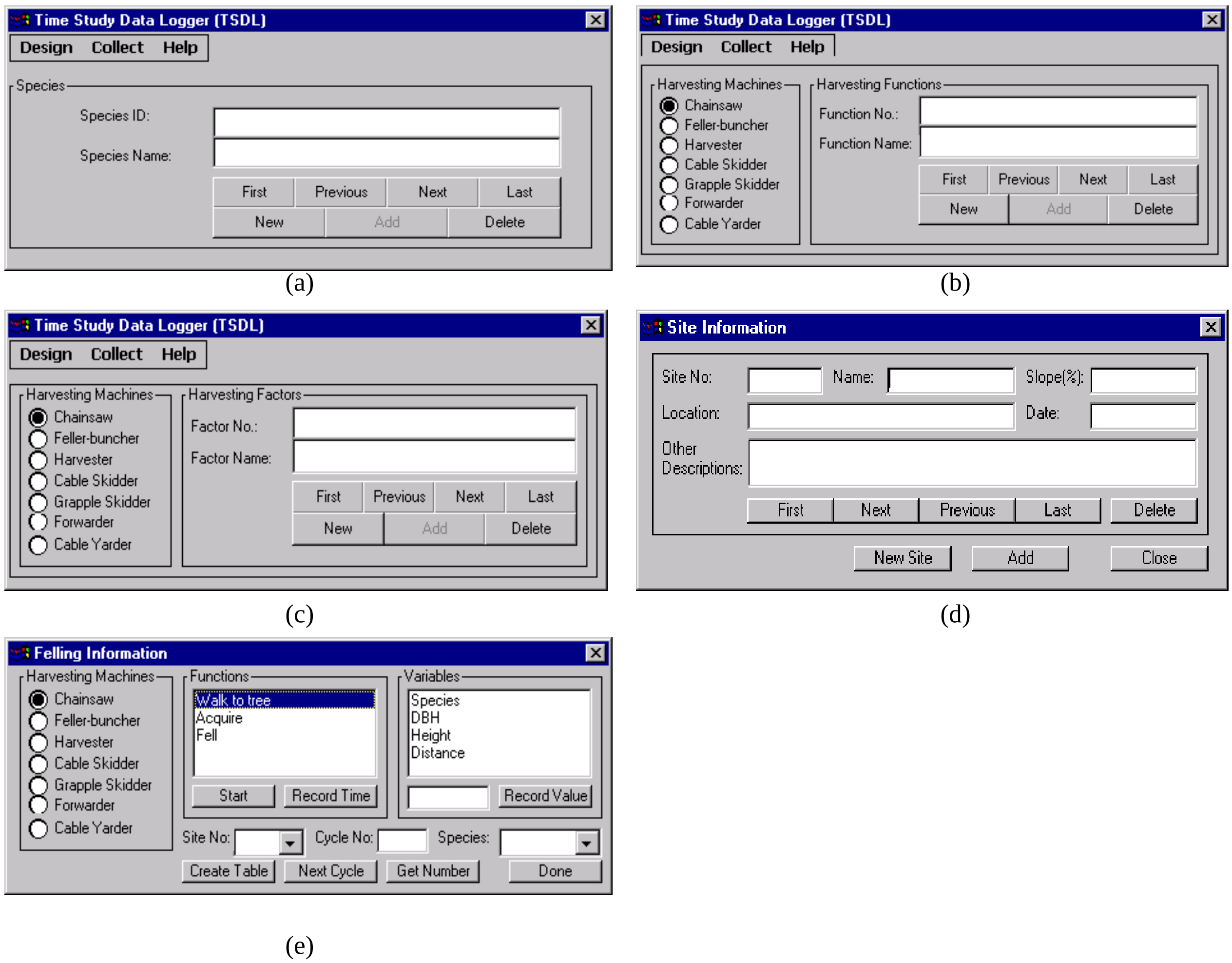

Figure 4. Main forms in the handheld-based time study system.

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