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A TIME TRIAL OF A REMOTE CONTROLLED WINCH MOUNTED ON A CABLE SKIDDER- A CASE STUDY

Robin Avery, Charles Crockett and Charles Simpson

Background:

In the spring of 2001, the University Forests Office at the University of Maine was contacted by Helmut Meier, principal of HMRadio. Mr. Meier offered to install a remote control for the winch on the University's 1984 Timberjack Model 208E cable skidder. In return, Mr. Meier asked the University Forests Office staff to use the device in conjunction with its annual harvesting operations, and make comments and evaluations as to the device's performance. The control was installed in the summer of 2001, and University Forests staff performed a time trial in February of 2002.

Objective of the Time Trial:

The University Forests Office staff chose to look at some very specific activities associated with skidding tree-length wood that might likely be affected by using a remote controlled winch, versus the normal winch control on the machine. Four specific things were looked at:

- The time required to hook up a "hitch" of wood using the remote control versus the regular control
- The time required to unhook a "hitch" at the roadside landing area using the remote control versus the regular control
- The number of times the operator got on and off the skidder while hooking using the remote control versus the regular control
- The number of times the operator got on and off the skidder while unhooking at the roadside landing area using the remote control versus the regular control.

Along with these observations, the total round trip time per hitch was measured, as well as the number of trees taken per hitch. This information was used to evaluate the effect on production of using the remote control versus the regular control on the skidding process of the harvesting operation.

Study Layout:

Trees were felled and limbed in advance of the time trial. Time was measured from when the operator left the skidder to hook up until he got back on the skidder to head to the landing. Time was measured from when the operator left the machine at the landing to unhook until he had unhooked, bucked and sorted the load and got back onto the skidder. Total round trip time was also measured, along with the number of times the operator got on and off the machine while both hooking up and unhooking the hitch. The number of stems skidded per trip was also measured to determine production figures. A total of fifteen (15) trips using the regular winch control were measured, and fourteen (14) trips using the remote control.

The Skidder:

The skidder used was a 1984 Timberjack Model 208 E equipped with sixty-five feet (65') of 5/8" mainline cable and eight, seven-foot long cable chokers.

The Pre-harvest Stand:

The stand harvested was a six-acre spruce plantation planted in 1936. Pre-harvest volume was 3,838 cubic-feet/acre with a basal area of 144 square-feet/acre. Stand composition was 75% white and Norway spruce and 25% white pine. There were 153 trees per acre.

Harvest Removals:

Fifty-six square feet per acre was removed in the harvest. That amounted to 1,814 cubic-feet/acre or 20.15 cords/acre. Only spruce was harvested, with a total of 60 trees per acre removed.

Results of the Study:

Using the remote control on the winch in this study reduced hook-up time by 38.3%, and unhook time by 25.6%. The average time per round trip was reduced by 22.6%. In addition, the operator got on and off the machine 51.6% and 56.7% during hook-up and unhook respectively.

The average total trip time using the regular control was 30.32 minutes. Using the remote control reduced the average total trip time by 6.84 minutes. Assuming the operator could make 12 trips/day using the regular control, he could make 15 trips/day using the remote control. With the average volume of wood per trip at 2.18 cords, the remote control could increase daily production by 6.54 cords.

Economic Impacts of the Remote Control:

The initial cost to purchase and install the remote control is estimated at $2,500-$4,000 depending on the type of skidder. The potential increased production indicated from this study is 32.7 cords per week. At a nominal rate of $15.00/cord, revenue would increase by $490.50/week. At that rate, payback for this system would be between 6-9 weeks.

Other Factors That Could Affect Results:

Numerous other factors could affect the results of using a remote controlled winch versus a winch with regular controls. These include, but aren't limited to:

- Length of mainline cable
- Number of chokers
- Terrain or adverse walking conditions
- Prefelling versus fell as you skid
- Number of product sorts
- Size of trees
- Size of skidder
- Skidding distance
- Others??

Conclusions:

This case study indicated favorable results using the remote controlled winch versus the winch with regular controls. It should be noted that only a limited number of trips were measured and no statistical evaluation was made of the results. There is a need for further study of this system, including measuring a variety of other factors which could affect productivity. And finally, the safety aspects of such a system need to be evaluated. There is some question as to whether this winch control system is legal under current safety regulations in the U.S.

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Thank you.

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FOREST FUEL REDUCTION: CURRENT METHODS AND FUTURE POSSIBILITIES

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ABSTRACT — Due to recent catastrophic wildfires, forest fuel reduction has become one of the most discussed topics in forest engineering research. Considerable money and resources are being spent in an attempt to seek answers for tough questions. Lack of information, especially concerning mechanical fuel reduction methods, has stemmed several studies. This paper compiles the available methods – mechanical and non-mechanical approaches to reduce forest fuel levels. One major area lacking information concerned with mechanical fuel reduction is the few available cost and productivity estimates associated with harvesting small stems. Small stems, the target of fuel harvesting, prove economically difficult to extract from the forest due to their low value and high cost associated with their removal. Results from a recent study in Alabama examining a cut-to-length (CTL) operation combined with a small in-woods chipper showed that the low impact system can effectively reduce fuel loads and keep operations small and efficient. Also, the small in-woods chipper was able to process resultant biomass from the operation into a merchantable product (energy chips). In areas where markets are available, the energywood can be used as an alternative energy source. These results are not only applicable in Alabama, but also have implications in the Pacific Northwest (PNW), where forest fire hazards are greater. Through a review and compilation of recent studies on CTL and cable yarding alternatives in the PNW, these implications are explored for a range of factors.

INTRODUCTION

Recent wildfires in the Western United States have caused the forest management community to take a closer look at active management practices on National Forests and private lands alike. Wildfire is a natural occurrence in any forested ecosystem, but fires of a catastrophic nature can cause severe damage to property and the timber asset (Hollenstein et al. 2001). Due to political, social, and environmental concerns, sustainable management practices capable of preventing severe fires have typically been avoided. This negligence brings us to the current situation characterized by severely overstocked stands in poor health conditions making forests susceptible to stand replacement wildfires. Small trees tightly spaced in the understory of mature forests create a fire ladder increasing the risk of a possible stand destroying fire. This stagnation lowers stand vigor and not only produces a fire hazard but also makes trees susceptible to insect attack. There is ample opportunity and much interest in employing pre-commercial thinnings to these stands that could alleviate the overstocking problem along with wildfire hazard. With the given situation, foresters and the research community must actively seek appropriate methods to sustainably reduce the forest fuel loading problem.

FUEL REDUCTION METHODS AND TRIALS

Prescribed fire has been used in the past as an attempt to reduce understory vegetation and the amount of small trees and litter present on the forest floor fueling wildfires. This valuable management tool has received much criticism due to smoke management liability issues and the possibility for fire escape into severely overstocked stands which can become uncontrollable and cross property boundaries.

Manual removal of understory vegetation is another method of fuels reduction. The method has been ineffective due to the intensive labor requirements and the small area that can be treated in a given time. Also, without the protection of a machine cab, workers are directly exposed to the hazards associated with timber harvesting; therefore, safety is a major concern in manual reduction treatments. Although, manual operations have downfalls, they benefit from low capital cost which allows greater flexibility that could be beneficial for small landowners or treatment of sensitive and/or urban areas. A recent investigation by Rummer and Klepac (2002) studied the performance and cost of a manual reduction operation using a forwarder for primary transport compared to a small-scale harvester/forwarder combination in Wyoming. They report costs of $26.93 per ton for the manual operation and $40.94 per ton for the small-scale mechanized system. These results indicate that manual reduction is substantially less expensive than mechanized operations. Although, their cost estimate for the manual treatment includes a used, fully depreciated forwarder. They found that by employing a new forwarder, costs would increase by 37 percent to $37 per ton, which is comparable to that of the mechanized system.

A more common and typically productive approach includes mechanical forest fuel reduction through thinning of overstocked stands. Hollenstein et al. (2001) reported that mechanical harvesting contrasts from prescribed burning due to the fact that the removal is immediately effective, and does not result in air pollution or smoke management issues. They also state that reducing fuel loads by thinning should slow or prevent the possibility of catastrophic wildfires and also produce large amounts of non-merchantable material. Mechanical thinning incurs problems due to the fact that harvesting small stems is expensive and the resulting wood product has low value, producing high harvesting costs per unit or area (Watson et al. 1986, Bolding 2002). Few cost and productivity estimates have been assigned to mechanical fuel reduction systems (Bolding and Lanford 2001). This fact spurs researchers to find suitable systems that can be adapted to various terrain, vegetation, and species types. Productivity and harvest cost comparison of five mechanized fuel reduction treatments are summarized in Table 1.

Brown and Kellogg (1996) combined a harvester and a small skyline system in a fuel reduction treatment in eastern Oregon. They found system productivity to be 7 tons per scheduled machine hour (SMH). Total cut and haul costs were estimated to be $42.44 per ton. A similar study by Drews et al. (2001) compared the productivity and cost of a harvester/forwarder system and a harvester/yarder operation also in eastern Oregon. Their study found cut and haul costs for the harvester/forwarder system to be $45.73 per ton and $79.93 per ton for the harvester/yarder system. Bolding (2002) also investigated a CTL fuel reduction system in western Alabama. In contrast to other investigations, this study estimated the cost and productivity of a forwarder transporting non-merchantable material to a small chipper for processing into energy chips.

System productivity was estimated to be 5.82 tons per SMH and cut and haul costs were $37.06 per ton.

TABLE 1. — Comparison of five mechanized fuel reduction treatments.

System	Reference	Treatment Location	Productivity (tons/SMH)	Cut-n-haul cost ($/ton)
Harvester/small yarder	Brown and Kellogg (1996)	OR	7.00	42.44
Harvester/small yarder	Drews et al. (2001)	OR	5.40	79.93
Small-scale harvester/forwarder	Rummer and Klepac (2002)	WY	2.88	40.94
Harvester/forwarder	Drews et al. (2001)	OR	8.10	45.73
Harvester/forwarder/chipper	Bolding (2002)	AL	5.82	37.06
Average			5.84	49.22

BIOMASS REMOVAL AND UTILIZATION

Most fuel reduction operations will be conducted in thinnings instead of clear-cut harvests. In thinnings, merchantable stems can be processed into products and the resulting logging slash (limbs, tops, and foliage) could be removed from the site at the same time to further reduce fuel loads. Although removal of slash will decrease the woody material present on the forest floor and possibly decrease fire hazards, there is also a nutrient loss that must be evaluated. For mechanical systems to become effective in reducing fuel loads, attention must also be given to the possible soil and site productivity implications associated with removing understory vegetation.

Barber and Van Lear (1984) examined the rate of weight loss and nutrient dynamics in decomposing woody loblolly pine logging slash in South Carolina. They state that logging slash contains relatively high nutrient concentrations essential for tree growth and if slash is removed, it will not be allowed to recycle naturally and will potentially have an effect on long term site productivity. They found that 76 percent of K, 56 percent of Mg, and 47 percent of Ca is released from loblolly pine logging slash during the first 5 to 6 years after harvesting. This indicates that the nutrient gains from logging slash will be most important after the regeneration period. Several studies address nutrient removals from whole tree harvests but little information is available concerning nutrient removals from fuel reduction treatments. Therefore, it is unclear if nutrient removals from fuel reduction harvesting adversely affects site productivity.

Samuels and Betancourt (1982) developed a computer simulation (FORMAN I) that modeled long-term fuel harvesting and its impacts on woodlands. Their model suggests that long-term population growth has an effect on woodlands. This reiterates the fact that as human population increases there will be a need for alternative sources of energy. Forest managers must take this fact into account when deriving long-term management objectives for our current forests, private and public. Stokes (1992) reported that most use of forest biomass for energy is by the forest industry. He also found that industry is more interested in utilizing residues taken to mills with conventional products instead of the recovery of forest residues.

There is no doubt that an opportunity exists to supplement our energy resource by sustainably managing forests for renewable energy production. If this scenario becomes reality, in the future, we will also have to be sensitive to the possible environmental and soil impacts associated with fuel reduction harvesting for alternative energy. Most current fuel reduction strategies focus on alleviating the fire hazard and not for intensively farming forests solely for biomass energy production. In contrast, fuel reduction strategies should be operations that regain control of stands in poor health. A typical fuel reduction harvest removes an overstocked understory and thins merchantable trees to a target density. This type of harvesting removes entire trees less than some merchantable size class and the residual slash (limbs, tops, and foliage) from felled merchantable trees. Such silvicultural practices would be able to restore the health of many of our forests. Nutrient removals do not appear to be significant enough to offset the benefits gained through the reduction of hazardous fuels; however, little literature is available addressing such concerns. Therefore, there is definitely an opportunity to further explore how a stand reacts to a fuel reduction thinning. With a predicted human population increase, we must find sustainable ways to harvest understory hazardous fuels for energy production to supplement our growing energy requirements.

Adegbidi et al. (2001) reported that the production of woody biomass for energy is being developed in industrialized countries as well as the United States. Yoshioka et al. (2002) reported that woody biomass as an energy resource has recently attracted much attention in Japan. They expect the energy utilization of woody biomass to contribute to revitalizing the forests products industry, which has been depressed for some time. There is much opportunity for this type of revitalization to occur in the United States. Much of the problem facing the United States is the fact that few bioenergy processing facilities exist. The utilization of the energy potential contained in woody biomass will be slow to gain wider acceptance without such facilities in place. Many countries are currently employing such operations for supplemental energy. Research is needed to assess a sustainable approach to the management of our forests in a fashion that reduces fuel loads and produces alternate energy.

CONCLUSION

Based on the results of this brief examination there appears to be a growing opportunity and need for research in the area of fuels management. Future research should address concerns such as:

1. The cost and productivity of purpose built small-scale harvesting equipment for extracting non-merchantable stems over a range of stand and terrain conditions,
2. Alternative products produced from non-merchantable material, such as energy chips or other engineered products,
3. The expansion of suitable bioenergy processing facilities,
4. The amount of merchantable material that must be removed to offset the costs of a fuel reduction treatment,
5. New harvesting and extracting technologies (i.e. purpose built harvesting heads, and composite residue logs from slash baling techniques),
6. Site productivity and soil impacts during and following a fuel reduction harvest, and

7. Decision support models for landowners and contractors, public and private, to aid in choosing an appropriate fuel reduction treatment and harvesting system along with costs and productivity.

LITERATURE CITED

Adegbidi, H.G., T.A. Volk, E.H. White, L.P. Abrahamson, R.D. Briggs, and D.H. Bickelhaupt. 2001. Biomass and nutrient removal by willow clones in experimental bioenergy plantations in New York State. *Biomass and Bioenergy* 20:399-411.

Barber, B.L., and D.H. VanLear. 1984. Weight loss and nutrient dynamics in decomposing woody loblolly pine logging slash. *Soil Science Society of America Journal* 48:906-910.

Bolding, M.C. 2002. Forest fuel reduction and energywood production using a CTL / small chipper harvesting system. Master of Science Thesis. Auburn University, AL. 111 pgs.

Bolding, M.C., and B.L. Lanford. 2001. Forest fuel reduction through energywood production using a small chipper / CTL harvesting system. In: Proc. 24th Annual Council on Forest Engineering Meeting; Snowshoe, WV.

Brown, C.G., and L.D. Kellogg. 1996. Harvesting economics and wood fiber utilization in a fuels reduction project: a case study in eastern Oregon. *Forest Products Journal* 46(9):45-52.

Drews, E.S., B.R. Hartsough, J.A. Doyal, and L.D. Kellogg. 2001. Harvester-forwarder and harvester-yarder systems for fuel reduction treatments. *Journal of Forest Engineering* 12(1):81-91.

Hollenstein, K., R.L. Graham, and W.D. Shepperd. 2001. Simulating the effects of fuel reduction and presettlement restoration treatments. *Journal of Forestry* 99(10):12-19.

Rummer, R., and J. Klepac. 2002. Mechanized or hand operations: which is less expensive for small timber? In: Proc. Small Diameter Timber: Resource Management, Manufacturing, and Markets. Washington State University Cooperative Extension; Spokane, WA. pgs. 183-189.

Samuels, M.L., and J.L. Betancourt. 1982. Modeling the long-term effects of fuelwood harvests on Pinyon-Juniper woodlands. *Environmental Management* 6(6):505-515.

Stokes, B.J. 1992. Harvesting small trees and forest residues. *Biomass and Bioenergy* 2(1-6):131-147.

Watson, W.F., B.J. Stokes, and I.W. Savelle. 1986. Comparisons of two methods of harvesting biomass for energy. *Forest Products Journal* 36(4):63-68.

Yoshioka, T., K. Aruga, H. Sakai, and H. Kobayashi. 2002. Cost, energy, and carbon dioxide (CO_2) effectiveness of a harvesting and transporting system for residual forest biomass. *Journal of Forest Research* 7:157-163.

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HARVESTING CONTRACTORS IN NORTHERN QUEBEC: A FINANCIAL AND TECHNICAL PERFORMANCE EVALUATION

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Introduction

Quebec contractors who sub-contract timber harvesting for the forest industry are experiencing organizational and financial difficulties (Petit 2002). On one hand, pressures are strong from forestry companies to deliver wood at the lowest cost. On the other hand, provincial forestry regulations force contractors to use new harvesting methods, which are considered more costly. To maintain their profitability, contractors must have tools that allow them to perfect their managerial strategy and better define their production costs. This performance analysis was undertaken by the Faculty of Forestry at Laval University, in a study carried out in partnership with several contractors.

Materials and Methods

Twenty-eight contractors in all, 16 using full-tree processing and 12 using shortwood harvesting (CTL), voluntarily shared their organizational, financial (balance sheets, nominal accounts) and harvesting data. The assembled information covered the period from 1997–2001 and most of the sub-contractors were working in the Saguenay-Lake St. John region.

Financial data were distributed as follows: expenses related to machine payments, salaries, parts replacement and equipment repairs, fuel and lubricant costs, and those for insurance, taxes, licences and permits. This grouping helped to take into account 90%, on average, of the total expenses incurred by contractors during their fiscal year. Based on previous studies (LeBel 1996), two facets were chosen for analysis: the profitability of contractors, on one hand, and an evaluation of their technical efficiency on the other. Economic models of production costs were determined for the two harvesting methods, and their variability vis-à-vis certain factors was tested. The measure of technical efficiency (Farrell 1957; Coelli et al. 1999) permitted the comparison of the capacity of contractors to harvest a maximum volume of wood while using a minimum of resources. This type of measure was used to complement the classical methods of evaluating performance, such as profitability.

Following the analyses for profitability and efficiency, indicators were chosen to build a management tool called an "instrument panel" (Voyer 2002). The panel provides the contractors with a tool to monitor their operations, and should provide them with pertinent information on their "resources/production" ratio.

Analysis of Profitability

Firstly, the analysis of profitability broke down the main elements of the annual expenses. Full-tree contractors had annual expenses of almost $1.51 million[1] for 122,600 m^3 harvested. Thirty percent of the expenses are for salaries[2], 25% to purchase parts and to repair equipment, 23% for

[1] The monetary unit used in this text is the Canadian dollar. Contractors deliver "road-side".

[2] Twelve employees on average.

monthly equipment payments[3], 12% for fuel and lubricant expenses, and lastly, 4% to pay for insurance, taxes, licences and permits. CTL operators have expenses averaging $761,000 for an average harvest of 51,000 m^3. Wages and machine payments account for the largest budget items, each accounting for 30% of expenses. Next, equipment parts and repairs account for 18% of expenses. Lastly, fuel/lubricant costs and insurance/taxes/licences/permits account respectively for 9% and 4%.

A cost model was developed for each type of operation to observe how expenses evolved in relation to the annual volume harvested (Fig. 1). For full-tree, the graph indicates that the cost of production of 1 m^3 of wood is at its minimum ($10.53/$m^3$) when a contractor can harvest almost 150,000 m^3 annually. This occurs very rarely, since contractors annually harvest 123,000 m^3 on average. The total profit maximization point is reached at 175,000 m^3. Over 50% of contractors operate at an annual volume of between 80,000 and 120,000 m^3, which corresponds to the part of the curve where any variation in volume will have a major effect on production costs. In other words, many contractors are in a precarious situation which, from one day to the next, could result in a loss. The precarious nature of production costs is due to the volatility of variable costs (wages, machine repairs and cost of parts). This leads one to believe that contractors should have indicators such as "wages/production" and "consumables[4]/production" to be able to rapidly identify problems and find a solution.

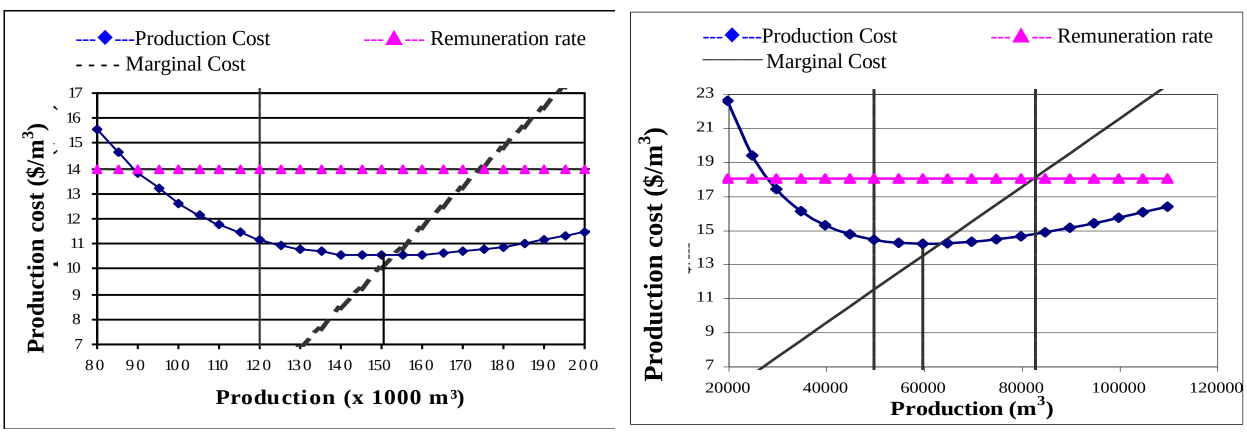

Figure 1. Cost model for full-tree (left) and for CTL operations (right).

The model of the production cost in relation to volume harvested for CTL operations indicates the same trends as for full-tree contractors. Over half the CTL contractors harvest less than 52,000 m^3, a situation that makes them vulnerable to the variations in their production level.

The minimum production cost ($14.16/$m^3$) is reached at a harvest level of 60,000 m^3. This level of production is easily attained when bucking instructions are kept to their simplest. Variations in the cost of production are small, even negligible when between 50,000 and 75,000 m^3 are

3 Five machines on average: one feller-buncher, two forwarders, and two delimbers.

4 Fuel + machine parts + repairs + lubricant.

harvested annually. In contrast, at less than 50,000 m^3 (half the contractors interviewed), a variation in production could have significant impacts. For example, a contractor who usually produces 60,000 m^3 per year, could have a bad year if he only cuts 50,000 m^3. This reduction in production will result in pushing his production costs from \$14.16/m^3 to \$14.40/m^3. This kind of increase is not negligible, but likely not fatal for a company that has accumulated a financial cushion. However, if the same situation is encountered by a contractor who usually produces 40,000 m^3, his production costs will go from \$15.26/m^3 to \$17.36/m^3. Once again, the sensitivity of the production cost is due to the volatile variable costs, which are imperative to monitor regularly and precisely.

The conclusion reached through these financial analyses is clear: the majority of contractors met during the study are in a position that is perhaps not critical, but is certainly uncomfortable. The risk of a financial loss is never far away. What can be done to make the situation less volatile? A careful analysis of the two graphs shown above reveals a primary solution: increase the volumes harvested to approach the minimum unitary cost of production, or better, harvest at levels that permit the maximization of profits. However, this seems very difficult and risky. How can more volume be harvested while using the same resources, knowing that the length of the season will not likely increase? Moreover, if these production levels were attained, what would happen if the needs of the forestry companies abruptly fell? In the short term, perhaps the simplest solution to improve the financial performance of contractors lies in a more accurate and precise management of each of the actions that can lower the source of variations.

Financial Profitability and Stem Unit Volume

Tree size is one important source of variation in most areas. By evaluating the sensitivity of production costs in light of variations in the unit volume of harvested stems, it was possible to show the importance of negotiating the payment rates offered by the company. And to be able to adequately negotiate his rate, it is imperative that the contractor know his exact production costs. Using a remuneration grid obtained from a company and the production costs of contractors representative of the sample, a simulation was carried out for one production season with the following scenario: the contractor changed sectors every four weeks and the unit volume of harvested stems varied. This introduced variation meant that a period of four weeks operating in a sector where the unit volume per stem is 10% less than average (determined by the company's remuneration grid at 0.13 m^3/stem) was compensated for by a period of four weeks operating in a sector where the unit volume is 10% greater than the average volume. Variations of 10, 15, 20, 25 and 30% were evaluated. The purpose of the simulation was to see if a contractor would be able to financially compensate for periods passed in a "bad sector" (low unit volume per stem) by an equivalent period in a "good sector" (high unit volume per stem).

The loss incurred during the first four weeks is not fully compensated for by revenues during the following four weeks. The variation in stem volume only amplifies this tendency. At the end of 40 weeks of simulation, the contractor harvested the same volume as if he had operated in sectors where the unit volume of each stem was equal to the mean volume. However, his financial statement indicated that the contractor has a \$56,000 loss caused by the wrong indexation of the remuneration rate[6]. The contractor, had he accurately estimated his production costs on a weekly basis, could have renegotiated his rate with the prime contractor to offset this financial loss. Similar situations were reported by other contractors. This help to demonstrate that a more accurate monitoring of expenses is essential and necessary.

Measure of Technical Efficiency

In the case of full-tree contractors, technical efficiency leads to the same conclusion as for the financial profitability analysis. Efficient contractors are those who operate with minimum production costs (!). The inefficiencies observed with other contractors especially come from too high parts and equipment repair costs, as well as for wages, and a lack of investment in their equipment. In other words, for the sample studied, it was noted that owning new equipment facilitates efficiency, especially because of less employee down time.

The results for CTL operators are also similar to those for financial profitability. Efficient contractors operate at their minimum production cost. The inefficiencies mainly stem from equipment payments, which signifies that compared to efficient contractors, the inefficient ones do not attain the production levels needed for the amounts they invest in their equipment. The reasons for this "non-optimal" use of equipment are many, and would merit more detailed analysis, but this once again reveals the need for more precise and regular monitoring of harvesting operations. The great advantage of efficiency analysis is that the results can be shared with the procurement managers of forestry companies without revealing the production costs of a particular contractor.

The Management Instrument Panel

The results of this study revealed a critical lack of key performance indicators (KPI). Indicators to monitor operations must be put into place and monitored on a weekly basis so that contractors can regularly make adjustments. According to the study's results (Bonhomme 2003), four indicators must be monitored: the "salaries/production" ratio ($/m^3), the "consumables/production" ratio, the weekly volume harvested and the cost of production. The first two indicators identify the sources of variation in the production cost. A "memory" of the value of these indicators should be established that can be referred to and define profitability levels in relation to operating conditions. These values would be useful in establishing a constructive dialogue with operations directors to identify means to improve the technical and financial performance of the company.

A computerized "instrument panel" is under development to monitor KPIs (Fig. 2). Establishing such a tool requires: firstly, contractors operating in similar conditions who commit to monitoring, on a daily or weekly basis, each of their expenses and their weekly volume; secondly, a person who manages the "instrument panel," which is in the form of a computer application. This person could be an accountant, the operations director of a cooperative, a neutral third party who is competent in the field (university graduate, researcher, etc.) or a contractor if he is ready to take on the slight extra administrative workload. The results could be

[6] It must be noted that simulations with grids from other companies could have showed a better fit between the contractor's cost of production and the rate paid.

compiled each week and allow the contractor to adjust his actions in the field, or even to negotiate his rate of remuneration using arguments that are backed up by hard data.

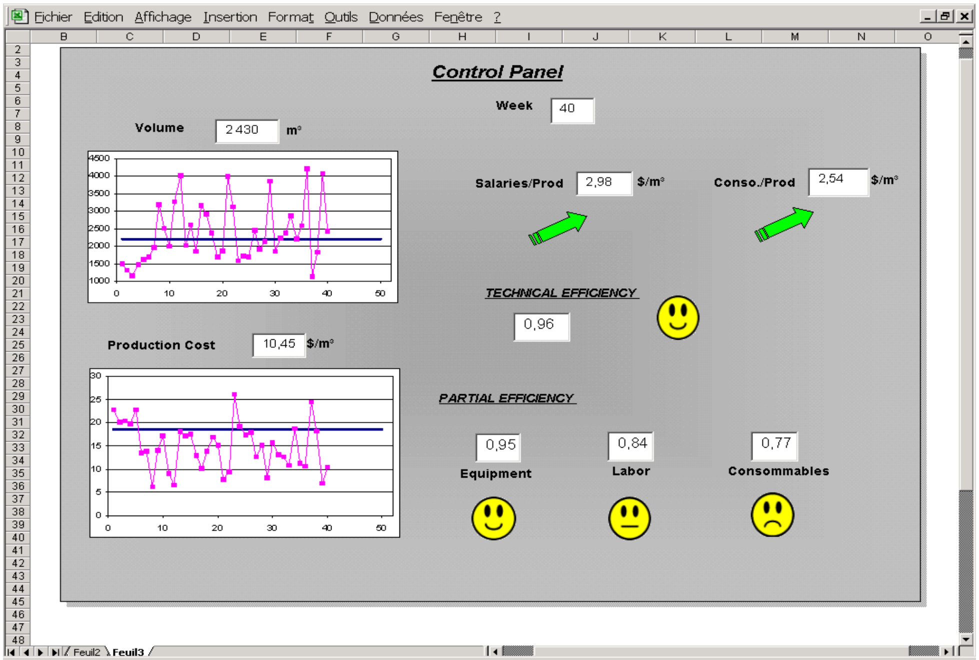

Figure 2. Section of the instrument panel being developed for some Quebec contractors.

In its current form, the instrument panel provides two graphs allowing the contractor to monitor the weekly volume harvested and the production cost, and to compare the values in relation to previously defined reference levels (flat line). Two indicators for the variable costs are represented by green arrows near the top. These arrows indicate that the indicator values are rising but have not yet passed the limiting reference value on the basis of preceding years, or of similar sectors.

Efficiency measures could also greatly help contractors to improve their performance. The four efficiency indicators show that the contractor is close to maximum efficiency but must be careful of his expenditures on consumables. These ratios could be available only in the case when several contractors would cooperate by grouping their financial and production data or if historical data were available. This practice should be tried by those wishing to implement a policy of continuous improvement in their operations.

Conclusion

Many contractors seem to be in a difficult position at this time. Some might improve their performance and overcome the constraints that are imposed on them. Equipment is now more sophisticated and management techniques should be also. Monitoring production and expenses must be at the heart of their operational and organizational strategies. This study revealed that contractors' performance could be improved if they could more quickly diagnose factors to modify in their operations, and effectively communicate this information with their business and financial partners. The management instrument panel is a proposal for tools that could assist them in that direction. Contractors are an indispensable link in the complex supply chain of the forestry industry. Proper communications and healthy partnerships is fundamental to supply chain management. The next step concerning this project is to further develop and test the instrument panel. Also comparisons with contractors from other regions could be attempted.

References

Bonhomme, Brice. 2003. Évaluer la performance des entreprises d'exploitation forestière québécoises par les critères de rentabilité financier et d'efficience technique. Mémoire de maîtrise. Université Laval. Québec, Canada. 130 p.

Coelli T., D.S. Prasada, and G.E. Battese. 1999. An introduction to efficiency and productivity analysis. Kluwer Academic Publishers, USA. 275 pages.

Farell, M.J. 1957. The measurement of productive efficiency. Journal of the Royal Statistical Society 120 (3):253–290.

LeBel, L.G., 1996. Performance and Efficiency Evaluation of Logging Contractors using Data Envelopment Analysis. Virginia Polytechnic and State University, VA, USA. Ph.D. dissertation. 201 p.

Petit, B. 2002. Un coup de barre s'impose pour redresser la situation du propriétaire forestier. Journal de l'Association des Propriétaires de Machinerie Forestière du Québec. Volume 11 / Numéro 2.

Voyer, P. 2002. Tableaux de bord de gestion et indicateurs de performance. Presse de l'Université du Québec. 446 p.

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A DESCRIPTION OF A PRIMARY FOREST PRODUCTS SUPPLY CHAIN MANAGEMENT SYSTEM

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Abstract

This paper describes a five-function supply chain management system for primary forest products. These five-functions, supply management, planning and scheduling, demand management, execution, and reporting, are used to organize the data and processes that will allow the firm to develop strategic, tactical, annual and monthly plans that are used to confirm orders with a weekly scheduling system to designed to fulfill these orders. The execution function will use logistical analysis while the reporting system will monitor the system's performance. Additionally, the reporting function will collect data that can be used to identify opportunities to improve those processes with high variations between planning and execution levels. It is believed that this type of system will allow a forest products firm to improve its competitiveness by increasing both customer service and operational efficiency.

Introduction

Supply chain management is a management philosophy that integrates activities and functions both within and outside of the company to improve customer service and operational efficiency (Pulkki 2001). The supply chain management system includes the physical products, logs and wood chips, and the information that flows throughout the supply chain. Examples of this information are payments to suppliers, invoicing customers and measuring delivery performance.

Jones (1999) described a supply chain management system that incorporates decision making from the strategic to operational levels. These integrated decisions are made for time frames that vary from 50 years to a weekly order fulfillment. Jones (1999) estimates that improved execution of the supply can results in a 15 to 60 percent reduction in inventory and a 20 to 30 percent improvement in delivery performance leading to an overall cost reduction for the supply chain between 20 to 30 percent.

Supply Chain Management System

This paper describes the functions in a generalized primary forest products supply chain management system (figure 1). These five functions are:

1. Supply management – Manages the availability and purchase of raw material.
2. Planning and scheduling – Develops the strategic through operation plans.
3. Demand management – Develops the forecasts through order entry process for all sales.
4. Execution – Executes the plans include the harvesting and transportation
5. Reporting – Collects data regarding the performance of the supply chain and analysis of why results occurred

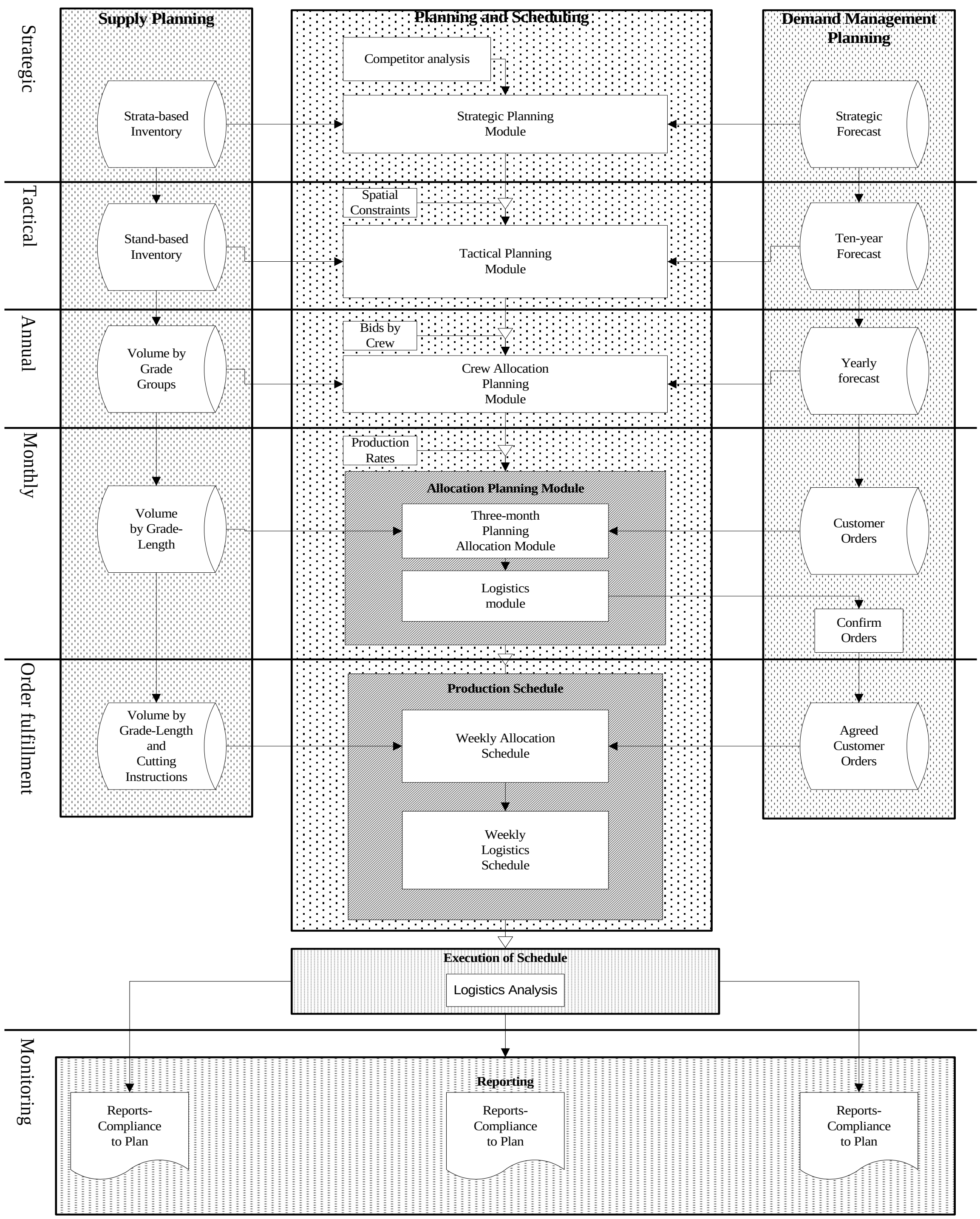

Figure 1: A description of the supply chain management system for primary forest products.

These functions interact to produce the strategic, tactical, annual and monthly planning activities that are implemented by the order fulfillment processes. Finally, monitoring occurs at and between all planning levels to confirm that the goals from the above levels are being implemented or to provide data that can be used to determine the causes for the variation between processes.

The system is designed for a company that purchases from both internal and external suppliers. Log and wood chip sales are to domestic and international customers. Another assumption is a weekly order cycle for domestic orders and a four to six week order cycle for international orders. The final assumption is that crews must complete their current unit before shifting to another unit.

Strategic planning is performed annually for a planning horizon of 2 to 3 rotations. The goal is to develop a long-term strategy that allows the firm to best competes in current and future markets. The firm will evaluate their long-term supply and production capacity required meet the future demands. The results from strategic planning will be:

1. Targets for areas to be treated by various silvicultural methods and logging systems.
2. Desired rotation lengths.
3. New facility development and location.
4. Procure or dispose of properties.
5. Acquire or dispose of long-term cutting agreements.
6. Targets for external procurement volume.

Tactical planning's time frame is approximately one half-rotation length. Similar to strategic planning, it is performed annually. Tactical planning will incorporate the spatial constraints such as the green-up constraints that are common in many local forest practices rules as well as the combined harvest and transportation problem. The objective is to maximize net revenue while implementing the goals produced from the strategy analysis. There is an increased resolution in the supply and production data, as it is now based on harvesting units instead of the coarser strata or croptype data used in strategic analysis. The forecasted sales data is similarly refined with yields in grades classes instead of product classes. The results from tactical planning are:

1. A set of units to be treated by various silvicultural prescriptions and logging system.
2. A set of road projects to be completed for each year.

The monitoring program will report the adherence to the goals established by the strategic plan.

Annual planning assigns crews to harvest units and road projects in a manner to optimized the net revenue with the goal to harvest all units assigned from the tactical forest plan are completed. Cost data is now based on actual bids while forecasted sales and supply data will use an ever-refining data resolution. Supply management will consider additional short-term stumpage sales or log purchases if shortages are forecasted. Likewise, a reduction in harvest capacity or increase in sales will need to occur if inventory exceeds target levels. This annual plan is the basis for annual budgeting process that publicly traded firms are required to complete. It often sets the performance targets for the year for much of the supply chain.

Monthly planning develops operational plans for a 3-month planning horizon. The goal is to confirm orders for the first two months. The third month is primarily used is to identify future opportunities to adjust the supply chain to improve revenue or customer service. It represents a significant change in the supply chain management process as demand changes from forecasted sales to customer orders for specific log grade in specific lengths. There is a need to correspondingly increase the resolution of supply data to allow for allocation of volume from a unit to a customer. As crews are restricted to their current locations until the harvest unit is completed, the flexibility of supply is limited to shifting the order in which the annual units are harvested. Logistic analysis will confirm that there is an adequate transportation capacity to support the customer orders. This will include the routing trucks and the assignment of vessels to loading and discharge ports to insure that draft restrictions at loading ports are not exceeded and that average discharge rates will be above the thresholds to prevent demurrage penalties.

Supply is allocated to customers using both the firm's and customer' policies. The firm may allocate supply to customers based on those with the highest net revenue or using a customer priority system. Additional rules can be established that can restrict order fulfilled such as the three listed below:

1. They will accept only a full order only.
2. They can accept any part of their order.
3. Any amount above a minimum volume but the percentage of their grades must meet their desired targets.

Log yard inventory levels are computed to determine if they are in compliance with the established policies. If the initial amount is above the maximum level, additional sales will be sought through price negotiations, new sales channels established, or crews will be placed on work quotas or eliminated from the production capacity. If inventory levels are below the safety stock levels, the choices are to increase the production through weekend work, procure additional production capacity or increase short-term purchases. Once inventory levels are within the desired range, orders are confirmed and communicated with customers for the desired period of time. Harvesting crews are notified of their next unit as the annual schedule may have been changed to meet the new demands.

The production schedule is the final element in the planning and scheduling function and it is very similar to the master production schedule found in many generic factory scheduling systems. The production schedule assigns crews a cutting schedule, an order for volume by grade and length combination. As orders can change from the forecasted order, the weekly order cycle attempts to accommodate these changes without sacrificing those orders that have already been confirmed from the monthly planning process. Execution will utilize logistics systems to optimize the distribution of the materials from the forest to customers. The goal will be to execute the plan with the maximum efficiency while meeting all confirmed orders.

Reporting will serve two roles. Role one will monitor the execution of the supply chain. It will inform the managers, customers and contractors regarding their performance by addressing the following types of operational questions:

- Are the confirmed orders being fulfilled at their agreed price?
- Was the production of the crews at their predicted levels?
- Did the grade distribution from stand meet anticipated percentages?
- Have log yard inventory remained within the desired range?

The second reporting role is to link the results from one level to another to insure that the objectives defined in strategic planning are carried to the execution level.

- Are the harvest levels by strata or croptype being treated in the tactical and operational plans similar to those recommended in the strategic plan?
- Are the units in the tactical plan used in the annual plan?
- What is the accuracy of the long-term forecasts?
- Are the grade predictions accurate in the supply forecasts?
- What is the accuracy of the forecasted customer order and the weekly order?

Those items with large variances between any of the planning levels and between the master planning schedule and execution level will be targeted for further analysis to determine the causes and what improvements must be made.

Conclusion

This supply chain management system divides the process of planning harvesting operations in a manner that will insure that they are aligned with strategy. It incorporates customer forecasts into the planning process from the strategic through to the operational levels. By constantly aligning the production and supply to demand will result in improved operational efficiency and customer service.

Literature Cited

Jones, I. 1999. Increasing Value Through Supply Chain Planning. New Zealand Journal of Forestry. 44(3):5-8.

Pulkki, R. 2001. Role Of Supply Chain Management In The Wise Use Of Wood Resources. Southern. African Forestry Journal. 191: 89-95.

SAFETY PROGRAM RECOMMENDATIONS FOR WOOD CHIPPING AND MAINTENANCE FACILITIES

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Management Commitment

The success of any safety program is directly linked to the level of enthusiasm that the manager displays to the workers at any chipping or maintenance facility. Without a serious dedication of time and resources to promoting an accident free workplace, any company can expect to battle morale and production shortfalls. It is the goal of the author in this short paper to pass on tips that seem to make a safety program effective.

Employee Involvement

The life of a safety program lies in the involvement of the workers who have the most exposure to potential injury. One of the first questions that a safety consultant or OSHA investigator will ask is for evidence from employees showing how involved they are in establishing and implementing safe work practices. The following is a partial list of the many ways that employees at all levels can cooperate to energize a safety program:

1. Participate and sometimes lead a weekly safety meeting.
2. Take part in an accident or incident investigation.
3. Play a part in a monthly safety audit.
4. Submit safety recommendations and follow-up with implementation.
5. Participate in annual review of safety policies.
6. Report near misses and help determine root causes to prevent accidents.
7. Make sure that visitors, vendors, and contractors follow safe procedures.
8. Provide feedback to those delivering annual safety training.

Job Orientation/Annual Training

No employee should begin a new assignment without the proper orientation to accomplish the task safely. Since the human element contributes to most accidents, never assume that a simple discussion of procedures and safeguards will prevent accidents. Safety trainers must make use of the experience of those receiving the orientation or training. While the consequences of not following safe procedures must be clearly understood, the benefits of maintaining an accident free workplace should always be the first concern. Considering the following list will enhance the quality of training:

1. Plan your session as far from distractions as possible.
2. Give the old training material you used last year a break and mix in the new.
3. Invite expert presenters. Benefit by using Department of Labor resources.
4. Always engage the audience and utilize the knowledge of the trainees.
5. Administer tests of knowledge using non-threatening, enjoyable methods.
6. Agree on frequent breaks and finish ahead of schedule.

Accident or Incident Reporting/Investigation/Tracking

Communicate clear expectations to everyone in the company, how near misses, first aid incidents, and reccordable accidents will be reported, investigated, and tracked. The mark of a mature and effective safety program is the attention given to near misses. When employees understand the benefit they give to their coworkers by reporting a near miss, that company is on the way to preventing most accidents. Incident investigations should:

1. –be completed in a timely manner, preferably before the site has been disturbed.
2. –include the employee involved, witnesses, and the supervisor
3. –where possible, include pictures and/or sketches added to written descriptions.
4. –never embarrass the employee involved. Include names only on medical reports.
5. –determine the root cause underlying the obvious reasons.
6. –involve investigators from outside the immediate work area for objectivity.
7. –produce results that the work team discusses soon after the incident.
8. –be compiled and compared to determine trends for emphasis later.

Safety Incentives

If designed properly, safety incentives can make the work environment safer by increasing each worker's awareness that their safety performance can benefit themselves and their coworkers. Follow these guidelines when designing your incentive program:

1. Gift certificates are more effective than cash awards which can easily be viewed as an entitlement over time, especially if the amount is significant.
2. Incentives linked to team performance work so long as the team truly can have an impact on each other's safe work habits.
3. Reset the incentive on short time periods, such as every quarter, after an accident.
4. Use safety meetings and special gatherings to celebrate safety achievements.

Compliance Checking

There is no substitute for monthly safety auditing to assess the state of safety compliance at your facility. By including a variety of participants over time, you will improve morale, find items that you would miss, and increase each workers commitment to keep the work place safe all the time. Audits should note that checked areas are in compliance along with findings and follow-up should be accomplished quickly and the date accomplished noted on the audit. Don't hesitate to use your state's department of labor as a safety consultant. Some of the following items should be included in your audit:

1. Are established safe work procedures being followed?
2. Is each worker wearing the appropriate personal protective equipment (PPE)?
3. Is the PPE defect free and has defective PPE been disposed of?
4. Is machine guarding adequate and secured in place? Are guard rails intact?
5. Is housekeeping an issue? An organized work area where clean-up follows each activity will benefit all team members.
6. Have electrical dangers been eliminated by the use such devices as GFCI outlets, defect free extension cords, double insulated hand tools, and frequent inspections?
7. Have fire extinguishers been inspected each month and replaced annually?
8. Are exits marked and have functioning emergency lights? Are emergency procedures rehearsed annually and are facility maps showing exits on display?
9. Are mobile equipment safety checks being documented daily? Is an operator's manual stowed in each operator's cab? Is the cab free of clutter? Is the bucket or boom lowered before the operator leaves the cab? Are steps kept clean and repaired? Are backup alarms functioning?
10. Are signs posted for hearing protection, pedestrian safety, and other precautions?

Job Hazard Analysis

The job hazard analysis (JHA) has also been called the job safety analysis, and can be accomplished proactively in any area with identified hazards, or as a way of filling gaps that exist in safe work procedures identified during accident or incident investigations. The three components of the analysis are:

1. the sequence of steps to accomplishing a particular job, usually 10-15 steps
2. identify particular hazards unique to each step of the job
3. write detailed work procedures that eliminate or minimize the risk of injury

The JHAs can become an effective training tool and can be used in safety meetings. Note: Persons most familiar with the task being analyzed should be consulted in writing the first draft of the JHA and be allowed to edit this draft before going to final print with the managers signature.

Industrial Hygiene

For most of our facilities a survey of industrial hygiene is required at least every 3 years. This will involve the measurement of how workers are exposed to noise and dust on an 8-hour time weighted average, and will determine the details of a hearing conservation program, and whether respirator use is mandatory, voluntary, or not required. Our company has required hearing protection for even brief exposure to noise levels above 85 decibels, which exceeds the OSHA requirement, but has proved successful in reducing hearing loss. You'll need to keep an updated sound survey by area and machine on your bulletin board, and post signs in areas of increased noise exposure showing where hearing protection is required. If you are currently requiring the use of respirators including even 2-strap dust masks, but have not implemented fit testing or a medical survey, you'll need to step back and add these features to your respirator program.

You can create an accident free workplace with a proactive attitude about promoting safety and by using a tenacious, non-compromising approach to requiring safe practices.

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A COMPUTERIZED METHOD FOR DETERMINING CABLE LOGGING FEASIBILITY USING A DEM

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ABSTRACT – This paper introduces a computerized method designed to determine cable logging feasibility by analyzing ground profiles using a digital elevation model (DEM). This method involves a series of computer algorithms to extract topographic information from a DEM, analyze payload and ground profiles, find proper intermediate support locations, and consider the full suspension requirement over the riparian management areas. A computer program has been developed to implement this method. Providing the users with interactive functions, the program can be used to identify feasible cable logging areas, find efficient tower locations, estimate load carrying capacity, and find proper intermediate support locations.

INTRODUCTION

Cable logging systems are often used to harvest timber in mountainous areas where road access is limited or additional protection to the ground is required. Cable logging involves expensive equipment and high-risk operations. Well-designed operational plans are crucial for successful applications of cable logging.

Planning cable logging operations is a challenging task. It requires consideration of the physical feasibility of the system, economic efficiency, and environmental concerns. The identification of cable logging feasibility necessitates the consideration of topographic conditions, yarding system capacity, tower and tailspar locations, intermediate support locations, and other environmental requirements such as full suspension requirement over the riparian management areas.

Several computerized methods for ground profile analysis have been introduced to assist forest engineers in planning cable logging operations. LoggerPC (Jarmer and Sessions 1992) is a widely used computer program that analyzes the load carrying capacity of yarding systems over specified terrain profiles that are derived from survey data. Interacting with GIS (Geographic Information System) database, PLANS (Preliminary Logging Analysis System) developed by the USDA Forest Service (Twito *et al*. 1987), extracts topographic information from a DEM and analyze harvest units based on specified landing locations and cable logging systems. However, neither PLANS nor LoggerPC automatically consider full suspension requirements over the riparian management areas or search for intermediate support locations along cable corridors for multiple span skylines. CPLAN (Chung 2002) does have this functionality as a subcomponent of an overall road and landing location optimization problem, but the planner cannot use the corridor analysis as a stand alone module. Recently, a cable logging feasibility stand alone module has been developed as an extension to the work done in CPLAN.

This paper describes the computerized method designed to determine cable logging feasibility by analyzing ground conditions while considering yarding systems, intermediate support locations, load carrying capacity, and full suspension requirements where necessary. GIS produced data such as a DEM and a stream coverage are used in this method to provide the topographic information and the riparian management areas (stream buffers). A computer program developed to implement this method extracts topographic information from a DEM and searches for the feasible cable corridor configuration which satisfies minimum load carrying capacity and the full suspension requirement above the riparian management areas. The method and the computer program are briefly introduced in this paper.

LOGGING FEASIBILITY ANALYSIS

In this method, users specify landing locations and a computer algorithm developed for this analysis projects 36 cable corridors at 10-degree intervals from each landing. The algorithm then evaluates each of the projected cable corridors for its logging feasibility and searches for a feasible cable corridor configuration (Figure 1). Two evaluation criteria are used: 1) the user-defined minimum payload per yarding cycle and 2) the full suspension requirement over the riparian management areas. Each of the cable corridors has to meet both requirements in order to become a physically feasible cable corridor.

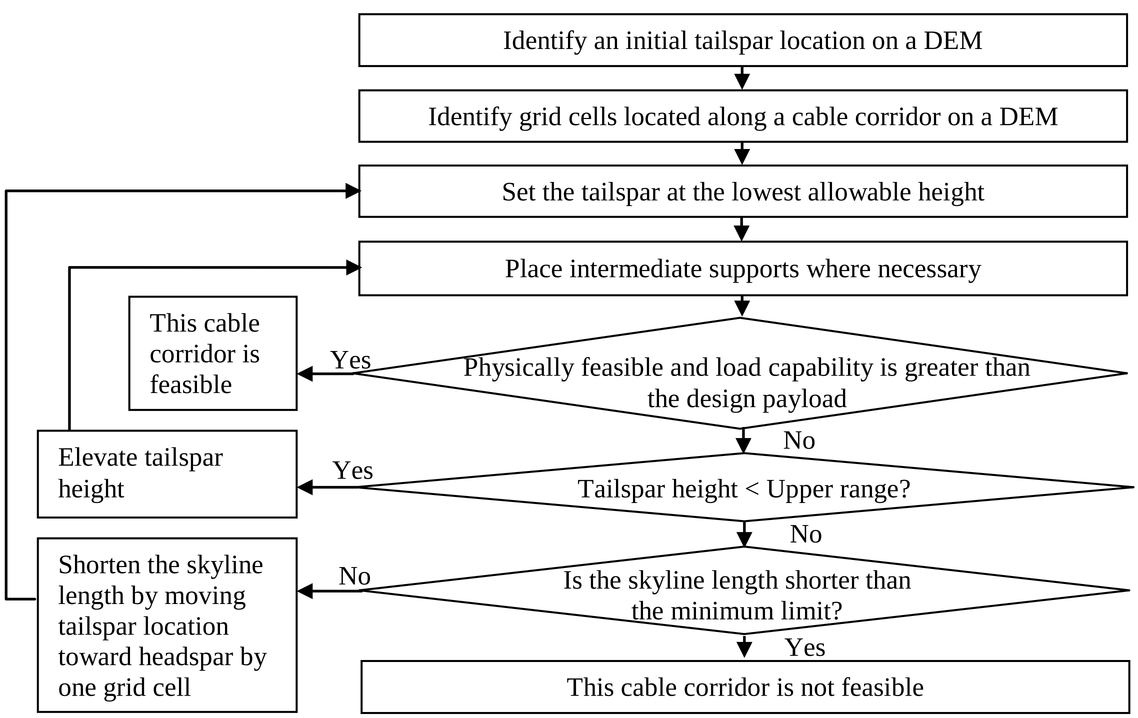

Figure 1. The algorithm to determine the logging feasibility of an individual cable corridor.

The computer algorithm determines the initial tailspar location of each cable corridor on a DEM using the maximum external yarding distance of the specified cable logging system with the assumption that an adequate tailspar is available. The algorithm then identifies the grid cells that are located along each cable corridor on the DEM. Each of these cable corridors is evaluated for its logging feasibility for a specified cable yarding system. Currently the analysis is limited to standing skyline systems. The algorithm applies the Phase I procedure suggested by Brown and Sessions (1996) to identify the maximum log load that can be carried along a given ground profile by a standing skyline system. The algorithm automatically places intermediate supports on convex terrain in order to ensure the minimum clearance of the skyline from the ground. The algorithm also allows the planners to input the available range of tailspar heights and searches for the minimum height satisfying the minimum payload per yarding cycle, which is referred to as the design payload in this paper.

Locating intermediate supports

Intermediate supports are required to ensure the minimum clearance of the skyline on terrain with a convex slope or a long constant slope. An automated algorithm to place intermediate supports developed by Sessions (1992) is implemented in this method with some modifications. The algorithm begins by placing intermediate supports on all terrain with a convex slope, then eliminating unnecessary supports using several design criteria. Since identifying intermediate support locations is mainly associated with consecutive terrain points, which are represented by grid cells on a DEM, the algorithm may place more intermediate supports than necessary. If the users limit the allowable number of intermediate supports along a cable corridor, the algorithm tries to keep the total number under the limit by eliminating the intermediate supports that have the least effect on payload as long as the user-defined design payload is achieved. The steps in the algorithm are presented below:

Step 1. Examine ground slopes between three consecutive terrain points along the profile and place intermediate supports on all terrain points where convex slopes are found (Figure 2a).
Step 2. Examine the slope change of the skyline at each intermediate support and eliminate the support if the slope is not convex (Figure 2b).
Step 3. Evaluate the deflection at each intermediate support assuming the support does not exist. If enough clearance is ensured, then eliminate the support. Otherwise, keep the support at the current terrain point. The allowable percentage deflection of the skyline and minimum skyline clearance above the ground are provided by the users (Figure 2c).
Step 4. Examine the slope change of the skyline at the intermediate support. If the slope exceeds the user-defined maximum slope change of skyline required for carriage passage, then this cable corridor becomes physically infeasible (Figure 2d).
Step 5. If the total number of intermediate supports is greater than the user-defined maximum number, then temporarily eliminate an intermediate support one at a time and calculate the payload. Record the payload, restore the intermediate support, and move to the next intermediate support and repeat this process.
Step 6. By comparing the payloads calculated from Step 5, eliminate the least effective intermediate support.
Step 7. Repeat Steps 5 and 6 until the total number of intermediate supports meets the user-defined allowable number. If the maximum load carrying capacity is not greater than the user-defined design payload, then stop the routine and this cable corridor configuration becomes infeasible.

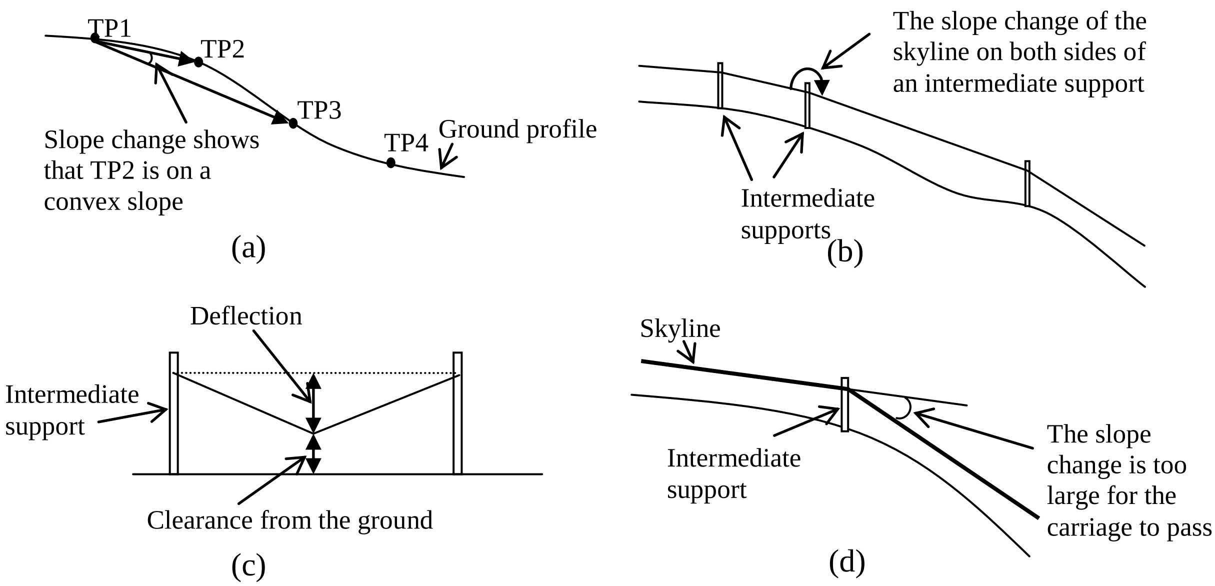

Figure 2. Design criteria on placing intermediate supports.

Full suspension requirement over the riparian management areas

Full suspension is often required over riparian management areas to protect vegetation and minimize disturbance to beds and banks of streams (Figure 3a). The algorithm overlays a stream coverage on a DEM to identify the riparian management areas (Figure 3b) and checks the log clearance when cable corridors cross any of those areas. If a cable corridor cannot produce enough payload per yarding cycle while satisfying the full suspension requirement, the current cable corridor configuration becomes infeasible and the algorithm searches for a new tailspar location along the corridor that satisfies both the design payload and full suspension requirements.

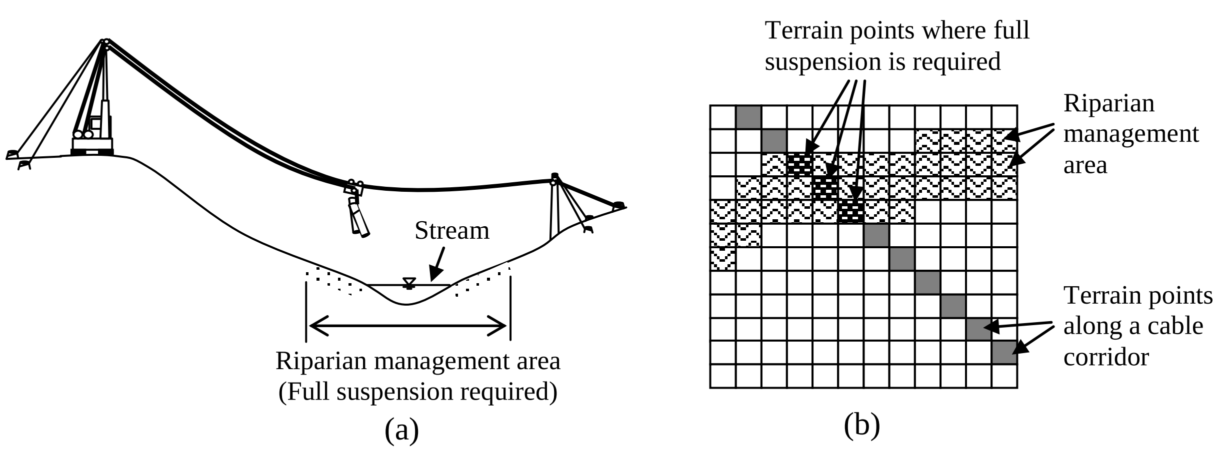

Figure 3. Riparian management areas requiring full suspension.

APPLICATIONS OF THE LOGGING FEASIBILITY ANALYSIS

This method has been implemented in a Windows based computer program, written in Microsoft Visual C++. Providing users with interactive functions, the program can be applied to identify feasible cable logging areas from specified landings (Figure 4a) while considering minimum design payload and full suspension requirement over the riparian management areas (Figure 4b), select efficient tower locations (Figure 4c), and find proper intermediate support locations while providing estimated load carrying capacity (Figure 4d).

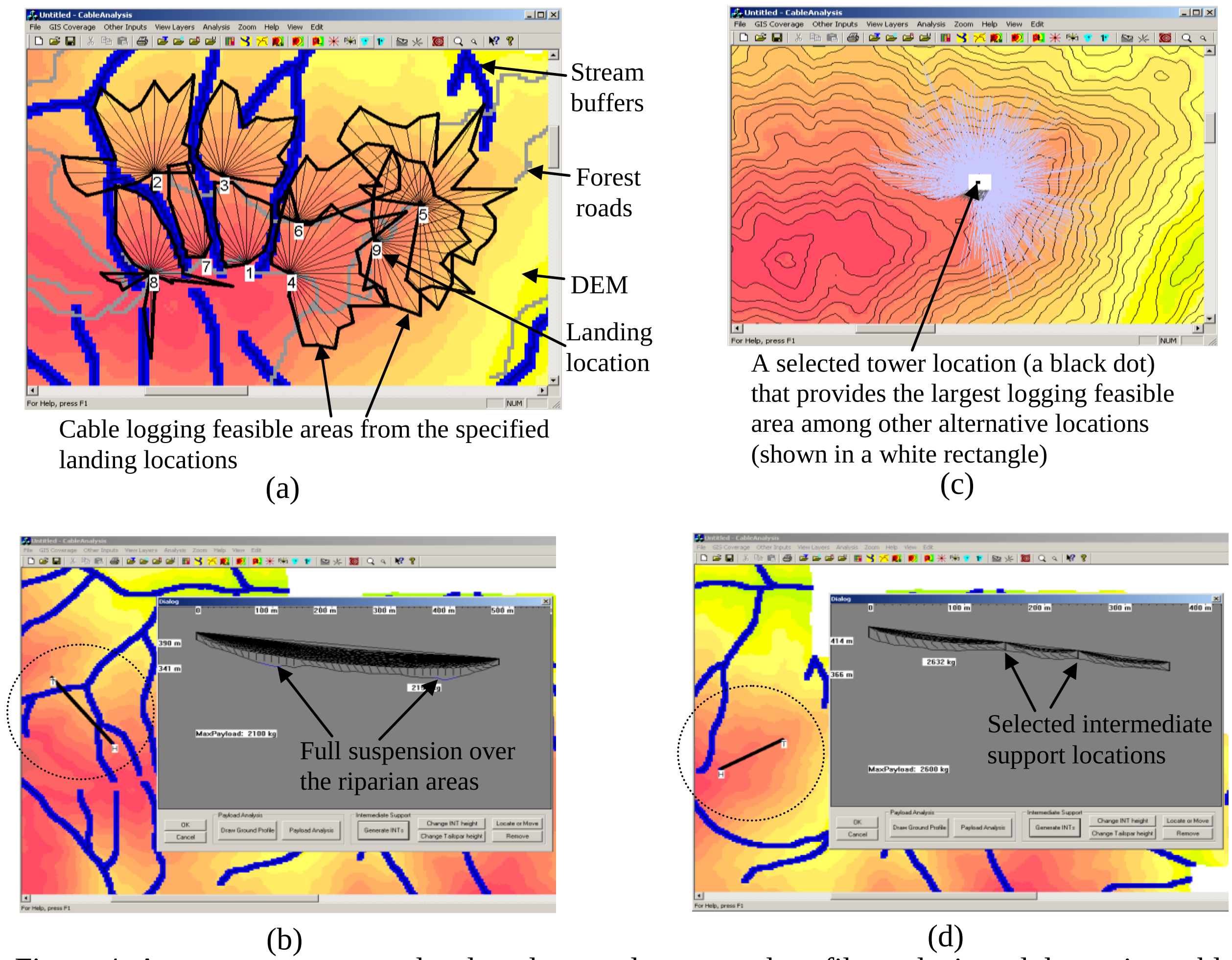

Figure 4. A computer program developed to conduct ground profile analysis and determine cable logging feasibility using GIS produced data.

CONCLUSIONS

An automated method to efficiently analyze ground profiles and determine cable logging feasibility is introduced. Incorporating modern computer programming languages and GIS technologies, a computer program has been developed to implement the method. Hopefully, the program can help forest planners efficiently analyze timber harvest areas and develop better cable logging plans that reduce the costs and environmental impacts of timber harvesting.

ACKNOWLEDGMENT

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REFERENCES

Brown, C. and J. Sessions. 1996. The standing skyline: a maximum log load solution procedure. *Forest Science*. 42(2): 220-227.

Chung, W. 2002. Optimization of cable logging layout using a heuristic algorithm for network programming. PhD dissertation, Oregon State University, Corvallis, OR. 209 p.

Jarmer, C. and J. Sessions. 1992. Logger-PC for improved logging planning. In Proceedings of Planning and Implementing Future Forest Operations, International Mountain Logging and 8th Pacific Northwest Skyline Symposium, December 14-16, 1992. Bellevue, WA.

Sessions, J. 1992. Unpublished software developed for educational use. Oregon State University, Corvallis, OR.

Twito, R.H., S.E. Reutebuch, E. Stephen, R.J. McGaughey, and C.N. Mann. 1987. Preliminary logging analysis system (PLANS): overview. Gen.Tech. Rep. PNW-GTR-199. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 24p.

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VALUE RECOVERY WITH HARVESTERS IN SOUTHEASTERN USA PINE STANDS

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Abstract

Cut-to-length is not the harvesting system of choice in the southeastern USA although it is perceived to be more environmentally friendly and to have the ability to recover more value from cut stems. In this paper we address the value recovery aspect of harvesters by comparing the optimal recoverable value, as calculated by optimization software, to the actual value recovered by the harvesters at three sites. The actual values recovered at the sites were respectively 93, 90 and 94%. At all the sites the harvesters tended to cut fewer but longer logs than the optimal solution suggested.

Introduction

In Nordic countries the cut-to-length (CTL) harvesting system is the system of choice with almost 90% of the total volume of wood harvested attributed to this system (Chiorescu and Gronlund 2001). The picture in North America is completely different with only 20 to 30% of logging being done by CTL (Gellerstedt and Dahlin 1999). CTL is used even less in the southeastern USA, with not more than 1% of loggers using this system (Greene *et al.* 2001), although it is perceived to have many environmental and value recovery advantages.

Value recovery is the process whereby stems are cut into logs according to pre-determined specifications with the objective to obtain the highest possible value. The maximum value is only recovered if the most valuable products (e.g. plylogs and sawlogs) are optimized. Value recovery plays an integral part in determining the profitability of harvesting as the profits of such an operation are dependent on the volume produced, the unit value of the products and the unit cost of production [profit = volume*(value – cost)] (Twaddle and Goulding 1989).

In 39 studies of value recovery with mechanized systems in Sweden, Finland, USA, Australia, and New Zealand summarized by Murphy (2003), the value loss ranged from 1 to 68% with an average of 20%. Boston and Murphy (in press) reported a value loss of 6 and 42% respectively in two mechanized log-making operations in the southeastern USA.

The objectives of this study (Conradie 2003) were therefore to: 1) determine the difference between the optimal recoverable value as calculated by optimization software and the actual value recovered by each harvester; 2) determine the difference between the optimal recoverable value and the actual value recovered by each harvester per product; and 3) determine the reasons for under and over recovery of products.

Methods

Three loggers were selected to participate in the study. All three used Ponsse Ergo harvesters with H73 harvester heads and the Ponsse Opti optimization system. At all the sites *Pinus spp.* (predominantly *P. taeda*) was harvested from natural pine stands and the method of payment for the wood was per unit of wood harvested. Site A, which was located in central Georgia, was clearfelled, while sites B and C, which were situated in central Alabama, were thinned.

At site A, 61 trees were selected for inclusion in the study, whereas 60 trees were included at sites B and C. At site A, the trees were selected and marked by the researcher, whereas at site B and C the harvester operator selected the trees to be felled. After the selected trees were felled they were marked with an identification number, and the tree number and stump height recorded. A tape was then attached to the large end (butt) of the stem and the following recorded: 1) Large end diameter (LED) of the butt over bark (OB); 2) DBH OB (only at sites B and C; at site A the DBH was recorded on the standing trees); 3) diameters OB at corresponding lengths from the butt; 4) quality features with their corresponding beginning and the ending lengths from the butt; and 5) tree height, excluding the stump. Once the data were recorded, the harvester operator optimized the felled trees while the researcher recorded, from within the cab, the products manufactured as well as their corresponding small end diameters (SED) and lengths. Once the felled trees were optimized, the researcher measured the actual SED or LED over bark and the length of each of the optimized logs.

The log dimension specifications, quality dimensions and stumpage prices for the different products were obtained from the harvester operator and the appropriate manager, as they were required to run the optimization (Table 1). At site A the specification for knots, sweep and external defects were the same for sawlogs and CNS logs but lower for pulp logs. The quality specifications decreased from plylogs to pulp logs at site B and at site C the quality specifications decreased from sawlogs to pulp logs. After all the required data were collected and the input files created, the AVIS (Assessment of Value by Individual Stems) optimization software was used to determine the optimal and actual value recovered (New Zealand Forest Research Institute 1995).

Table 1. Log dimension specifications and prices at all sites, June-August 2002.

Site	Log type	Minimum SED (cm)	Lengths (m)	Price (US$/m^3)
A	Sawlogs	20	3.8, 5.0, 6.2	30.75
	Chip-n-Saw logs	15	3.8, 5.0	12.75
	Pulp logs	5	3.7 to 4.9	2.10
B	Plylogs	23	5.4	35.00
	Sawlogs	20	5.1	20.00
	Chip-n-Saw logs	15	3.2, 3.8	10.00
	Pulp logs	5	3.0 to 6.1	2.50
C	Sawlogs	19	3.8, 5.1	20.00
	Pulp logs	8	4.3, 4.9, 5.5, 6.1	2.50

Results

At site A, 18 percent of the stems were cut to the exact optimal value (i.e., zero value loss). In the optimal solution, AVIS manufactured 289 logs with a total volume of 60.4 m^3 and a value of $1,596.89, whereas in the actual solution (before adjusting for out-of-specification logs) 241 logs with a total volume of 60.4 m^3 and a value of $1,512.03 were made (Table 2). Thirty-four of the logs (five plylogs, three CNS logs and 26 pulp logs) in the actual solution were out-of-specification and the values of these logs were therefore decreased to reflect their true value. This resulted in an additional value loss of $33.45, thereby increasing the total value loss to $118.31(7.4%). At this site 92.6% of the value was recovered.

Table 2. Characteristics of the sampled sites and the observed products recovered using single-grip harvesters with computer assisted bucking at three sites in the Piedmont region of Alabama and Georgia, June-August 2002.

Measure	**Site A**	**Site B**	**Site C**
Harvest Method	Clearfell	Thinning	Thinning
Stems harvested (n)	61	60	60
DBH (cm)	31.4	25.0	22.1
Total Height (m)	24.6	21.1	18.2
% Stems Cut to Exact Optimal Value	18%	5%	43%
# of Products Cut from Stems	3	4	2
# of logs: optimal	289	255	161
# of logs: actual	241	220	140
% Difference	-16.6%	-13.7%	-13.0%
Length: optimal (m)	1253.9	1114.9	791.6
Length: actual (m)	1236.2	990.7	750.2
% Difference	-1.4%	-11.1%	-5.2%
Volume: optimal (m^3)	60.4	35.0	25.9
Volume: actual (m^3)	60.4	34.2	25.5
% Difference	0.0%	-2.3%	-1.5%
Potential Optimal Value	$1,596.89	$701.31	$380.92
Value of Logs Before Adjustment	$1,512.03	$641.36	$357.46
# Logs Out of Specification	34	4	15
Value Adjustment for Out of Spec Logs ($)	$33.45	$11.99	$0.10
Total Value Lost ($)	$118.31	$71.94	$23.56
% Value Lost (% of Optimal)	7.4%	10.3%	6.2%
Percent Value Recovery	92.6%	89.7%	93.8%

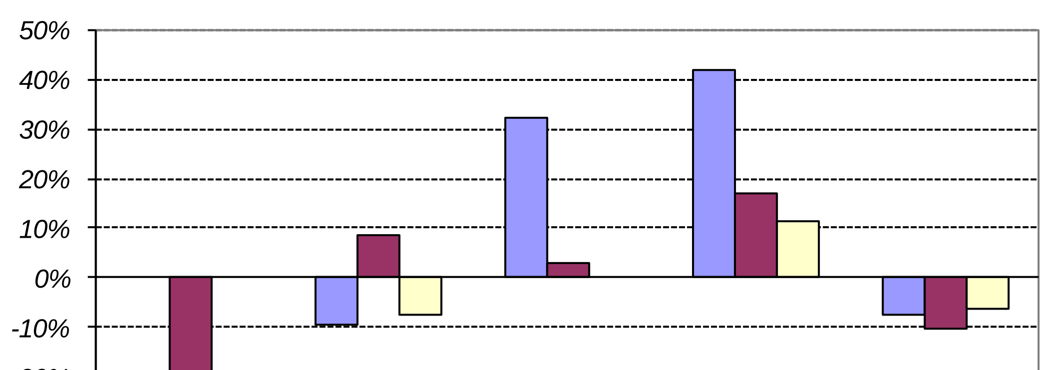
At site B only five percent of the stems were cut to the exact optimal value. In the optimal solution, AVIS manufactured 255 logs with a total volume of 35 m^3 and a value $701.31, whereas in the actual solution (before adjusting for out-of-specification logs) 220 logs with a total volume of 34.2 m^3 and a value of $641.36 were made. Four of the logs (two plylogs and two CNS logs) in the actual solution were out-of-specification. The value of these logs were reduced to reflect their true value and resulted in an additional value loss of $11.99, thereby increasing the total value loss to $71.94 (10.3%). At this site 89.7% of the value was recovered.

At site C 43 percent of the stems were cut to the exact optimal value. In the optimal solution, AVIS manufactured 161 logs with a total volume of 25.9 m^3 and a value $380.92, whereas in the actual solution (before adjusting for out-of-specification logs) 140 logs with a total volume of 25.5 m^3 and a value of $357.46 were made. Fifteen pulp logs in the actual solution were out-of-specification and the actual value recovered was therefore reduced by a further $0.10, which increased the total value loss to $23.56 (6.2%). At this site the actual solution recovered 93.8% of the optimal value.

Discussion

Under recovery of higher-value products (plylogs and/or sawlogs) contributed to an observed over recovery of lower-value products (CNS and/or pulp logs) at every site (Figure 1). The under recovery of the sawlogs at both sites A and C was caused by the preference of the actual solution to manufacture longer logs. In the optimal solution for site A for example, 71% of the sawlogs were shorter than 5 m while the observed solution cut 87% of the sawlogs to lengths of 5 m or longer. We observed this preference for cutting longer logs than suggested by the optimal solution with every product and at each site. This is likely a legacy of the region's focus for years on tree-length logging and fiber recovery, not value maximization.

At site B, both plylogs and sawlogs were under recovered in value which resulted in an over recovery of CNS and pulp logs. This was due in part to measurement errors caused by the harvester's diameter measuring system. The operator did not regularly check the measurement accuracy of the harvester head or recalibrate it. As a result, when measurement errors started to occur they were not noticed. As a result, only 5% of stems were cut to their exact optimal value.



	Ply	Saw	CNS	Pulp	Total
Site A		-9.7%	32.2%	42.0%	-7.4%
Site B	-20.0%	8.7%	3.0%	16.9%	-10.3%
Site C		-7.4%		11.5%	-6.2%

Figure 1. Percentage over and under recovery of value by product at each site.

The value losses observed at the three sites included in this study are similar to the value loss of 6% reported by Boston and Murphy (in press) in a similar study conducted in the southeastern USA. They are also at the lower end of the range as reported by Murphy (2002) from 39 studies worldwide. A further study should be conducted to ascertain the reasons why loggers preferred to make the longer lengths and if the costs savings from making and handling fewer, longer logs make-up for the loss in value recovered.

Additional work should examine how value losses with CTL systems compare to those experienced with tree-length systems. Specifically, does the additional cost of producing, sorting, and handling more short logs in the woods return more total value than delivering long logs that are merchandized in millyards. In addition, how are costs and benefits shifted within the wood supply chain if such a shift occurs?

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Literature Cited

Boston, K. and G.E. Murphy. (in press). Value recovery from two mechanized log-making operations in the southeastern United States. Southern Journal of Applied Forestry (accepted 2003).

Chiorescu, S. and A. Gronlund. 2001. Assessing the role of the harvester within the forestry-wood chain. Forests Products Journal 51(2):77-84.

Conradie, I.P. 2003. Cut-to-length harvesting systems in the southeastern USA: Value recovery and adoption by potential users. M.S. thesis, University of Georgia, Athens. 129 p.

Gellerstedt, S. and B. Dahlin. 1999. Cut-to-length: The next decade. Journal of Forest Engineering 10(2):17-24.

Greene, W.D., B.D. Jackson, and J.D. Culpepper. 2001. Georgia's logging businesses, 1987 to 1997. Forests Products Journal 51(1):25-28.

Murphy, G.E. 2002. Worldwide experiences with mechanisation and value recovery. In: Proceedings of the Woodfor Africa Conference, July 2002, Pietermaritzburg, South Africa. College of Forestry, Forest Engineering Department, Corvallis, Oregon. Pp.23-32

New Zealand Forest Research Institute. 1995. PC AVIS Version 1.8 - Users Manual. Rotorua, New Zealand. 85 pp.

Twaddle, A.A and C.J. Goulding. 1989. Improving profitability by optimising log-making. New Zealand Journal of Forestry 34(1):17-23.

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An Exploration of the Analytic Hierarchy Process and its Potential for Use in Forest Engineering

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ABSTRACT - Many problems in forest engineering involve the use of expert judgment to inform models of user preferences and priorities. One technique that may be useful in making this process of incorporating expert judgment more transparent and its application more objective is the Analytic Hierarchy Process (AHP). AHP involves structuring problems as a hierarchy, completing pairwise comparisons between attributes to determine user preferences, and using these comparisons to calculate weights for each individual attribute. Before AHP is applied to forest engineering problems, however, the assumptions, strengths, and weaknesses of the method must be explored and understood. In addition to discussing the theoretical foundations of AHP, this paper will give an example of an AHP application to a forest engineering problem.

INTRODUCTION

Modeling approaches to problem solving in natural resources and specifically in forest engineering often rely on expert judgment to inform models of user preferences and priorities. These preferences are used to make tradeoffs between alternatives. Often these alternatives contain data that are physical and biological, quantitative and qualitative, and measured on many different scales. The reason expert judgment is necessary is that in many cases science has not determined quantifiable relationships between cause and effect. Multi-Criteria Decision Analysis (MCDM) is a field of theory that analyzes problems based on a number of criteria or attributes.

Many MDCM techniques exist, such as goal programming and combinatorial optimization. However, these techniques have several drawbacks. For example, the weights placed on individual attributes being compared, such as acres harvested, tons of sediment, and dollars of net present value, are required to serve two purposes. First, to make the variables measured on different scales comparable, and second, to adjust the relative importance of each variable to the problem. The relative contribution to each of these purposes can not be separated from the total value of the weight being used.

An alternative MCDM method called the Analytic Hierarchy Process, or AHP, is presented here. AHP is not a new technique, but it is a model that has not been widely applied in natural resource situations despite its suitability to many problems faced in forest engineering and natural resource management. This paper will discuss the AHP methodology in general and offer examples of its use in natural resources management situations.

ANALYTIC HIERARCHY PROCESS

The Analytic Hierarchy Process (AHP) was originally developed in the mid-1970's by Thomas L. Saaty (Saaty 1977) and has been used widely in many fields such as business and operations research. The AHP involves the following three basic steps:

- Structuring problems as a hierarchy;
- Completion of pairwise comparisons between attributes to determine user preference; and
- Weighting of attributes and calculation of priority.

Structuring the problem as a hierarchy

AHP requires that problems be structured hierarchically so that the overall goal of the problem is represented at the top level of the hierarchy and the individual alternatives to be compared form the base of the hierarchy. At the center of the hierarchy are one or more layers containing the attributes that will be used to compare alternatives.

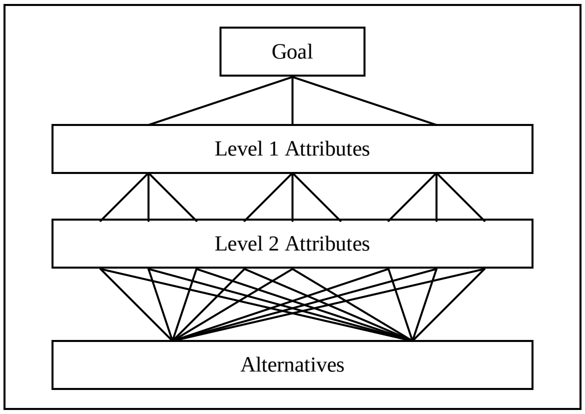

Figure 1: Representing the problem as a hierarchy

The hierarchy represented in Figure 1 shows an overarching goal at the top. For example, this may be to minimize the impact of a forest road network on aquatic vertebrates. The next level in the hierarchy contains attributes upon which the alternatives will be compared. Following the same example these may be factors such as sediment, barriers to fish passage, and slope stability. The third (and more if needed) level of the hierarchy contains refinements of these attributes. For example, if we look at the sediment attribute, the impact of sediment on aquatic vertebrates may be a function of the total amount of sediment produced by a road segment, the size of the sediment produced, the distance between the road segment and the stream in question, and the type of vegetation between the road segment and the stream in question. The bottom level of the hierarchy contains the alternatives being considered. Alternatives for this example would include road segments that are currently impacting aquatic vertebrates through the introduction of sediment to a stream channel, are prone to slope stability failures, or contain a stream crossing that is not passable to fish.

Pairwise Comparisons

Pairwise comparisons are made between each of the attributes and are evaluated based on the contribution of each attribute to the overall goal (the highest level of the hierarchy). Comparisons are evaluated on a scale from one to nine (Figure 2), termed the fundamental scale, where one signifies equal importance between the attributes and nine is used when one attribute is strongly more important than the other attribute. This nine point scale is based on the now-famous finding of Miller (1956) that the average person can simultaneously compare approximately seven (plus or minus two) objects without becoming confused. Reciprocals are used to express the strength of the weaker of the two attributes. For example, if A is 7 times more important than B, then B is 1/7 as important as A.

Intensity of Importance	Definition	Explanation
1	**Equal importance**	**Two activities contribute equally to the objective**
2	Weak	
3	**Moderate importance**	**Experience and judgment slightly favor one activity over another**
4	Moderate plus	
5	**Strong importance**	**Experience and judgment strongly favor one activity over another**
6	Strong plus	
7	**Very strong or demonstrated importance**	**An activity is favored very strongly over another; its dominance demonstrated in practice**
8	Very, very strong	
9	**Extreme Importance**	**The evidence favoring one activity over another is of the highest possible order of affirmation**
Reciprocals of above nonzero numbers	If activity A has one of the above nonzero numbers assigned to it when compared with activity B, then B has the reciprocal value when compared with A.	

Figure 2: The Fundamental Scale used for pairwise comparisons in AHP.

Pairwise comparisons are carried out for each group of attributes at each level of the hierarchy and recorded as a positive reciprocal matrix.

The original version of AHP required that the user also complete pairwise comparisons for each attribute of each alternative being compared (Saaty 1980). This is an acceptable method if fewer than seven alternatives are being compared. However, if the problem becomes larger than this, the number of comparisons between alternatives becomes unwieldy. Depending on the specific nature of the problem, this relative value can alternatively be assigned linearly as a proportion of the largest value present (Saaty 1994) or based on some other non-linear function (Weich 1995).

Saaty (1977) suggests that these matrices of pairwise comparisons be relatively consistent, meaning that if A > B and B > C, then A > C. However, this is not always the case in practice. Take, for example, the children's hand game of "Rock, Paper, Scissors" where paper always beats rock, scissors always beat paper, and rock always beats scissors. These rules are logical but inconsistent. A useful approach to addressing these inconsistencies has been proposed by Karapetrovic and Rosenbloom (1999) and uses quality control techniques. Instead of requiring individual matrices to meet some external definition of consistency, it is proposed that the consistency of matrices be tracked over time using moving average and range control charts to detect errors such as mistakenly entering a 2 where 7 was the correct value.

Weighting of Attributes and Calculation of Priority

Various methods for calculating attribute weights from the pairwise comparison matrix have been proposed. Saaty (1977, 1980) calculates the principle right eigenvector of this positive reciprocal matrix while others (Lootsma 1996) have used the normalized geometric mean of the rows of the priority matrix. The method involving geometric means is a simpler method computationally and has not been conclusively shown to be inferior to the eigenvector method.

The calculation of priority for one alternative as compared to another alternative is the product of the attribute weight and the relative attribute value summed across all attributes for each alternative.

CRITICISMS OF AHP

Two major areas of criticism have arisen from the use of AHP to solve practical problems. These are:

- Rank reversals of alternatives, and
- Modes of eliciting pairwise comparisons.

Rank Reversal

In the original version of AHP (Saaty 1977) pairwise comparisons are completed between the attribute values of the alternatives and normalized to sum to one. In this approach the relative attribute value of an alterative depends on the attribute values of the other alternatives being compared. When an alternative is added or deleted from consideration, the relative value of the new set of attribute values will change. This can cause the resulting ranking of attributes to change. In some cases this is appropriate and follows the economic principle of scarcity creating value.

However, in other cases rank reversal is not acceptable. These are cases where alternatives are being compared individually against some standard. This can be done in AHP by dividing the attribute values of each alternative by the maximum attribute value of all alternatives being compared. This is Saaty's ideal mode of the AHP (Saaty 1994) and does not allow rank reversals to occur.

The decision maker will need to decide whether the nature of the problem being considered should allow rank reversals to occur.

Pairwise Comparison Elicitation

The claim has been made that the question "How much do you prefer Attribute A over Attribute B?" is arbitrary and without basis (Dyer 1990). Several suggestions have been made to rectify this perceived flaw.

One of these suggestions is through the use of linking pins (Schoner et al. 1993). This approach is similar to Saaty's ideal mode except that the question now becomes, to use the same example as above, "How much do you prefer sediment (500 tons) to vegetation (fern)?" where 500 tons of sediment and fern are the maximum values for these two attributes represented by the alternatives being compared.

It would appear reasonable for the decision maker to have in mind the range of attribute values present in the alternatives being presented. For example, if two of the attributes being compared were distance from road segments to the nearest stream and the amount of sediment produced by those road segments, the decision maker's preferences would be different in comparing a range of sediment between one and five tons per year and distance of 500 to 1000 meters as opposed to comparing sediment ranging between 500 to 1000 tons per year and distances varying between one and five meters. However, in practice the preferences of decision makers do not change when the ranges of the attributes are manipulated (Weber 1997) and questions like "How much do you prefer

Attribute A over Attribute B?" are easier to answer as compared to "How much do you prefer sediment (500 tons) to vegetation (fern)?"

EXAMPLE

Let us assume we have the six transportation routes as shown in Figure 3 to compare where we want to not only minimize the total distance of the route, but also the use of potentially unstable areas (see Wing et al. 2003 for further description of the problem). For this example, we will assign relative attribute values for each route as a percentage of the largest value for each attribute overall. This will produce values between zero and one, with larger values being the more "expensive" values, or those that lead to a greater increase in the total transportation cost.

Route	Dist. (km)	Area (m^2)	slope (%)	Surface Type
1	600	3,000,000	15	Paved
2	1200	1,000,000	20	Gravel
3	800	2,500,000	15	Gravel
4	1500	50,000	35	Dirt
5	2000	100,000	20	Dirt
6	900	150,000	30	Gravel

Figure 3: Example route data.

Where:

Dist. = Total route length in kilometers,

Area = Sum of upslope contributing area in square meters, and

Slope = Average angle in percent of the hillslope the route is crossing.

For the Surface Type attribute a different approach must be taken. Here, we can either assign values between 0 and 1 for each surface type or we can use pairwise comparisons between the surface types to determine weighting values. Figure 4 shows a matrix of pairwise comparisons for Surface Type (D = dirt, G = gravel, and P = paved). The last two columns of Figure 4 give the normalized geometric mean of the rows as well as the value that will be used for attribute values. Either of these values could be used, however, to be consistent, all other attribute values are decimal percentages of the largest attribute value present and this practice should continue for Surface Type as well. It is important to remember the "direction" of the problem. For this example, the higher the value, both for the relative attribute values and the attribute weights, the larger the contribution to the overall cost of transportation. Therefore, lower values, both of attribute values and later, overall priority values, indicate the least costly, or more preferred options. Problems can be worked in either "direction", but care must be taken to be consistent throughout the problem formulation, implementation, and interpretation.

	D	G	P	Normalized Geometric Mean	Attribute Value
D	1	3	9	0.66	1.00
G	1/3	1	7	0.29	0.44
P	1/9	1/7	1	0.05	0.08

Figure 4: Using AHP to determine Surface Type relative attribute values.

Figure 5 shows the positive reciprocal matrix resulting from pairwise comparisons of the four attributes under consideration. The final column of Figure 5 is the normalized geometric mean of the rows used as the criteria weights.

	Distance	Area	Slope	Surface Type	Weight
Distance	1	5	3	9	0.578
Area	1/5	1	3	5	0.223
Mean Angle	1/3	1/3	1	7	0.159
Surface Type	1/9	1/5	1/7	1	0.040

Figure 5: Matrix of pairwise comparisons and final weights

Figure 6 shows relative attribute values for the example problem, the total priority values, and the relative rank preference for each route.

Route	Dist. (km)	Area (m^2)	Slope (%)	Surface Type	Preference Value	Rank
1	0.30	1.00	0.43	0.08	0.47	2
2	0.60	0.33	0.57	0.44	0.53	4
3	0.40	0.83	0.43	0.44	0.50	3
4	0.75	0.02	1.00	1.00	0.64	5
5	1.00	0.03	0.57	1.00	0.72	6
6	0.45	0.05	0.86	0.44	0.43	1

Figure 6: Example results using AHP to prioritize transportation routes based on minimizing total transportation costs, both economic and environmental.

It is interesting to note that while distance was considered to be the attribute that had the strongest influence on total transportation cost, the route with the lowest distance value was not the most preferred route once the other three attributes were also taken into consideration.

CONCLUSION

The major strength of the AHP is that it allows attributes measured on different scales to be compared (Saaty 1980). This is especially important for this example problem where comparisons must be made between values such as meters of distance, square meters of upslope contributing area, degrees of hillslope, and a categorical surface type. AHP also forces the user to make explicit values used in decision making (Keeney 1988) and is useful in situations where the quantification of cause and effect relationships is left to professional judgment.

AHP provides the decision maker with a great deal of flexibility in formulating a problem. For example, it is up to the decision maker to decide if rank reversals should be allowed or if weights should be assigned to alternative attribute values linearly or based on some other non-linear function. This flexibility allows the decision maker to fit the problem formulation specifically to a problem under consideration.

This paper has presented a brief overview of AHP methodology and an example demonstrating the technique's potential usefulness in comparing alternatives with multiple criteria measured on different scales. AHP can be particularly useful in cases where it is left to professional judgment to determine the relative contribution of each attribute towards the objective.

LITERATURE CITED

Dyer, J.S. 1990. Remarks on the analytic hierarchy process. Management Science. 36:249-258.

Karapetrovic, S. and E.S. Rosenbloom 1999. A quality control approach to consistency paradoxes in AHP. European Journal of Operational Research. 119:704-718.

Keeney, R.L. 1988. Value-driven expert systems for decision support. Decision Support Systems. 4:405-412.

Lootsma, F.A. 1996. A model for the relative importance of the criteria in the Multiplicative AHP and SMART. European Journal of Operational Research. 94:467-476.

Miller, G.A. 1956. The magical number seven plus or minus two: Some limits on our capacity for processing information. Psychological Review. 63:81-97.

Saaty, T.L. 1977. A scaling method for priorities in hierarchical structures. Journal of Mathematical Psychology. 15:234-281.

Saaty, T.L. 1980. The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation. McGraw-Hill, New York. 287 p.

Saaty, T.L. 1994. Highlights and critical points in the theory and application of the Analytic Hierarchy Process. European Journal of Operational Research. 74:426-447.

Schoner, B., W.C. Wedley and E.U. Choo 1993. A unified approach to AHP with linking pins. European Journal of Operational Research. 64:384-392.

Weber, M. 1997. Remarks on the paper 'on the measurement of preferences in the analytic hierarchy process' by A. A. Salo and R. P. Hamalainen. Journal of Multi-Criteria Decision Analysis. 6:320-321.

Weich, B.G. 1995. Analytic hierarchy process using Microsoft Excel. *In* Engineering. California State University, Northridge, p. 24.

Wing, M.G., J. Sessions, and E. Coulter. 2003. Preliminary investigation of digital elevation model resolution for transportation routing in forested landscapes. *In* Proceedings of the Second International Precision Forestry Symposium, June 15-18, 2003, Seattle, Washington.

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REDUCTION AND UTILIZATION OF FOREST FUEL LOADING IN LOUISIANA

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Abstract: The warm, humid climate of the U.S. Gulf Coast region may promote rapid decomposition of forest material, but it also promotes rapid growth. This growth can lead to a rapid buildup of fine biomass that could fuel wildfires during dry weather. Opportunities for prescribed burning are limited, particularly in the wildland-urban interface areas north of New Orleans. This paper addresses some of the progress made toward four objectives: 1) determine quantities and types of biomass available in the Florida Parishes of Louisiana, 2) assess methodologies for the mechanical treatment and removal of excess fuels from the forest in preparation for use, 3) determine some potential uses of the removed biomass, and 4) identify economic opportunities for new businesses in the realm of excess forest fuel removal. The status of current fuel reduction machinery is presented. A whole-tree utilization operation that has potential for forest fuel reduction activities is evaluated.

Introduction

In Louisiana, 92,603 acres were destroyed by wildfire in 2000, including 21,702 acres in pine plantations (LDAF 2001). There is a need, therefore, to reduce this fuel loading to help better protect our forests. This is not an easy endeavor, however. Removal of small stems, shrubs, and non-merchantable material can be very time consuming and expensive. Therefore, a study was initiated to determine the amount of biomass that should be removed, harvesting techniques available, accessibility, and potential end use of removed fuels from fuel to wood-based products.

Objectives

The study, of which this paper is a part, has a four-fold objective:

1. Determine quantities and types of biomass available by forest type and accessibility of these materials.
2. Assess issues surrounding the extraction of biomass and the capability and economics of available harvesting technology.
3. Determine potential uses for biomass removed including fuel and wood-based products.
4. Identify economic opportunities for new businesses and impacts on surrounding communities.

Methodology

This study is intended to consist primarily of an extensive literature search supplemented by some local case studies. In the process of the project, the authors have also found an opportunity to manufacture and test some panel products made from small pine stems.

Literature Search and Information Gathering

The Florida Parishes region (eight parishes east and north of Baton Rouge) is the area in the state of greatest fire concern because of the extensive rural-urban interface. These parishes are all forested, mostly with pine, which is the forest type that tends to have a large fuel buildup. Small, non-industrial, private landownerships can hinder efforts to reduce forest fuels; yet, the outbreak of wildfires can be the most critical in these areas. Figure 1 shows the commercial timberland ownership classifications in these parishes.

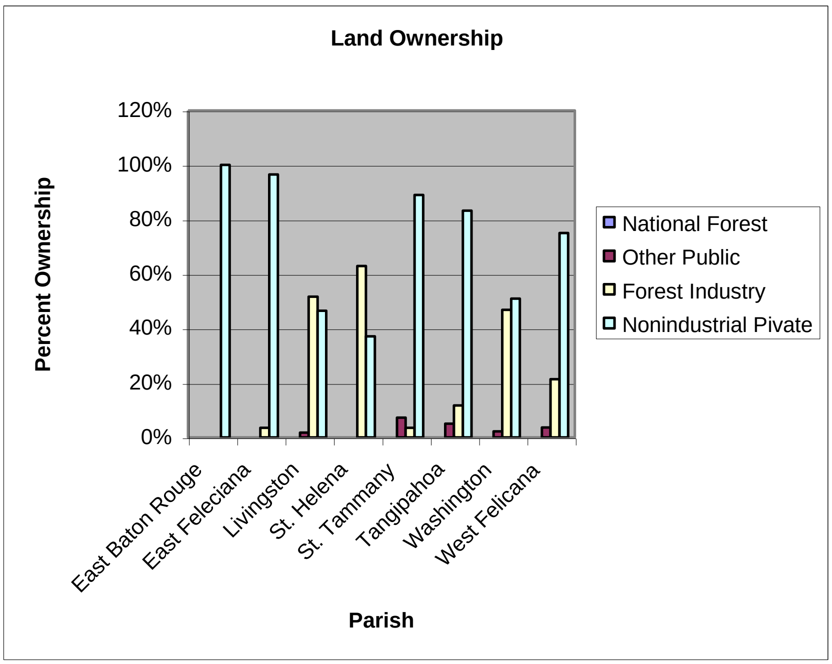

Figure 1. Commercial timberland ownership proportions in the Florida Parishes of Louisiana. The rural-urban interface is most critical in East Baton Rouge, Livingston, St. Tammany and southern Tangipahoa parishes. The strongly fragmented ownerships in these areas increase the need for forest fuel reduction programs but will also make the implementation of such programs difficult to administer (Source: Rosson 1993).

Mechanical treatment of the forest may be an effective way to reduce forest fuels at urban/forest interface. Although prescribed burning may not be an option in all cases, mechanical fuel reduction may need to be combined with a prescribed burn afterward, particularly where sprouting may be a problem. By performing mechanical fuel reduction first, the intensity of heat and smoke might be reduced to an acceptable level near urban areas.

Methods to modify the fuel profile may include:

1. Lop & scatter -- This a widely used slash treatment method for pre-commercial thinning pine stands in California. The lopping operation is carried out using a chain saw, and the material is then scattered. This is one of the least expensive methods used, but is also the least beneficial slash treatment for hazard reduction; this approach will not work in stands of densely packed trees if the thinned slash might cause a fire hazard since it is not removed from the ground.
2. Cut with chain saw and hand pile – This may be the only option on steeper slopes. Small winches could be used if larger material has to be moved.
3. Cut and machine pile -- A tracked machine with a boom can be used to cut and pile undesirable biomass. The equipment type varies with the terrain conditions.
4. Brush cutting, shredding & mowing -- A small tracked or tire machine that has good maneuverability can be used for this operation with different attachments to carry out the cutting, shredding or mowing operations. A secondary piling operation is required, because the machine will be able to perform only the primary cutting, shredding or mowing. A machine which can perform both the primary and secondary operations is very much in need. This could save time and money.

Machines like brush cutters, forestry mowers, mulchers, site preparation and land clearing machines can be used to mulch down the accumulated biomass. The machines currently on the market for the express purpose of fuel reduction tend to be of three major designs: a front-mounted rotating drum with teeth on it designed to run over brush, a rotating disk mounted on a short boom on the front of a crawler or skidder-like carrier, or a rotating disk mounted on the long boom of an excavator-style carrier. All seem effective, but none are designed to collect the ground material, making the fuel reduction operations costly and possibly still leaving too much fuel on the ground. If the mulched material can be removed effectively, this could help reduce the cost of fuel reduction.

Some machines are capable of having different types of attachments. This gives them the flexibility to carry out more than one type of operation for a given machine. This helps in capital cost reduction. Front end attachments that mount on to different types of carriers, like excavators or farm tractors, give the owner options to decide on which type of attachment he can buy based on the performance of the carrier he already owns.

A Case Study

Mr. James Fincher of Andalusia, AL, has a whole-tree in-woods chipping operation. The product output of his operation is chips for pulp/paper and boiler fuel (hog fuel). In August 2002, this operation was thinning an 11-year-old loblolly pine plantation near Leakeville, MS, with typical diameters breast height ranging from 10 to

14 inches. The equipment consists of two operational feller-bunchers (plus a spare), two skidders, an in-woods chipper (Morbark 2455 Flail Chiparvestor), a spare chipper, and a recycler (Bandit 2680 Beast Recycler). The Chiparvestor delimbs and debarks, producing fine quality chips suitable for paper pulp. The Chiparvestor has two chutes; the first chute produces delimbed and debarked material and the second chute produces wood chips. The reserve chipper is swapped out regularly to minimize down time for maintenance. The recycler is stationed next to the Chiparvestor; it further grinds down the limbs and the bark that came from the first chute of the Chiparvestor. Finally, two trucks are stationed at the chute of the recycler and the second chute of the Chiparvestor, where the ground material is blown into chip vans.

The crew consists of six operators plus truckers. The machines use about 350 gallons of fuel per day. The chip vans are hauled by three owned trucks and 2 or 3 contract trucks. Details of the operation were provided by the loggers and by the recycler sales representative in August 2002.

The Chiparvestor ($650,000 new) is powered by two diesel engines: a 6-cylinder 325 hp and an 8-cylinder 800 hp. Key maintenance points include:

- Flails chains can break with wear, causing severe damage downline to the chipper knives, so it is very important to check and replace them as needed.
- Bottom flail chains are checked twice a week, and worn chains are replaced.
- Top flail chains are checked weekly, and worn chains are replaced.
- Chipper knives are checked daily and typically replaced daily.
- The replaced knives are reconditioned at the machine shop and are used again.
- Greasing is performed daily.

According to the sales representative, the Recycler ($200,000 new) holds its resale value well. After three years, its resale value is reported to be roughly 80% of its purchase price, despite the recommended life of four years. It has a productivity rate of 25 tons/hour. The total power of the machine is 365 hp: 300 hp is used by the hammer mill and 65 hp is used to operate the discharge chute. The machine is operated manually. The designer plans to incorporate remote control to eliminate the need for a person operating near the machine (safety concerns). Key maintenance points include:

- Need to reharden cutter bodies (10/month out of 60 cutter bodies)
- Replace about 3 teeth per day (of 60 teeth).
- Belts last for 1500 to 2000 hours.
- Conveyer lasts for 1500 hours and up.
- Infeed chain lasts for 6000 hours.

The operation was producing 9 to 10 truckloads of pulp chips and 4 to 5 truckloads (29 tons/truck) of recycled material, which was being used as boiler fuel. In smaller timber, the ratio of chips to hog fuel is 1:1. The pulp/paper mill consumed about 100 truckloads of fuel per day.

Conclusion

Whole tree chipping operations do a considerable job of removing excess fuels from southern pine plantations, but are unlikely to be suitable for small landownerships where timber production is not a priority, especially in the rural-urban interface. There are also concerns about whether these operations remove too many nutrients from the soil. However, they demonstrate that excess fuel removal can be done in an economically responsible manner.

Several machines on the market are designed to grind excess ladder and brush fuels. However, these machines have incorporated no mechanism for the utilization of the material they grind. There is a need to develop these machines further so that the ground material can be harvested. A look at agronomic harvesting machinery may provide clues that are usable by forestry machinery with respect to multiple stem processing and other processing needs that are key to the economic handling of small material.

References

Bolding, C.M., and B.L. Lanford. 2000. Forest Fuel Reduction Through Energy Wood Production Using a Small Chipper/CTL Harvesting System. School of Forestry and Wildlife Sciences, M. White Smith Hall, Auburn University, AL 36849.

LDAF Louisiana Department of Agriculture and Forestry. 2001. Wildfire Protection. http://www.ldaf.state.la.us/forestry/forestprotection/index.htm

MacDonald, A.J. 1999. Harvesting Systems and Equipment In British Columbia. FERIC Handbook HB-12; ISSN 0701-8355; ISBN 0-7726-3827-6.

Rich, B. 2001. Thinning, Fuel Manipulation and Prescribed Fire in Dry Forest Types. Forest Management Supervisor, Missoula Unit. Montana Department of Natural Resources and Conservation: Missoula, Montana.

Rosson, J.F., Jr. 1993. The Woody Biomass Resource of Louisiana, 1991. U.S.D.A. Forest Service, Resource Bulletin SO-181. 114pp.

Ryans, M., D. Cormier. 1994. A Review of Mechanized Brush-Cutting Equipment For Forestry. Special Report No. SR-101.ISSN 0381-7733. Forest Engineering Research Institute of Canada. Web Site: http://www.feric.ca

Windell, K., and S. Bradshaw. 2000. Understory Biomass Reduction Methods and Equipment Catalog. Tech.Rep.0051-2826-MTDC. USDA Forest Service Technology & Development Program, Missoula, Montana.

PLANNING AND CONDUCTING A TIMBER HARVEST ON UNIVERSITY OF MAINE FORESTLAND- A FORESTER'S AND A LOGGER'S PERSPECTIVE

Jack Frost and Charles Simpson

Background:

The University of Maine owns approximately 7,500 acres of forestland, which along with an equal amount owned by the University of Maine Foundation is managed by the University Forests Office. The Dwight B. Demeritt Forest is the original University Forest, located within the City of Old Town, and Town of Orono, Maine. The Demeritt Forest contains almost 3,000 acres that is bordered by approximately 35,000 residents when school is in session. This forest has been harvested annually since 1939, and is heavily used for recreation, educational activities and research as well. The Demeritt Forest has an estimated 50,000-75,000 recreational visits annually, and contains groomed ski trails and other trails and roads used for walking, biking, horseback riding, etc.

The Proposed Harvest:

In the summer of 2001, a harvest was planned for a 61-acre block in the center of the Demeritt Forest. The particular block was selected because of its visibility to the forest users and the need for silvicultural treatment. Two primary gravel roads on the forest ran through the block, and recreational trails ringed the perimeter, including ski trails groomed in the winter by University Forest staff.

The Forester's Perspective

Planning the Harvest:

The sensitive nature of the harvest site called for special considerations in the planning stages. Safety of the public was the top concern. As many as 10-25 people would likely pass through the harvest/loading area daily. Aesthetics, always a high priority consideration, became even more important. Protection of soil and water integrity of the area was of concern as well, calling for a winter harvest on frozen ground. Another special consideration was protecting the road surface and the improved recreational trails, which included several park benches within the harvest area. And the silvicultural goals of the harvest could also not be overlooked. The stand contained high quality pine, spruce and hardwood sawtimber that would benefit from a thinning, but be negatively affected by a poorly planned or conducted harvest.

Choosing a Logging Contractor:

As in all harvesting operations, the success or failure of the job depends heavily on the commitment and professionalism of the logging contractor. For this operation, requests for proposals (RFP) were send to several cut-to-length harvesting contractors who had been in business for several years. The RFP listed out the specifics of the harvest, including silvicultural goals and the special considerations mentioned above. The University Forests Office offered the opportunity to provide up to three years of harvests on University lands to the chosen contractor if the work was completed to its satisfaction. In addition, the RFP also queried the contractor as to the type of equipment they used, the background and experience of their equipment operators, their work history (references), and other pertinent information. In effect, the contractors were being interviewed for a job requiring special abilities. In the end, Forests For the Future, Inc. of Anson, Maine was chosen to do the job.

The Harvest:

After the harvest block was marked off and the contractor chosen, the University Forest staff prepared for the harvest by flagging of all stream and wetland buffers. State required Harvest Notification Numbers were expanded upon to include information about the harvest and posted at wood landings. The haul roads entering the forest were signed warning people of trucks and forestry operations (as is done on all of our harvests). The recreational trails adjacent to the harvest block were barricaded and signed as the harvest took place in their vicinity. Once the harvest left those areas, trails were re-opened for use. University Forest staff talked to the equipment operators and truck drivers to explain the special safety considerations on this harvest.

Once the harvest began, the typical inspections were conducted looking for the typical concerns. Some normal harvesting protocols were altered however. The six-wheeled forwarder was operated without the eco-tracks to protect the road and trail surfaces. Trucking was conducted by straight framed, self-loading trucks instead of tractor-trailers. This reduced the need for large turn-arounds or landings. The logging contractor was encouraged to use the recreational trails in an area as forwarding trails to discourage their use by skiers and walkers.

The Results:

A total of 950 cord equivalents of timber were harvested, from pulpwood to veneer logs. The silvicultural goals of the harvest were met with minimal impact on the recreational trails, roads and sensitive areas. Roads and trails were used throughout the operation by recreational users with no incidents of endangerment. Only one complaint of the harvest was registered with the University Forests Office.

The Logger's Perspective:

Planning the Harvest:

As a logging contractor, professionalism is a must to maintain a successful business. As a Maine Certified Logging Professional and Maine Master Logger, planning is key to success. This harvest provided several opportunities as well as challenges. The wood to be harvested was of good quality and very accessible. The volume removal and size of the wood fit the cut-to-length system well. A good job here could mean another three years of attractive work on this landowner. Working on university property would provide a good future reference for landowners considering future harvests. Having a forester involved in the harvest, with well-defined silvicultural objectives helps the contractor do a good job.

Some challenges include the relatively long distance from home and familiar markets. Trucking would be a challenge over these distances. The heavy recreational use of the property would require responding to questions of passers-by, and taking extra caution throughout the operation for safety reasons. Working around recreational trails, research areas, etc. requires extra time and care so as not to disturb the site.

The Harvest:

Once the Timber Sales Agreement was signed, the contractor placed cautionary signs around the harvest block. Another set of signs were placed centrally along the road that informed passers-by of the logging contractor's name, the names of the equipment operators, the fact that everyone involved in the harvest was a Certified Logging Professional and the contractor was Master Logger Certified. The landowner was also identified, along with the required Harvest Notification Number for that job.

Production was most affected by numerous conversations with passers-by to explain what was happening. Several visits by college forestry classes were welcomed, but cut into production somewhat. Vehicular traffic along the truck road also had some effect on production. Numerous vans and busses passed by going to labs. Numerous, small landing areas for the wood required extra time to load. Several times either the processor operator or forwarder operator would find some indication of a special use being made of an area and need to check with the forester before proceeding.

The Results:

The overall results of the harvest were favorable. The recreational users of the forest seemed supportive of the operation in most cases, although some took some special explaining to convince. Completion of this job has led to additional work on university lands as hoped. Experience gained from this first operation has made subsequent ones somewhat easier to deal with.

Summary:

Harvesting timber on forestland that has heavily competing uses presents special challenges and considerations. Safety and aesthetics are probably the two most important, along with positive public relations and education. Such harvests can be successful for both the land manager and the logging contractor. The key is that the two parties plan and work together throughout the operation to insure mutual goals are achieved. This is very important, given the increase fragmentation of productive forestland in the Northeast, and the diversifying goals of the landowners.

University Forests Office
University of Maine
Since 1939

HARVEST NOTIFICATION FORM

#240980

EXPIRES 9-10-03

OLD TOWN

This forestry operation is being conducted on University of Maine Forest Lands under supervision of:

Charles J. Simpson- Woodlands Manager
University Forests Office
Maine Licensed Professional Forester #446
215 East Annex
University of Maine
Orono, Maine 04469-5725

If you have questions about this operation Call 581-3624

2003 Council on Forest Engineering (COFE) Conference Proceedings:
"Forest Operations Among Competing Forest Uses"
Bar Harbor, September 7-10, 2003

USING SHORT-ROTATION HARDWOOD PLANTATIONS AS "GREEN" INVENTORY FOR SOUTHEASTERN PULP MILLS.

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ABSTRACT

As a routine wood source for a pulp mill, recent past studies have shown that intensively-managed, short-rotation hardwood plantations are not cost effective. The objective of this study was to determine if these plantations may be cost effective as "green" inventory, replacing some portion of high cost remote woodyard inventory. Three southeastern pulp mills were used as case studies in a net present value analysis. Short-rotation hardwood plantations of eastern cottonwood (*Populus deltoides*) were used to replace a portion of remote woodyard inventory, with wood delivered to a pulp mill only when inventory levels become critical. If this "green" inventory is not used, these plantations continue to grow until needed. With current yield from an experimental fiber farm, short-rotation plantations were not cost effective as "green" inventory. However, if yield could be increased approximately 33% through expected genetic improvements, all three pulp mills could have reduced overall wood cost by establishing a fiber farm.

INTRODUCTION

Procuring wood, especially hardwood, during the winter months for a pulp mill in the Southeast has some difficulties. Soft ground reduces the operational feasibility of many sites, forcing companies to store hardwood in woodyards for retrieval during wet weather. Short-rotation, intensively-managed hardwood plantations grown on dry sites could replace some volume companies are storing in remote woodyards.

An earlier part of this study determined hardwood fiber farms are expensive to establish and the wood from these hardwood plantations delivered to a pulp mill is well above that of normal delivered furnish (Gallagher, 2003). It was also a much higher cost than what Bar (1998) determined, probably due to yield differences. Both reports indicate that it could be several years before hardwood stumpage prices in the South increase to the level necessary to justify intensive culture plantations as a daily source of fiber. However, short-rotation hardwood plantations could be used as a "green inventory" alternative to supply a pulp mill during severe weather. "Green inventory" refers to a strategically located, intensively managed, short-rotation hardwood plantation (fiber farm) that could be harvested at any time to provide a surge of wood into the pulp mill.

Wood cost savings should accrue since the company will buy less wood to be stored on remote woodyards (a more expensive option) and will replace it with wood purchased directly from the woods to the pulp mill. If less wood is purchased during the inventory building phase in a given year, savings should occur in total wood cost. The additional volume in "green inventory" hardwood plantations would be harvested only when the procurement manager for each pulp mill determines inventory levels at the pulp mill have reached a critical stage. If a dry winter occurs, and the pulp mill wood inventories do not drop below acceptable levels, the hardwood plantation will be left standing to grow another year. Then, the following winter, a reduced volume will need to be purchased for storage on remote company woodyards.

Assuming this occurs over a period of several years, a substantial reduction in total, overall wood cost may be achieved.

Wood stored in remote woodyards typically carries a $10/ton premium over deliveries directly to the mill from the woods (Martin, 2001). Wood stored at a remote woodyard must be unloaded, stored, and then reloaded onto trucks or railcars. These additional operations, along with some deterioration as the wood ages in the woodyard, add cost to the material. Additionally, remote woodyard material must then be transported to the pulp mill, further increasing costs. The amount of additional costs will vary with age of the wood (amount of deterioration), distance to the mill, and size of the woodyard, but $10/ton is typical. Thus, if 10,000 tons of material were available in "green inventory" and could replace an equal amount of remote woodyard inventory, a potential $100,000 savings in wood cost during the year ($10/ton savings x 10,000 tons) could be realized. Although our earlier analysis showed that wood deliveries from a fiber farm cannot compete on a cost basis with gatewood, this additional savings over remote woodyard storage may offset the relatively high cost of the fiber farm material used when pulp mill wood supplies are low.

Thus, this research project has the following specific objectives:

> Using a decision model developed in an earlier study, determine the cost feasibility of using short-rotation, intensively managed plantations as "green inventory" in actual pulp mill inventory situations. Actual hardwood inventory and costs for three southeastern pulp mills will be used as case studies to validate the feasibility of "green inventory".

MATERIAL AND METHODS

The cost feasibility of short-rotation hardwood plantations as "green inventory" for Southeastern pulp mills was analyzed by determining the total wood cost savings of keeping "green" inventory instead of roundwood inventory on remote woodyards. Three cooperating southeastern pulp mills who supplied hardwood wood cost and inventory levels over a three-year period were used as case studies to determine if using short-rotation hardwood plantations as "green inventory" would have reduced wood cost.

For each of the three years, hardwood inventory levels were analyzed to determine if pulp mill inventory ever reached a critical level. The critical level was defined by procurement personnel from each mill and was determined to be when actual inventory levels dropped below 50% of inventory goal; however, it will vary slightly with season. Inventory goals are set by management and are determined to be the amount of wood the pulp mill needs to store each month to effectively buffer day-to-day and week-to-week inventory fluctuations, and these goals provide a set probability that the mill will not run out of wood, causing a curtailment in paper production. Actual inventories, of course, vary based on consumption and deliveries. Only when inventory reached a critical level would green inventory be harvested and delivered to the pulp mill.

Savings could occur each year for the available volume of "green" inventory as an equivalent volume of roundwood would not be purchased and stored at remote woodyards. The savings for this volume was the $10/ton additional cost associated with remote woodyard roundwood.

Each pulp mill was analyzed as a separate operation, first using low yield and then high yield plantations. For each analysis, it was assumed that a fully operational fiber farm was already established with equal acres in each age class for the selected rotation length in the decision model, as though the green inventory system were already up and running after initial establishment in order to understand how a working fiber farm could influence annual operations and costs. For each year at each pulp mill, there are three potential cash flows: 1) costs to operate the fiber farm, 2) annual savings from the volume of wood in hardwood plantations, and 3) replacement of high cost deliveries.

Costs each year to operate the fiber farm were summarized and considered as expenses. These costs were calculated on the acres in each age class of plantation on the fiber farm. Savings were totaled by multiplying the amount of volume available from the hardwood plantations by the woodyard premium ($10/ton). Volume was only included from plantations that were age 5 and higher.

The last annual cash flow in the decision model came from offsetting wood purchases with plantation wood. This occurred only during a year when green inventory was harvested. All the costs associated with the hardwood plantations were already accounted for on an annual basis in the decision model as an expense. When the green inventory wood was harvested, it was then delivered to the pulp mill at the average harvesting cost for the area (all stumpage cost was included above as expenses). This plantation wood offset the highest priced hardwood delivered during a similar time period (within 2-3 months). Therefore, the price differential between plantation wood and these suppliers was accounted as savings.

All the costs and all the savings over the three-year period were used as cash flows in a net present value analysis, similar to the way Lothner (1981) analyzed plantations in his study. Two scenarios were analyzed with the decision model for each pulp mill. The first analysis was done using the lower yield plantations that are representative of the operational, industry fiber farm located in the Southeast. A second scenario was completed for each pulp mill using the higher yield plantations, assuming that genetic improvements and operational efficiencies result in the higher yielding fiber farms.

While the decision model was being used, if a dry winter occurred and critical levels were not reached, the volume was carried over to the next year and additional volume was added due to growth. Also, in the event of several dry years in a row, an assumption was made to harvest any plantations reaching age 10.

RESULTS AND DISCUSSION

Pulp Mill #1 Analysis

Pulp mill 1 (Figure 2) had the lowest hardwood inventory goal of the three mills, peaking at 80,000 tons during the winter. For this first analysis with the low yield decision model, it was assumed a 400-acre plantation was already established. All plantation costs for that year were $199,321. There were 8323 tons of green inventory available, therefore, that amount of less wood was purchased and stored in remote woodyards at a savings of $10/ton and totaling $83,229.

The hardwood inventory level for pulp mill 1 was input into the decision model. During year 1, actual inventory level never reached the critical level of less than 50% of goal, so no short-rotation plantations were harvested. All the acres across each age class were carried into the next year.

Year 2 plantation costs of $186,002 and savings of $122,335 (12,234 tons x $10/ton) are shown in Table 1. During year 2, low inventory levels in February resulted in 57 acres (1 age class) of hardwood plantation being harvested with a total of 3984 tons of fiber. Looking at hardwood deliveries to the pulp mill during that same period, some woodyard wood delivered for $34.21/ton. Roundwood from the plantations offset that woodyard material and delivered for

$12/ton (because all the other plantation costs were already accounted for), so an additional wood cost savings of $85,294 was realized.

During year 3, low inventory levels in October caused by reduced deliveries of wood resulted in 57 acres of hardwood plantation being harvested, again with a total of 3984 tons of fiber. These fiber farm deliveries offset some roundwood that arrived at the mill at a of cost $33.74/ton and generated a wood cost savings of $84,656.

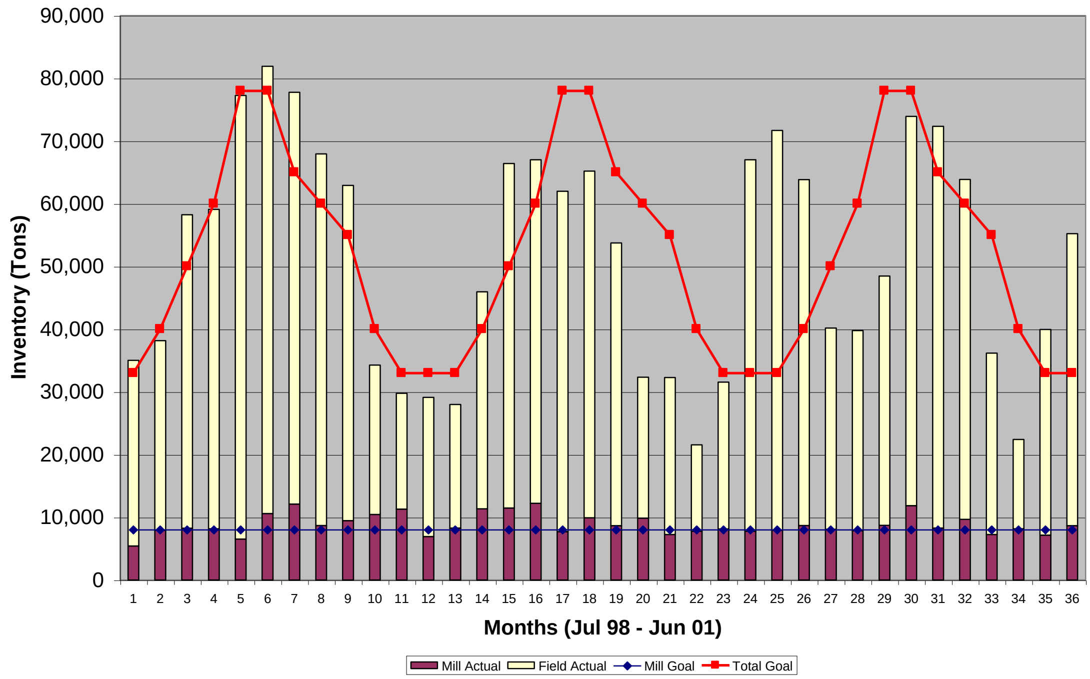

Figure 2. Hardwood inventory levels for pulp mill 1. The actual mill and field (woodyards) inventory are stacked as a bar against the lines that indicate inventory goals.

A three-year summary of the costs and savings are shown in Table 1. The net present value of this cash flow was a negative $83,694. Even though annual cash flows were positive for two of the three years, the fiber farm with a low yield was never able to make up for the first year loss.

Table 1. Summary of all cash flows ($) for a net present value analysis of green inventory for pulp mill 1 with low yield plantations on a 400-acre fiber farm.

	Plantation costs	Inventory savings	Wood cost savings	Annual cash flow
Year 1	199,321	83,229	0	-116,092
Year 2	186,002	122,335	85,294	+21,627
Year 3	198,713	122,454	84,656	+8,397
	Net present value =	($83,694)	Average=	-28,689

Finding the net present value negative for the low yield plantations was expected given the high delivered cost for hardwood plantations developed in the previous chapter. A second scenario was run using the earlier assumption of higher yielding plantations and therefore lower costs per unit. These higher yields should come through genetic improvements and operation optimization (Stanturf, 2003). The same 400-acre farm is established (Table 2), so plantation costs for the three years of the analysis are the same. Inventory savings are higher because there is additional volume available each year from the higher yielding plantations.

The need to harvest follows a similar pattern to the first scenario: no wood was cut in year 1, 57 acres were harvested in year 2 and 57 acres were harvested in year 3. Wood cost savings for the offset deliveries amounted to $111,702 in year 2 and $112,896 for year 3. The net present value for this scenario is a positive $63,485 (Table 2). While year 1 was again a negative cash flow, years 2 and 3 had much higher positive cash flow from both inventory and wood cost savings, thereby resulting in a positive three-year average.

Table 2. Summary of all cash flows ($) for a net present value analysis of green inventory for pulp mill 1 with high yield plantations on a 400-acre fiber farm.

	Plantation costs	Inventory savings	Wood cost savings	Annual cash flow
Year 1	199,321	111,029	0	-88,292
Year 2	186,002	163,175	111,702	+88,875
Year 3	198,713	163,333	112,896	+77,516
	Net present value =	$63,485	Average=	+26,033

The benefit of getting additional volume from the high yield plantations for the same plantation costs, thereby allowing more woodyard inventory to be offset annually and more deliveries offset when plantations are harvested is shown by the positive NPV. While the volume is still nowhere near what Bar (1998) estimated, the additional volume is enough to the necessary savings to justify a fiber farm.

Pulp Mill #2 and 3 Analyses

The inventory graphs are not shown because of space limitations, however for both mills, they were able to keep actual inventory at or near inventory goal most of the time during years 1 and 3. But for both pulp mills, year 2 was impacted by slow deliveries and inventory fell to critical levels. For these analyses, both mills required multiple age classes of green inventory to be harvested in year 2 to prevent curtailment of pulp mill operations.

The year-to-year costs and savings for each individual analysis from the decision model can be found in Appendix B. A summary of all the analyses is found in Table 3. Pulp mills 2 and 3 were similar to pulp mill 1 in that they all had negative net present values with low yielding hardwood plantations. All 3 mills had a positive NPV once the higher yielding plantations were involved.

The underlying effect that drives the savings for fiber farms is not having to store large quantities of wood on woodyards to prevent pulp mill curtailment. It's the stochastic nature of wood deliveries that Galbraith and Meng (1981) first reported when doing inventory analysis that allows this assumption. And while supply, demand and production lead time change regularly due to environmental restraints, as shown by LeBel and Caruth (1997), some wood deliveries will still make it to the pulp mill. Only in the event of an extended drop in deliveries would fiber farms then support procurement efforts and prevent the mill from possible curtailments.

Table 3. Summary of the net present values for low and high yield hardwood plantations as green inventory for three southeastern pulp mills (numbers in parenthesis are negative).

Scenario	Pulp Mill	Yield	Acres	Net present value	Average annual cash flow
1	1	Low	400	($83,694)	($28,689)
2	1	High	400	$63,485	$26,033
3	2	Low	600	($584)	($2,640)
4	2	High	600	$236,820	$84,150
5	3	Low	600	($47,533)	($17,669)
6	3	High	600	$168,040	$61,521

CONCLUSIONS

The objective was to examine the cost and operational feasibility of establishing a strategically located, intensively-managed, short-rotation hardwood plantation ("fiber farm") to serve as "green inventory" for a southern pulp mill. Once established, the green inventory should allow the firm to reduce the traditional amount of purchased and stored woodyard "winter" inventory that *may* be needed to insure an adequate raw material supply. During the winter, if and when pulp mill inventory declines to a predetermined "critical" level, some portion of the green inventory would be harvested, otherwise it would remain growing for potential use in a future year.

The results of the green inventory analyses on three cooperating southern pulp mills show that the concept may be operationally feasible and cost-effective under the following conditions:

a. The pulp mill uses similar practices as the three case study pulp mills to build inventory for the winter, storing wood in remote woodyards for later retrieval when deliveries are slow.
b. Yields from the fiber farm increase over time above volumes previously reported by the limited operational trials in the South. This is reasonable to expect, given the documented increase in yields realized from existing, large-scale operations in the Pacific Northwest through genetic manipulation.
c. Wood from the fiber farm would not be needed or used *every* year, allowing substantial cost savings from reduced woodyard inventory to accrue and additional growth to occur during periods of the rotation. If (expensive) fiber farm wood deliveries had to be used too frequently, any woodyard inventory savings would likely be depleted.

In summary, wood from intensively managed, short-rotation hardwood plantations is currently too expensive to become a regular source of furnish for southern pulp mills any time soon, but may, under certain circumstances, be strategically used in a limited capacity as "green inventory" to reduce overall wood cost through inventory savings for some mills.

Literature Cited

Bar, I. 1998. Fertigated hardwood plantations in the Southeast. Proceedings of the Short-Rotation Woody Crops Operations Working Group, Vancouver Washington. p. 81-84.

Galbraith, J. E. and C. H. Meng. 1981. Simulating optimum inventory of harvested wood. Journal of Forestry, Vol 79 (5): p. 292-295.

Gallagher, T. V. 2003. Assessing the Cost and Operational Feasibility of "Green" Hardwood Winter Inventory for Southeastern Pulp Mills. Virginia Tech Dissertation.

LeBel, L. and J. S. Carruth. 1997. Simulation of woodyard inventory variations using a stochastic model. Forest Products Journal, Vol 47 (3): p. 52-57.

Lothner, D. C., D. Rose, J. Zavitkovski and K. Ferguson. 1981. A financial analysis of poplar intensive cultures in the Lake States. In Energy from biomass and wastes. V. Institute of Gas Technology, Lake Buena Vista, FL. p. 145-163.

Martin, A. L. 2001. Retired Procurement Manager. Personal conversation about inventory levels and costs for a hardwood consuming pulpmill.

Stanturf, J. A., R. C. Kellison, F. S. Broerman and S. B. Jones. 2003. Productivity of southern pine plantations: where are we and how did we get here? Jour of Forestry. Vol 101 (3): p. 26-31.

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FOREST ENGINEERING RESEARCH AT FERIC

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Abstract

This paper provides an overview of the structure, organization and financing of FERIC (the Forest Engineering Research Institute of Canada). It also describes today's strategic orientations for FERIC's research program and presents challenges we face for the future.

What is FERIC?

Brief history

The Forest Engineering Research Institute of Canada (FERIC) was established jointly by Canada's forest industry and the federal government on April 1, 1975. FERIC's initial mandate was to conduct research and to develop machine concepts that would improve the efficiency of wood harvesting operations. This was expanded in 1981 to include silvicultural operations, in 1984 to address the specific problems associated with managing and harvesting small woodlots, and in 1999 to deal with the operational aspects of fighting forest fires.

Structure

FERIC's Head Office is located in Pointe-Claire, Quebec. Researchers are evenly divided between two divisions located to serve the needs of members across Canada. Western Division, based in Vancouver, concentrates its research activities in British Columbia, Alberta, and Saskatchewan. Eastern Division, based in Pointe-Claire, covers eastern Canada, from Newfoundland to Manitoba. Western Division's Wildland Fire Research Group is located in Hinton, Alberta. The divisions, although physically separate, form an integrated research team with complementary research programs, and may each undertake research of Canada-wide interest and application.

Linkages with other forest research organizations

FERIC is one of three industrial forest research organizations in Canada. The other two are Paprican and Forintek. Paprican provides research and training services to its members in the areas of pulp and paper manufacturing, whereas Forintek covers the industry's needs regarding manufacturing solid wood products. Together, the three organizations cover the entire spectrum of forestry activities from the stump to the finished product. FERIC also works with other research organizations, particularly on the biological aspects of forest management. In Canada, these research areas are mainly covered by provincial and federal laboratories and by universities.

Organization

Forest industry members

Membership in FERIC is open to any organization engaged in the harvesting, transportation, or use of wood, or in silvicultural activities. Currently, 90 corporations are members of FERIC and through their companies and affiliates, they account for about three-quarters of Canada's total wood harvest. Membership is now open to non-Canadian companies, and FERIC recently recruited its first American member. Recruitment will prioritize American affiliates or parents of Canadian companies and companies located in states bordering Canada.

Associate members

Associate membership is now open to suppliers of forest companies, and particularly to equipment manufacturers and distributors. Associate members receive full access to FERIC's technical information, help formulate FERIC's R&D projects, and gain additional opportunities to connect with FERIC's industrial members and their contractors. They also get privileged access to FERIC-developed technologies and techniques and firsthand knowledge of the industry's needs.

Government partners

The Government of Canada (through Natural Resources Canada's Canadian Forest Service) has been a FERIC partner since FERIC's inception. Most provincial and territorial governments are also partners, as the management of public forest lands in Canada is under their jurisdiction.

Board of directors

FERIC is governed by a board of 22 directors that represents member companies, the Government of Canada, provincial governments, and universities.

Advisory committees

FERIC's work program is developed with the guidance of advisory committees whose members represent member companies and partners, and advise FERIC staff on the orientation of research activities. The committees review the research program's progress and identify new issues and projects. They also review and evaluate project proposals and rank them for inclusion in the following year's program. New proposals may develop from existing projects or may be proposed by members or by FERIC staff.

Funding

FERIC derives its funding from membership fees, contributions by the Government of Canada and provincial governments, and contract research. Currently, FERIC has a total operating budget of C$10 million provided by:

- Members 43%
- Government of Canada 33%
- Provincial governments 9%
- Contracts, grants and other 15%

Levels of R&D activity at FERIC have more than tripled since 1975. Increased funding requirements were covered by an expansion of the assessment base through the recruitment of new members, adjustment of membership fees and of the Government of Canada's contribution, and new revenue sources, such as provincial participation, contract research, and grants.

Assessment of membership fees

Membership fees are based on a company's wood utilization; the present rate equals C$0.043/$m^3$, with a minimum annual fee of C$4300. To put this in perspective, this fee amounts to roughly 0.1% of the total delivered wood cost at the mill. For members without mills, membership fees are negotiated based on the level of the company's forestry activities. Canadian members can benefit from tax credits that reduce the net cost of their contribution.

Research program

Research and development activities

The overall objective of FERIC's research program is to help its members improve the efficiency of their silvicultural, wood harvesting, processing, and transportation operations through improved operating methods and machines. The program covers four major work areas:

<u>Silvicultural Operations (site preparation, reforestation, stand tending, thinning)</u>

The objective is to assist members and partners in the implementation of intensified forest renewal and stand management programs. Research in this area is aimed at evaluating and developing the methods, machines, and attachments necessary to carry out various silvicultural operations at minimum cost under the range of different forest conditions across Canada.

<u>Wood Harvesting (felling, processing, and extraction to roadside)</u>

Projects are aimed at increasing the efficiency and utilization of current logging equipment, at developing new methods and equipment to reduce harvesting costs, at improving operator comfort and safety, and at minimizing the environmental impact of logging.

<u>Transportation and Roads</u>

Transportation of wood is a high-priority area at FERIC. Research currently concentrates mainly on truck transportation from the forest to the mill. Projects are directed at optimizing transportation systems, which include both the road network and haul operations.

<u>Engineering and Specialized Technologies</u>

This work area supports FERIC's membership in the areas of mechanical design, equipment maintenance, instrumentation, computer hardware and software support, and advanced technologies; researchers work closely with manufacturers and provide them with assistance in equipment development.

Delivery of results

The delivery of research results and their implementation in the field is the ultimate goal of FERIC's work. In fact, FERIC devotes as much of our resources to communicating our research results as we do to developing the solutions.

Communication with members and partners is mostly done by the researchers themselves. We believe that the best person to explain a new method or technique or to promote the merits of a new innovation is the person who developed the information in the first place. Direct contact is the preferred mode for communicating. Although concise technical reports are generally produced upon the completion of a project, we do not rely primarily on printed material to convey the project's results. Telephone conversations, visits to operators in the field, workshops, and field demonstrations are the preferred means for transferring results. Increasingly, we will work directly with members to help them implement a novel approach. Implementation with early adopters is an efficient way to promote innovation.

FERIC distributes our non-restricted information fairly openly to non-members. However, information that is deemed critical and that can provide a competitive advantage to members and partners is "restricted" and made available to members only for at least several years.

Program orientations and sample results

FERIC's mission is to provide our members with knowledge and technology to conduct cost-competitive, quality operations that respect the forest environment. It's important to note that our mission statement *does not* contain the word "research". This choice of wording emphasizes our commitment to providing and implementing *solutions* for the benefit of our membership. The mission statement also highlights our three primary objectives: reducing wood costs, improving fiber quality and utilization, and improving environmental performance. All FERIC R&D projects address at least one of these objectives and many address all three simultaneously.

Reducing the cost of delivered wood was FERIC's main *raison d'être* when the Institute was created. Today, improving productivity and work efficiency remains a key goal of our program. At the same time, improving fiber utilization and quality has become an increasingly important issue. Fiber shortages in some areas are forcing companies to stretch fiber recovery to its limits. Similarly, quality work and quality products are paramount objectives. Achieving greater value with the available resource and adding value all along the value chain are increasingly recognized as essential means for improving competitiveness.

Improving environmental performance has taken an increasingly important place in FERIC's program since the early 1980s. This research involves the development of systems that better protect soils, water, esthetics, wildlife habitat, and other non-timber values. Although it's hard to quantify such results, FERIC's assistance to members in this area is considered to be very important.

Projects are directed at finding solutions that can generate value for FERIC members. The annual return on investment for companies who implement FERIC's research results has typically ranged from 5 to 10 times their annual membership cost. What kind of research has provided such paybacks? Consider a few examples:

- The introduction of wide tires for skidders in the early 1980s improved productivity on soft sites by up to 60%, with 40% decreases in fuel consumption.
- Transportation is a large component of delivered wood costs; FERIC has helped introduce a number of innovations to reduce haul costs, including tridem drives, central tire inflation (CTI), lightweight vehicles and components, multi-purpose trailers, among others.
- FERIC helped manufacturers adapt onboard weigh scales for forestry haul trucks so drivers can maximize their loads without risking fines for overloading.
- Where clearcutting is no longer tolerated, companies are adopting a range of strategies developed by FERIC researchers to make partial cuts economical and environmentally acceptable.
- FERIC has gathered 25 years worth of site-preparation data to guide members on the most cost-effective means of preparing a site for reforestation.
- FERIC decision-support software lets managers pick the most suitable haul vehicle for specific roads and operating conditions, estimate harvesting and silviculture costs, predict the effects of harvesting operations on subsequent silviculture, and maximize the efficiency of grading operations.
- The *MultiDAT* datalogger lets equipment managers monitor the performance of forestry machines and optimize machine uptime.
- FERIC has championed the adoption of road-building technologies such as arch culverts, plastic retaining walls, dust suppressants, soil stabilization, and the use of geosynthetic materials.

Challenges and opportunities for the future

The FERIC formula has changed relatively little during its first 25 years; however, the forestry sector has seen an accelerated rate of change in the new millennium and FERIC must adapt to stay ahead of the changing environment. Some of the key drivers of change are:

Globalization and consolidation within the forest industry

The ongoing consolidation within the industry means that FERIC's membership is increasingly made up of fewer, larger members. In fact, 80% of FERIC's revenue from industrial members now comes from about 10% of members. Member companies are often foreign-owned or own important assets outside Canada, and this offers both challenges and opportunities:

- A single large company's dues can be relatively large, so their needs must be very specifically met, sometimes in parallel with the needs of smaller members.
- Decisions regarding membership in FERIC are sometimes made outside Canada's borders, and the desire to belong to a consortium is not necessarily a priority.
- FERIC has an opportunity to serve the whole company, not simply the Canadian subsidiary.
- Linkages with similar international organizations has become more vital.

A more competitive world, with spending more closely scrutinized

Globalization has created a more competitive environment for the forest industry. In this framework, every dollar expended is examined to determine whether it provides the company with a clear benefit. Contributions to research institutes and associations have been scrutinized very closely during the last few years, resulting in the disappearance or transformation of several organizations.

FERIC can demonstrate a good ROI and can stand up to questioning by company accountants. However, it currently appears unlikely that the industry is prepared to significantly increase its membership contributions. The industry is more likely to increase its contribution to FERIC in the form of fees for custom services. This will likely involve a shift towards more fee-for-service activities and potentially a decrease in the level of the regular R&D program.

A systemic approach to optimization (a broadening horizon)

Companies strive to maximize the value of the products they deliver to their customers. They view their overall operation as a continuous supply chain from the stump to the client, with each link contributing to the overall value of the final product. This implies that R&D solutions are not independent silos—optimization must be done *globally*. Research projects can address concerns that extend far beyond a research organizations's individual boundaries and require concerted efforts. Present research organizations have well-defined work areas and these pose obstacles where inter-organizational project must be developed. It is appropriate to question whether the existing governance is appropriate in this context.

Liaison at a regional level

FERIC presently incorporates two main divisions, and its researchers spend considerable time in the field. The nature of our solutions is such that implementation is mainly done by company field staff at a regional level. FERIC could be more effective at delivering and implementing our research program if we set up regional bases that would let us work more directly with our members in each region. Efforts are thus underway to locate FERIC liaison personnel in key forestry regions. Their role would involve mainly information transfer and staying informed of member needs.

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THE TECHNOLOGY OF THOUGHT IN FOREST OPERATIONS

Melanie D. Hobbs[1] and Pierre E. Zundel

1.0 Introduction

The thesis of this paper is that the psychology of forest operations planning needs more formal study. Our purpose is to argue this thesis and to introduce our own research on how foresters think: a study of the problem solving and environmental risk management behavior of forest road construction supervisors in New Brunswick, Canada.

1.1 Psychological factors are important

To the casual observer, a veteran forest engineer working in familiar terrain may appear to plan operations by rote. The engineer would likely recognize patterns in the operations planning problem (retrieved as "chunks" of information from the long-term memory (Gellerstedt 2002)) and apply learned routines or rules-of-thumb (heuristics). However, the nuances of the problem situation could interrupt learned routines and invoke new or different behavior (like contingency planning and innovating). Old routines and new branches forming in the working memory would be imperceptible, even to keen observers like trainees or auditors.

Formal (meaning "scientific") observation of problem solving behavior would result in a better record of routines, innovations and missteps. This sort of information is important because it documents the knowledge of career foresters, and could improve the realism of training, assessment, and decision aids. This approach has been used to study the clinical problem solving skills of physicians (Rimoldi and Raimondo 1998) and to train medical students (Barrows 1985). Similar attention is due to the individuals who ultimately deliver on public and corporate expectations of forest stewardship and technical expertise.

Attending to employee performance is critical at a time when the forest industry is under unprecedented[2] scrutiny and expectations are high. If we define our research subjects as lower to middle managing industrial forestry professionals, it is evident that many are solving highly complex problems in a task environment with many new dimensions. Technological changes, regulatory changes, and market trends have motivated organizational change in woodlands offices e.g. switching from company- to contractor-run fleets, and function- to regionally-defined roles. This has meant an expanded role for many personnel, with less time to reflect on decisions or think about planning and leading. Neither their attributes as problem solvers, nor the quality or efficiency of their solutions is well known.

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2 We say 'unprecedented' because, as one index, we found that the incidence of the word 'forestry' in major Canadian newspapers doubled this decade over the previous ten years using the Canadian business reference database (CBCA).

1.2 Psychological factors are not well known

In this section, we discuss industry, academic, and government contributions to our current understanding of the psychology of forest operations planning.

There is some movement in industry toward characterizing employee personalities and work habits. Some companies conduct personality-typing inventories, hire efficiency consultants and spend time on morale building. Professional competency programs have also developed, which are like preventative maintenance for skilled workers (e.g. in Canada the Ontario Ministry of Natural Resources professional competency program). There is also some movement in Canada and the United States to change university forestry accreditation programs to assess more directly the actual competence of graduates rather than the 'content' of the programs (Society of American Foresters, 2000). At the supervisory level, the Certified Logging Professional Program (CLP) has developed a certificate for contractors and supervisors in Maine and New Brunswick.

There has been some study of machine operators in the forest industry that report on the effects of increased experience (Björheden 2001) and on the processes used to make decisions in single-grip harvester operation (Gellerstedt 2002). However, there does not seem to be a parallel movement in the research community to find ways to assess competence at the supervisory level. Machine operators are studied because we believe that they are determinants of operational success, but, perversely, we do not study the people who manage whole operations.

Forest engineering literature is replete with information on machines and computer programs: the accoutrements of the modern-day forest engineer. However, there is little published on the thinking and problem solving of the humans that make use of these tools to manage whole operations. We searched for topical articles using the TreeCABWeb reference database of agroforestry publications. This source includes Skogforsk and USDA Forest Service publications. For a body of articles specific to forest engineering, we also searched through Forest Engineering Research Institute of Canada (FERIC) and International Journal of Forest Engineering (IJFE) abstracts.

Using standard keywords from the AGRICOLA thesaurus, we retrieved only a small number of records on psychological factors in operations planning. For example, only one article on 'problem solving' in forestry was listed in the TreeCABWeb database since 1993. For the period 1982-1992, only 1.1 % of the FERIC publications bore either of the keywords 'decision' or 'planning'. This increased to 2.3% in the following decade (1993 to 2002). However, many of these were handbooks and none made a direct study of the psychology of the planner. 17.4% of IJFE articles were coded using the keywords 'decision' or 'planning' since its inception in 1989 . Of these, however, only one dealt with the psychology of the planning process (representing 0.5% of the total).

Our conclusion from this review is that the number of articles on the technology of thought is growing, but overall the proportion is still very small. Most are devoted to DSS, which aid planners but do not assess them. Without careful study of the kind we propose, it is difficult for the DSS developer to know what the decision process actually is for a complex task, across many people and many regions. It is also difficult to know how well a forester or engineer may complete a task, with or without a DSS.

Government monitors report on failures to meet regulatory norms for a task, but the reports they provide cannot tell us what chain of decisions and events may have led to a failure to comply. As an example, Table 1 tallies the number of violations recorded by the New Brunswick Department of Natural Resources for culverts installed during the period 1992-1997.

Table 1. Number of stream crossings and monetary penalties by licensee (1992-1997)

Licensee	No. of crossings	No. of monetary penalties	Violation rate (% of total)
A	484	11	2.3%
B	369	5	1.4%
C	288	2	0.7%
D	265	8	3.0%
E	167	4	2.4%
F	161	7	4.3%
G	160	6	3.8%
H	124	2	1.6%
I	80	4	5.0%
J	44	2	4.5%
TOTAL	2142	51	2.4%
Source: New Brunswick Department of Natural Resources Harvest Monitoring Coordinator 2002			

Clearly, the overall number of violations is low relative to the total number of installations in five years (2.4%). However, if we look at the violation rates by licensee, they differ markedly (from a low of about 1% for licensees B and C to a high of 4 to 5% for licensees I and J). Does the difference lie in the terrain, the road supervisor's decisions or the intensity of monitoring? Without a look at the entire planning process, we can only tally the consequences, rather than know the antecedents of the violation.

Relying on government monitoring into the future to assess professional forestry competence is also problematic, at least in Canada, because of funding cutbacks. For example, the province of Ontario moved to industry self-inspection of licensed forests after half of its inspection staff were cut in 1998. The Pembina Institute of Alberta[3] which evaluated the Ontario monitoring process, has reported that industry inspectors in that province are not protected from the province by retaliation from their employers. Also, industry-sponsored inspectors report fewer cases of industry transgressions than ministry inspectors (Pembina Institute 2003). The idea that forestry companies may have to self-police in the future is perhaps the most persuasive argument yet that we should understand the origin of employee motivations and mistakes.

2.0 Our approach

As part of a long-term UNB research project focusing on 'how foresters think', we have chosen to assess the problem-solving and environmental risk management behaviour of forestry

[3] The Pembina Institute is an independent, not-for-profit environmental policy research and education organization.

professionals. Risk management is an important parameter to assess because it can assist in the decision making process and the "…pragmatic consideration of environmental matters, as is required by a business." (McCallum and Fredericks 1996). This is particularly salient for a natural resource-based business like forestry.

2.1 Methods

We have chosen to assess certain behaviours in the context of stream crossing design problems – a task that is often identified as an environmentally sensitive and high cost activity for the forest industry. Our general approach has been to ask practicing professionals to solve a simulated stream crossing problem. We trace their progress and observe these features:

- Pieces of information used to solve the problem (the 'tactic'), and cash or time costs;
- Heuristic decision rules applied to the problem (e.g. priority setting);
- Final design specifications and installation plans (e.g. sediment control, water control)
- The order in which the preceding occurred and the total time taken.

The observations were made in a controlled environment (the participant's home office) using a computer simulated problem rather than a real problem in the field. Thirteen industrial forest road supervisors (of a total population of fourteen), two New Brunswick government hydraulic engineers and three fish biologists (of a possible six) were sampled. Three main instruments were used: 1) a web-based computer program to track the nature and order of information requested to solve the problem (the PBLM (Zundel 1999)); 2) a retrospective interview on the problem solution and environmental risks and 3) the subject's handwritten notes and calculations. Table 2 gives some analysis of the 'tactic' recorded by the PBLM for one subject.

Table 2. Sample analysis of a forestry participant's tactic and consensus with peer group

Schema	Order	Query	Peer Usage
Orienting - Tenure - Location - Scope	1	Who owns the land?	**50%**
	2	Where is the site located in the province?	30%
	3	Request 1: 12500 map of road centerline and stream intercept	**50%**
	4	What is the area of the basin drained by the watercourse?	**100%**
	5	Request 1:50,000 topographic map	**60%**
Designing - Sizing - Type	6	View the DFO table of culvert diameters based on drainage area	**80%**
	7	What is the vertical profile (grade) of the stream?	30%
	8	How wide will the road traveling surface be?	**80%**
	9	Request price list for round structural plate steel pipe culverts	10%
Estimating - Pricing - Needs - Supply	10	Request price list for round corrugated steel pipe culverts	**50%**
	11	What are the approach grades of the finished road design?	**50%**
	12	What equipment is available for installing the structure?	**80%**
	13	Has the watercourse experienced previous alterations?	10%
	14	Contractor: How long do you estimate the installation will take?	20%
	15	What materials are available from suppliers for gravel fill?	40%

Although early in the analysis, we have noted phases of *orientation*, *design* and *resource estimation* in some tactics (indicated in Table 2). We have also compared tactics using pattern recognition and scoring methods. Pattern recognition methods measure the degree of consensus among subjects. The scoring methods score the subjects' environmental risk management performance from different stakeholder viewpoints. The simplest index of consensus is the percent use of an item by each group (e.g. the last column of Table 2 shows nine of this subject's fifteen queries were also made by at least 50% of his peers). This group of industrial forestry personnel relied heavily (80% usage) on a government-issue pipe sizing decision aid (item #6). This was distinct from the hydraulic engineers and fish biologists who derived the size using nomographs.

2.2 Limitations of this approach

We recognize several limitations of our approach. Although not measured, test anxiety was apparent in some cases. For example, one subject specified a bottomless arch culvert but it was later revealed in the retrospective interview that he had never before installed one. Also, participants could not view or experience the site as per usual except by photograph. The subjects often substituted the site conditions from their own license for those of the case problem site (e.g. soil type). It is possible that this substitution of the familiar is a coping strategy. These problems likely interfered with normal processing and affected the results. Another source of bias is the age-old problem of 'thinking about thinking': when assessing others' thinking the researcher determines how the experiment is framed, the quality of the observations, and how the data is interpreted. These limitations suggest that further trials under field conditions would be useful.

3.0 Conclusion

Forest engineering research in the past three decades has focused on machines (hardware) and formal systems (software). With the exception of a small amount of work on machine operators the human cognitive dimension ('wetware') has largely been ignored. The more recent focus on ergonomics and logistics should not preclude consideration of cognition in 'human factors' engineering. Studying psychological factors can help identify training and education needs, develop more realistic and helpful decision support systems and improve professional competence. Given the psychological demands on forestry professionals in practice, this research frontier may yield gains in efficiency and quality.

4.0 References

Barrows, H.S. 1985. How to design a problem-based curriculum for the pre-clinical years. Springer Publishing Co. Inc., New York. 148pp.
Björheden, R. 2001. Learning curves in tree section hauling in central Sweden. *Int. J. For. Eng*. 12(1): 9-17.
Gellerstedt, S. 2002. Operation of the single-grip harvester – motor sensory and cognitive work. *Int. J. For. Eng*. 13(2): 35-47.
McCallum, D. and Fredericks, I. 1996. The Utility of Risk Assessment and Risk Management in the ISO 14001 Environmental Management System Framework. *Presented at the Air and Waste Management Association 89th Annual Meeting.* June 23-28, 1996.
The Pembina Institute. 2003. Forest Industry Self-Inspection and Compliance in Ontario. 83pp.

Rimoldi, H.J.A. and Raimondo, R. 1998. Assessing the process of clinical problem solving. Advances in health sciences education. 3:217-230.

Society of American Foresters. 2000. Final Report of the Task Force on Forestry Education Accreditation. Society of American Foresters. Bethesda, MD. 32 pp.

Zundel, P.E. 1999. The Problem-Based Learning Module - Computer based professional education at a distance. *In*: Moore, R. and D. Devo [Eds.] *Proc. Atlantic Universities Teaching Showcase, Vol.4. Saint Thomas University* Fredericton, NB. October 15-16, 1999.

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OPTIMIZING THE COMBINED HARVESTING AND ROAD CONSTRUCTION COSTS FOR A DISPERSED HARVESTING REGIME

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INTRODUCTION

Planning for forest harvesting is based on two principal elements: road construction and the selection of cutover areas. Moreover, these elements represent the most significant timber harvesting costs. Forest planners can already use proven analytical tools to take these aspects into account when planning operations. Among these, the optimal road spacing model, which minimizes the combined road/forwarding cost, determines the size of the road network needed to provide access to an area (Matthews 1942, Thompson 1992, Plamondon *et al.* 1994).

In recent years, forestry has been at the centre of international discussions about sustainable development. In this regard, to promote the multiple use of forests while maintaining biodiversity, forest managers are reconsidering how to plan interventions in light of new forestry practices. Among these, methods that favour the distribution of cutovers over an area are likely to result in increased costs associated with establishing and maintaining the road network (Ketcheson 1982, Gingras 1997, Favreau *et al.* 2000, Nadeau 2002).

According to the road spacing model, fibre supply costs can be minimized by optimizing the forwarding distance. It therefore seems necessary to review current forwarding practices in order to include the possible consequences of the choice of cutover distribution in the cost of the road network. The analysis of a combined cost model was done to determine the effects of a dispersed harvest scenario on the forwarding distance and road construction costs.

Determination of the combined cost

The model used to calculate the combined road/forwarding cost was presented for the first time by Matthews (1942). This simplistic model is only valid for haul roads and presumes they are parallel and uniformly spaced. The equation that expresses the combined road/forwarding cost in relation to the forwarding distance is obtained by adding the cost of the forwarding function to the unit cost for road construction. The primary derivative of this function will determine the optimum distance that will minimize the combined cost.

Cutover dispersal and effect on the road network

Dispersing cutovers means that a larger territory must be accessed to harvest a given volume. Thus, because the distance between cutting blocks is greater, road construction must be accelerated during the initial years after implementing this system (Ketcheson 1982, Nelson *et al.* 1991, Hedin 1995). Also, the roads will be used for a longer period and will require maintenance and restoration to support on-going harvesting operations (Nadeau 2002). Consequently, there is a financial impact associated with moving up road construction costs and adding road maintenance and restoration costs.

As noted, dispersing cutover areas has a direct impact on overall road costs. Additional long-term capital and maintenance costs represent a significant financial burden, and must be considered when evaluating road spacing. Also, for strip cuts, Johnson *et al.* (1987) evaluated that an increase in the forwarding distance from 183 m to 366 m would reduce additional capital road costs by 26%. However, these authors did not integrate the increase in forwarding costs in their analysis; their hypothesis overestimates the true savings. A modification is therefore needed to take into account the true effect of combined road/forwarding costs when carrying out dispersed harvesting.

METHODS

The approach used was to compare the combined road/forwarding cost of a conventional harvesting scenario to the cost of a dispersed harvesting scenario. Simulations were carried out using the Matthews simplified model (1942), adapted from Plamondon *et al.* (1994). However, to take the importance of roads into account in a strategy favouring dispersed cutover areas, an adapted version of the model was created (Figure 1).

Combined road/forwarding cost :

$$C_{combined}\ (\$/m^3) = C_{roads} + C_{forwarding} = AEC \times \left[\frac{10}{2b(V)d}\right] + \left[\frac{C_{ope}}{58.61 d^{-0.2339}}\right]$$

$$AEC = \sum_{n=1}^{m} \frac{S_n}{(1+i)^n}\left[\frac{i(1+i)^m}{(1+i)^m - 1}\right]$$

Mean optimal forwarding distance (d_{opt}):

$$d_{opt} = AEC \times \left[\frac{10 \times 58.61}{2b(V)(0.2339)C_{ope}}\right]^{\frac{1}{(1+0.2339)}}$$

List of variables and symbols:

d :	Mean forwarding distance (m)
V :	Volume per hectare to harvest (144 m^3/ha)
b :	1 or 2; forwarding on one or two sides of the road (two sides)
C_{ope} :	Hourly operating cost of forwarder ($70/pmh)
AEC :	Equivalent annual road cost ($/km)
i :	Discount rate (5.8%)
S_n :	Annual expenditures
n :	Year (1, 2, 3, ..., *m*), where *m* is the analysis horizon

Figure 1. Establishment of the combined road/forwarding cost and the optimal mean forwarding distance [adapted from Plamondon *et al.* (1994)].

The comparative analysis was done using Montmorency Forest. This 60 km^2 territory has been managed for almost 40 years using a dispersed cutover regime. Records of forestry operations expenses for this period go back to 1963, which made it possible to prepare a complete picture of the costs pertaining to the road network (construction, maintenance and restoration).

Forwarding cost

The shortwood harvesting system was used for the analysis. Since no local data were available for the operating costs of the shortwood forwarder, the productivity equation in Plamondon *et al.* (1994) was used for the simulations. The cost of the operation is obtained by applying the hourly equipment rate to the calculated productivity.

Road cost

The overall road cost of the harvesting network was determined for the two intervention scenarios (conventional and dispersed). For the conventional scenario, the cost includes only the unit cost of construction. For the dispersed scenario, the additional capital and maintenance costs must be absorbed, therefore they are added to the unit cost of construction in order to generate an overall road cost.

The cost calculation is done on the basis of the equivalent annual cost (EAC) on a 60-year horizon, which is the rotation period. To express the cost in terms of $/km, the calculated annuity is divided by the mean length of roads that are constructed or maintained annually. At Montmorency Forest, the harvesting road network totals 87.4 km. Consequently, for the analysis horizon, mean annual construction is 1.456 km. Though these values may seem minimal in comparison to industrial operations usually encountered in Quebec, they are little influenced by the scale of the analysis.

Road construction

Establishment of the harvesting network at Montmorency Forest took 40 years. In comparison, a conventional scenario would have taken 60 years, assuming a constant annual development. At the end of the rotation, since all the wood has been harvested, it is presumed that independent of the scenario, the same road network would have been developed. However, to support the dispersed harvesting regime, more roads must be built at the start of the rotation, causing a desynchronization between road construction and harvest levels in the short term. The effect of the desynchronization comes from having moved construction costs forward. The EAC of road construction for the conventional and dispersed scenarios are $14,165/km and $17,399/km, respectively.

Road maintenance

Distributing the harvest over time and space makes it necessary to carry out additional maintenance and restoration work to maintain road quality. At Montmorency Forest, additional road maintenance and restoration work results in EACs of $1,097/km and $1,458/km, respectively. It is assumed that the conventional harvesting scenario would not entail these expenses, since the roads are generally used only while harvesting is carried out and are then abandoned until the next rotation.

Taking into account the additional costs associated with dispersed cutting areas, combining calculation hypotheses shows that road costs for conventional and dispersed scenarios are $14,165/km and $19,954/km, respectively.

Combined road/forwarding cost

Given that the road cost for the dispersed scenario is higher than for the conventional scenario, a comparison of the combined costs clearly shows that the optimal forwarding distance for the dispersed scenario will be higher than for the conventional scenario (Figure 2). The additional capital and maintenance costs increase the minimum combined cost by \$0.36/m^3, increasing from \$5.33/m^3 (Point A) to \$5.69/m^3 (Point C). The mean optimal forwarding distance therefore increases from 243 m to 321 m.

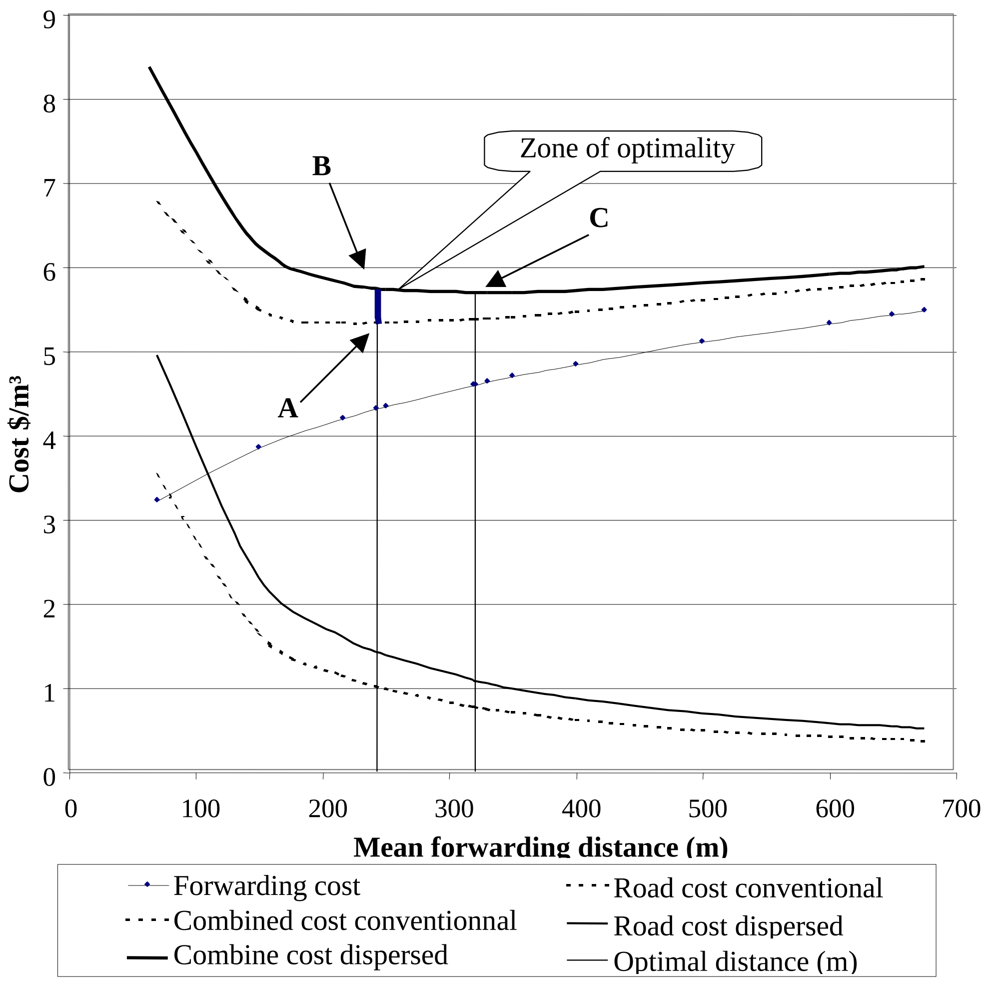

Figure 2. Comparison of the combined road/forwarding cost for the conventional and dispersed scenarios.

If the dispersed harvesting regime is introduced without increasing the forwarding distance, the system will not be optimized and will cost \$5.74/m^3 (Point B) rather than \$5.69/m^3 (Point A). Consequently, by increasing the mean forwarding distance it will be possible to reduce the combined cost, since to operate optimally, the forwarding distance in the dispersed scenario must be 321 m (moving from Point B to Point C). In this case, the increased distance will result in reducing the road network density from 2.05 km/km^2 to 1.56 km/km^2 and the associated road cost by \$0.35/m^3. On the other hand, the forwarding cost is increased by \$0.29/m^3. In this way, changing from a forwarding distance of 243 m to 321 m results in a reduction in the combined road/forwarding cost of \$0.05/m^3, or 1 percent of the total cost.

Analysis of results

When introducing the dispersed harvesting regime, the choice of a cutting pattern that will maximize the volume harvested per kilometre of road is of great importance, since it will directly influence the additional need for roads. Also, the maintenance costs will have a significant effect. Because the additional cost is borne by the dispersed scenario, a variation in the costs incurred will have a direct impact on the cost differential. At the other extreme, the road cost and the capital cost will result in little variation, since they affect the two scenarios in an equivalent proportion. Finally, another factor to consider is the choice of harvesting system, and therefore the type of forwarding equipment to use.

Notwithstanding these factors, for this analysis it was assumed that the conventional scenario was already operating at its optimal forwarding distance. In this regard, the behaviour of the combined cost function near its optimum is only slightly sensitive to a variation in the distance. It is therefore not surprising that there is such a low potential to reduce costs. However, if the conventional scenario had operated at a shorter than its optimum distance, the situation would have been different. For example, if the mean distance for the conventional scenario had been 150 m, the potential for reducing the cost would have been $0.48/m^3. Consequently, operating at a shorter distance than the system's optimum is more costly than is operating at a greater-than-optimum distance.

DISCUSSION

In the case of the Montmorency Forest, reducing the combined cost by using optimum spacing results in an annual gain of $720 (annual volume harvested: 12,000 m^3). Objectively, though the reduction is small, increasing the mean forwarding distance results in a net reduction of the combined cost and reduces the increase in road costs entailed by the dispersed cutting regime. However, when the implications of such an increase are taken into account, the potential gain is perhaps only illusory. For example, it is probable that an increase in the forwarding distance results in an increase in the frequency and severity of rutting. Moreover, because space to pile wood at roadside is limited, it is possible that operations could be complicated by such a measure, since increasing the depth of cutover blocks will increase the volume of wood delivered to roadside. Finally, it is not certain that the terrain will allow the operations manager to establish a wider-spaced road network. Hilly terrain and a complex drainage system will limit the possibility of increasing the forwarding distance. It is probable that in some regions, such an increase is impossible. Yet, any reduction in road density must be considered with great attention since the lost of productive area has become a major concern in several jurisdictions.

CONCLUSION

This analysis confirms that the optimal forwarding distance for a dispersed harvesting regime is greater than for a conventional regime. The increase is attributed to additional capital and road maintenance costs, factors that were adapted to Matthews' model. The calculation hypotheses used at the Montmorency Forest suggest that increasing the forwarding distance reduces the combined road/forwarding cost by 1 percent for a dispersed harvesting regime. However, though the analysis suggests that a reduction of the cost is possible, other factors must be taken into consideration.

REFERENCES

Favreau, J., Gingras, J.-F. 2000. Cost analysis of harvesting with dispersed cut blocks. FERIC Advantage Vol 2., no. 45, 5 p.

Gingras, J.-F., 1997. Harvesting with residual blocks or leave strips: an economic comparison. FERIC TN-263, 8 p.

Hedin, I. 1995. L'effet des coupes par petites trouées sur la planification, la mise en place et le déroulement des opérations. WSI 3358 FDC 311, CPPA Woodlands 76th Annual meeting, Montréal, March 1995. pp. 63–67.

Ketcheson, D.E. 1982. The impact of strip cutting on logging costs. Pulp and Paper Canada, 83(7):29–34.

Johnson, J.D., Smyth, J.H. 1987. Harvesting and renewal costs of stripcutting relative to those of clearcutting on shallow-soil upland black spruce sites in north central Ontario. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Report O-X-380. 15 p.

Matthews, D.M. 1942. Cost control in the logging industry. McGraw-Hill, New York, NY. 374 p.

Nadeau, F.-R. 2002. Analyse de l'influence de la dispersion des aires de coupes sur le coût d'approvisionnement dans un contexte de forêt mosaïque. Mémoire de maîtrise en préparation. Université Laval, Sainte-Foy, Qc.

Nelson, J.D., Finn, S.T. 1991. The influence of cut-block size and adjacency rules on harvest levels and road networks. *Can. J. For. Res.* 21(5):595–600.

Plamondon, J. A., Favreau J. 1994. Établir la distance de débardage optimale en fonction du coût des chemins. FERIC, FT-219. 8 p.

Thompson, M. A. 1992. Considering overhead costs in road and landing spacing models. *Journal of Forest Engineering* 3(2):13–19.

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EVALUATION OF SYNTHETIC ROPE FOR STATIC RIGGING APPLICATIONS IN CABLE LOGGING

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ABSTRACT – Provides a descriptive assessment of synthetic rope in static cable logging applications. Applications include guylines, intermediate support lines, tree straps, and snap guylines. Problems and potentials from trials were assessed from observations of researchers and logging contractors. Synthetic rope works well as a replacement for steel wire rope for these static rigging applications. Loggers were more likely to try additional applications after using synthetic tree straps. Strength of the synthetic rope was the single largest concern with users. Initial cost was a significant drawback for most logging contractors who tried synthetic rope during this study. Additional research is needed to determine damage and wear criteria for synthetic rope.

INTRODUCTION

Steel wire rope is used for many logging applications. This material has served the forest industry well in terms of strength, durability, and longevity. Steel wire rope is difficult to use because of properties which make it stiff, heavy, and unyielding. These properties cause fatigue, exhaustion, and may contribute to worker injuries.

An alternative to steel wire rope is synthetic rope. Garland et al. (2002) showed the characteristics and properties of synthetic rope make it suitable for use in logging applications. However, the suitability of synthetic rope for logging applications needs to be evaluated to determine which synthetic ropes are suitable candidates for replacement of steel wire ropes.

The objectives of this study were to replace steel wire rope with synthetic rope for selected logging contractors to reduce workloads, improve efficiencies with cable logging, and determine the extent to which synthetic rope is suitable for use in static rigging applications. Longer term use by loggers was seen as an important means to assess the rope and find new problems and opportunities.

Few studies have addressed the use of synthetic rope for static rigging applications in cable logging. Takumi (1998) assessed the use of synthetic rope as guylines for a mobile tower yarder. Technora synthetic rope in this study was found to have sufficient strength and fatigue life to be used as guylines. However, it was difficult to estimate the fatigue life and strength loss from the appearance of the rope. The study also found the synthetic rope lost strength more rapidly than steel wire rope. The study used the number of cycles over a sheave as the basis for residual strength measurements.

Synthetic rope in our tests is Amsteel Blue[1] and is made from ultra high molecular weight polyethylene (UHMWPE Dyneema fibers) which makes it lightweight yet strong (The American Group, 1997). On average, synthetic rope weighs 1/9th that of the same nominal diameter steel wire rope. The high strength to weight ratio makes synthetic rope a suitable candidate for static rigging applications commonly used in cable logging.

The Amsteel Blue rope is constructed of synthetic fibers woven into a 12-strand braid. The twelve strand braid yields the maximum strength to weight ratio and is comparable in strength to steel wire rope, yet floats. This type of rope has a high flex-fatigue life and wear resistance compared to other products made from UHMWPE.

Cost is a factor to consider when choosing materials for static rigging applications. On average, synthetic rope costs 2-4 times as much as similar diameter steel wire rope. Logging contractors are cost sensitive and the cost for synthetic materials must return added benefits that exceed the additional cost.

Static rigging typically requires line lengths of 100 to 250 feet for various rigging conditions. Typically, these lines are used to guy tail trees at the far end of yarding corridors. Coiled lines are often carried to these locations where they are rigged. Intermediate supports also require rigging for both the intermediate support jack line and the guylines which stabilize the support tree.

Tree straps are used to hang blocks and other rigging in trees. The size of these tree straps is determined by the size of the skyline on the yarder. Typically a steel wire rope 7/8 inch diameter tree strap or larger would be required to meet the current Oregon Occupational Health and Safety Administration (OR-OSHA) safety code (www.orosha.org/standards/div_7.htm). Steel wire rope tree straps are difficult to bend around a small tree and keep positioned while securing blocks, shackles, and other rigging hardware. This presents a safety hazard for tree climbers.

APPLICATIONS EVALUATED

Our research focused on the use of synthetic rope for four static rigging applications. The applications were:

- Guylines
- Intermediate support lines
- Tree straps
- Snap guylines

Five logging contractors were supplied test samples of synthetic rope for one or more of the rigging components listed. The longest trial lasted from 1999 to early 2003 (3.25 years); however, the same contractor had used one or more types of synthetic rope for 5.5 years. Other trials with the remaining four contractors are still underway.

[1] Amsteel Blue is a product of Samson Rope Technologies, Ferndale, WA. www.samsonrope.com. Mention of trade names does not constitute an endorsement by Oregon State University.

GUYLINES

The need for lightweight, flexible guylines is recognized in the logging industry. A steel wire rope guyline of 5/8 inch diameter, 150 feet in length weighs approximately 111 pounds. A similar guyline made of synthetic rope may weigh only 18 pounds. The purpose of a guyline is to support or stabilize a spar tree, tail tree, intermediate support tree, machinery or equipment.

Figure 1. Synthetic rope guylines and strap supporting tail tree block

Loggers carry guylines up and down steep, treacherous hillsides to the location of intermediate support trees or to the end of a yarding corridor where they are used on tail trees. Garland et al. (2002) found times for carrying a 150-foot coil of steel wire rope and coil of synthetic rope for 150 feet downhill did not differ significantly; however, carrying steel wire rope uphill took twice as long as carrying synthetic rope uphill. Although the downhill carrying times did not differ significantly, there was an obvious safety advantage of carrying an object that weighed 18 pounds versus one that weighed 111 pounds down a 45 percent slope.

Figure 2. Guyline wraps on a tree and shackled to another tree

Ten guylines were placed into service during the study period. Two 5/8 inch diameter, 125-foot guylines were given to each logging contractor for use in their cable logging operation. The guylines were used on a Diamond D210 swing yarder, John Deere 330LC yoader[2], Koller K501 yarder, and a Howe-Line Mark IV yarder. This variety of conditions and range of logging equipment commonly found in the Pacific Northwest provided a good basis for evaluation.

Guylines were configured with two buried spliced eyes, one on each end of the guyline. Buried spliced eyes yield the ultimate breaking strength of the rope (specified for testing) and are the simplest end termination to create. Typically guylines are shackled back to themselves when they are rigged in a tree. This allows a simple and fast connection method (Figure 1.) The other end is brought down to a tree or stump where it is terminated. Often, several wraps are made on the anchor tree or stump to take up excess length and the guyline itself terminated at another tree or stump in close proximity. Once wraps are made (Figure 2), the guyline is terminated with another shackle. The termination process involves making wraps on the termination tree or stump, bringing the line back over itself and wrapping the line until the slack is completely removed. The line is then shackled back to itself (Figure 3). This method is a suitable technique for terminating synthetic rope guylines.

[2] A yoader is an excavator-based cable yarder with no guylines to stabilize the machine itself.

Figure 3. Termination of guyline with shackle

Guylines must be tightened to provide stability. Synthetic rope guylines may be tightened sufficiently by hand because it is possible to pull the guyline tight without much sag (deflection) in the guyline. It is not always possible to pull the sag out of steel wire rope guylines to properly position the tree for loading.

Another tightening process can be done using the twister strap that involves using a stick or similar object to reduce the overall length of the guyline. This method yields residual strengths of approximately 80 percent of double the catalogue breaking strength. Yet another approach is to use a rigging chain and come-a-long (ratcheting pulling device) commonly used to tighten steel guylines. A way to employ the rigging chain approach is to use the grab hook end instead of the open hook end of the chain. Once the guyline is tightened, the rigging chain can be removed from the guyline with ease.

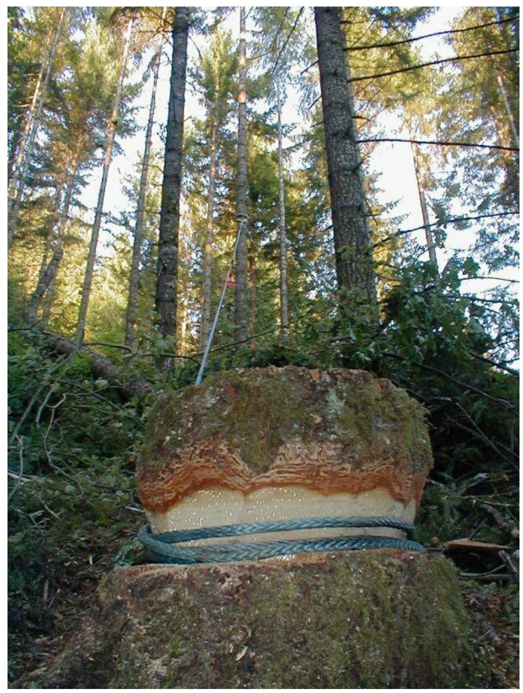

Figure 4. Synthetic intermediate support line

Testing of the residual strength of synthetic guylines was performed in a laboratory setting at Oregon State University. The guylines tested included both the 3.25 year use and the 5.5 year use ropes. The average residual strength for the 3.25 year use guylines (9/16 inch Amsteel Blue) was 15,341 pounds. The average residual strength of the 5.5 year use guylines (5/8 inch Amsteel Gray) was 16,720 pounds. The 3.25 year use ropes had a percent yield of 38% of the catalogue minimum breaking strength. The 5.5 year use ropes had a percent yield of 46% of the catalogue minimum breaking strength.

A potential benefit during rigging trees with synthetic rope may be the use of rappelling devices (used for rock climbing) to descend from the tree. Although not recommended in the current Oregon Division 7 Forest Activities Code, the use of a rappelling device such as a figure eight descender could reduce fatigue and rigging times by allowing the rigger to rappel down the tree instead of climbing down.

INTERMEDIATE SUPPORT LINES

Four trials were conducted to evaluate the use of synthetic intermediate support lines. The lengths tested included three 125-foot and one 250-foot intermediate support lines of 5/8 inch diameter synthetic rope. The most common rigging configuration consisted of attaching the intermediate support jack to the intermediate support line and terminating the support line at a stump or tree (Figure 4). Tightening and attaching the intermediate support line is similar to tightening a guyline.

A proper notch is needed when attaching synthetic rope to a tree or stump. If the cuts made to form the notch do not match, they produce a recess from the saw kerfs between the horizontal cut and the beveled cut. When a load is placed on the line, rope will "bite" into the recessed kerfs. This makes removal of the line difficult when heavy loading occurs during yarding. Matching the horizontal and bevel cuts of the notch avoids this problem.

TREE STRAPS

Three trials were conducted to evaluate the use of synthetic tree straps. One tree strap was configured in an endless loop design while the other two were configured as a single strap with a buried spliced eye at each end. The endless loop design was preferred by one logging contractor because the splice used to construct the endless loop actually increases the stiffness of the tree strap. The single strap with spliced eyes is a more common configuration found in the Pacific Northwest.

Tree straps are wrapped up in the tree above a branch whorl to aid in stability. A block is then attached directly to the tree strap or with the aid of a shackle (Figure 5). The tree strap may be configured in a basket design where the end is fed through the opposite end of the sling (endless loop), or the single strap with eyes are brought together and attached to the block. The tree straps used in this study were 7/8 inch diameter Amsteel Blue ™. The specific advantages of these two designs were not the focus of this study; however, the following observations came from the trials:

Figure 5. Synthetic tree strap, endless loop design

1) When constructing an endless loop design, the length of the strap when stretched should be no shorter than 6 feet. Any length shorter than this is unpractical for most tree sizes (14 inches – 26 inches) found in the Pacific Northwest.
2) The single straps with eyes were 20 feet long. The extra length of this design allowed the strap to be wrapped multiple times around the tree providing more stability than with a shorter strap.

Stiffness of material is a factor to consider when selecting a tree strap. Because steel wire rope is quite stiff, it is difficult to wrap around a tree, hold in position, and attach rigging. Synthetic rope can be wrapped around a tree quite easily and results in less rigging time. Garland et al. (2002) found that the time to rig an intermediate support tree was on average two minutes longer with steel wire rope than synthetic rope. This time difference was attributed to the increased difficulty (i.e. properties) of steel wire rope. The steel wire rope used was 5/8 inch diameter, considerably more flexible than 7/8 inch steel wire rope. Significant gains can be achieved with synthetic rope to replace the larger steel tree straps commonly used.

SNAP GUYLINES

One snap guyline was evaluated during this study period. The purpose of a snap guyline is to prevent the yarder tower from overturning backwards in case of skyline or mainline failure. The snap guyline is simply a safety mechanism for some yarder towers. The snap guyline was used on a Koller K300 yarder and was 5/8 inch diameter by 100 feet. The snap guyline was shackled to the top of the tower, and terminated at a stump or tree in the direction of the yarding corridor. It is usually only necessary to tension the snap guyline by hand. The light weight and ease of use might increase use of a synthetic snap guyline for logging crews.

DISCUSSION

This study evaluated the use of synthetic rope to replace steel wire rope in static cable logging applications. The assessment of each application was descriptive and based on observations made by researchers and logging contractors.

Synthetic rope guylines proved to be suitable for replacing steel wire rope guylines. The reduction in weight, ease of use, and simplicity in rigging are all benefits. The average breaking strength of two used 9/16 inch Amsteel Blue guylines was 38 percent yield (15,341 pounds) of catalogue minimum breaking strength. These guylines would have been suitable for use on skylines up to 5/8 inch diameter. The ropes tested for residual strength were of normal wear that is specified by the rope inspection and retirement guidelines set forth by The American Group (1997). Further research is needed to establish retirement guidelines for used synthetic rope guylines.

Visual inspection of the used guylines did not indicate any severed or cut strands. It is important to acknowledge that most logging equipment has sharp metal edges which can damage synthetic rope and reduce residual strength. Eliminating the contact with sharp metal edges will provide a longer service life from synthetic rope.

A technique used but not evaluated during the trials is the potential use of rappelling devices for descending trees. This approach should be further evaluated to determine the feasibility and implications for safety code inclusion.

Synthetic intermediate support lines have distinct advantages over steel wire rope. With steel wire rope lines, initial raising of the support jack often requires a come-a-long and can be a tedious process to raise the support jack to an acceptable height. With the reduction in weight, synthetic rope can be raised much easier and often without the aid of a come-a-long thus saving time and increasing efficiency. Wire rope uses u-bolt clips or Crosby clamps to secure guylines or intermediate support lines, while synthetic rope offers a reduction in the time spent rigging and de-rigging because a shackle is the only terminal connection. Other quick terminations may be on the horizon for synthetic rope as research continues.

Synthetic rope tree straps were immediately acceptable as replacement for steel wire rope straps. Once logging contractors felt comfortable with the strength and durability of synthetic rope in this application, they were more likely to try other applications such as guylines or intermediate support lines of synthetic rope. A pre-conceived notion about the strength properties was the largest factor of concern for loggers during these trials. The basket design and single strap with eyes were the only tree strap configurations studied during these trials.

Synthetic snap guylines are safety measures for cable logging and are easy and simple use. One logging contractor was more likely to use synthetic rope for this application due to the lighter weight of material and ease of rigging.

CONCLUSIONS

This preliminary evaluation of synthetic rope for use in static rigging applications shows synthetic rope to be suitable for replacing steel wire rope in these applications studied. Further analysis to determine damage and wear criteria is suggested to identify replacement criteria for ropes in various applications.

Cost of the synthetic rope is an initial drawback for most logging contractors. However, the benefits of using synthetic rope for static rigging applications in cable logging seem to outweigh this concern. Benefits such as decreased rigging times, reduced workloads due to lighter weight materials, ease of use, and a potential to increase production are factors to consider when assessing the cost-benefit ratio between steel wire rope and synthetic rope.

REFERENCES

Garland, J., J. Sessions, S. Pilkerton, and B. Stringham. 2002. Using Synthetic Rope to Reduce Workloads in Logging. Final Report, Worksite Redesign Program. Oregon Occupational Safety and Health Administration. Portland, OR.

Oregon Administrative Rules, Chapter 437, Division 7, Forest Activities Code (draft), Oregon Occupational Health and Safety Administration. Salem OR. www.orosha.org/standards/div_7.htm. Retrieved May 27, 2003.

Takumi, U. 1998. Application of Super Fiber Rope as a Guyline for a Mobile Tower Yarder. P. 70-75 in Proceedings of the IUFRO/FAO Seminar on forest operations in Himalayan forests with special consideration of ergonomic and socio-economic problems, Heinimann, H.R. and J. Sessions (eds.). Kassal University Press, GmbH. ISBN 3-933146-12-7. 160p.

The American Group. 1997. Marine and Industrial Ropes. Rope catalogue. Ferndale, WA. 39p.

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SKOG
FORSK
Claes Löfroth
2003-06-13

IT-study in four haulage rigs brings

greater fuel economy with training and better roads

Driving habits affect fuel economy. A comprehensive study of four round-wood haulage rigs showed differences up to 8% between drivers on the same rig. Better roads also improve fuel economy.

Our TRANSMIT project used a computerized system that automatically recorded continuous operational data on four roundwood rigs. The project was designed to gather data to help reduce fuel consumption.

On designated reference roads we found that fuel consumption could vary up to 15% for different drivers, showing a significant potential to increase fuel economy.

After special training for fuel efficient driving (named Heavy EcoDriving), fuel consumption could be reduced 10% without changing average speed. Six months after completing the training, fuel consumption remained three to five percent better.

The quality of the road is also important. Comparatively, the worst surfaced roads caused 25 to 40% higher consumption than the best roads. Hauling on forest roads could require 70% more diesel compared to the best paved roads.

Facts: Millions of data from four haulage rigs

Operational data were gathered from four roundwood haulage rigs. A computer was linked to the 'black box' of each rig to register RPM, fuel injection and such. A GPS receiver kept track of the rigs' position the entire time. The drivers added information about the quality and type of road, load, and such.

Every morning the data was down-loaded wirelessly to Skogforsk. The rigs were driven a total of 720,000 km in just over a year of study.

The project involved collaboration between Hogia Innovation AB, Telia Mobile AB, Scania Infotronics AB, Volvo Truck Corp. JF Skogs AB Södra Skogs-ägarna, Holmen Skog AB and Skogforsk.

150 million liters diesel annually

Every year the Swedish forestry industry transports some 60 million cubic meters roundwood from the forest to production facilities. This costs SKR 2.8 billion (US$ 310 million), of which one quarter is fuel costs. A hauler driving 170,000 km annually spends over SKR 500,000 on diesel alone. All told, Swedish roundwood haulers consume some 150 million liters diesel in a year.

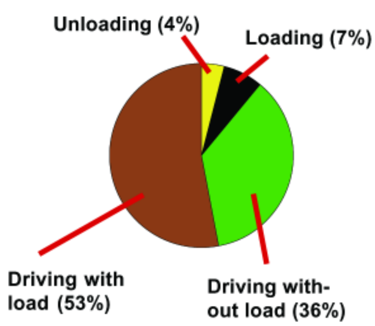
We started project TRANSMIT to get basic data on the fuel economy of roundwood haulage rigs under varying conditions. We gathered operational data from haulage rigs for analysis, and found:

n The average transport took approximately 4.4 hours, including 35 and 20 minutes, respectively, for loading and unloading.
n The average speed underway was 50 km/h (not loading and unloading).
n Each truck averaged 800 ton(metric)/km transport work.

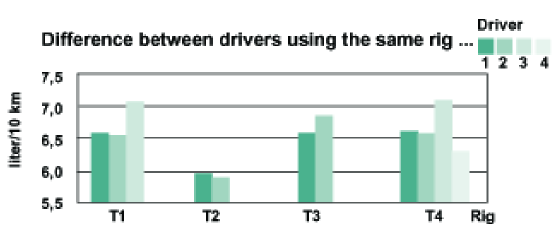
We recorded 7.7 million data in over a year. Altogether these provide a clear picture of the rigs' fuel consumption.

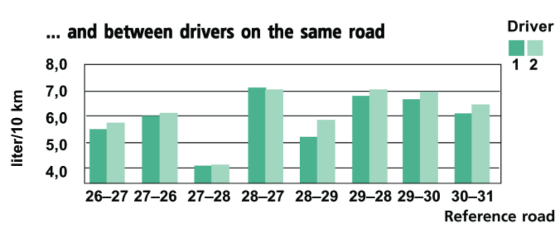
Seasonal Affects
Our findings show nearly 9% higher fuel consumption in winter compared to summer.

Work moment
More than 50% of total fuel consumption for all four rigs went to driving while loaded. Loading and unloading used only 11%.



Clear difference between drivers





The operational data showed significant differences in fuel consumption between each of the four rigs, as much as 15%. But the rigs can't be compared due to differences in road quality, load characteristics, mean transport distance, and such.

We did compare drivers on each rig and found significant differences, up to 8%. The average was 4% between the 'best' and 'worst' driver using the same rig.

Drivers also showed significant differences when driving the same reference road. Which shows that fuel economy can be improved with better driving habits.

Higher fuel consumption

on poor roads

The study had the drivers enter data on the quality of the roads they drove. This was compared for fuel consumption and shows that consumption was 25 to 40% higher on the worst paved roads compared to the best. The difference in fuel economy was 65 to 70% between the worst quality forest roads and the best paved roads. The road quality also affected average speed, where we found that on:

- Gravel roads average speed was 30 to 50 km/h.
- Poor paved roads average speed was 50 to 60 km/h.
- Better paved roads average speed was 60 to 90 km/h.

REFERENCE ROADS

To check our data for the effects of road quality on fuel consumption, several reference roads were selected. GPS was used to register every time a truck drove on these roads.

In northern Sweden, a significant difference in fuel economy between gravel roads and paved roads was found. In southern Sweden, all our reference roads were paved, so the differences between these roads were less.

GOOD PAVEMENT ON THE REFERENCE ROAD

The reference road clearly showed the effect of road quality on fuel economy. The reference road was paved with asphalt during the study period. Driving on the gravel section showed 11% higher fuel consumption than on the paved part.

CONCLUSION

Previously, good roads were shown to increase traffic safety and benefit rational forestry. Our study shows that good quality roads also increase productivity and fuel economy for industrial roundwood haulage.

Better roads are certainly good for both the economy and the environment.

Heavy EcoDriving is specialized training to improve economic driving habits. This includes theoretical study and practical training. All the drivers in Project TRANSMIT took part in this training.

They started by driving 25 km 'as usual', that is, without any instruction. Then the drivers received critique and tips about their driving habits. They then got a chance to use this information to drive the same 25 km stretch of road.

Improvement in fuel economy averaged 10% the second time around, even though they kept the same average speed. This finding can result from the drivers focusing on fuel economy during the test. However, three to ten months after the course, the drivers showed 3 to 5% lower fuel consumption than before undergoing the training.

Heavy EcoDriving was developed by the Transport Unions Occupational and Work Environment Board with the National Association of Driving Schools and the Department of Roads.

General Tips for Heavy EcoDriving

- Plan ahead, plan breaking ahead of time, use the motor break.
- Accept reduced speed on uphill.
- Use the momentum a 60 ton rig naturally has. Ease of the gas and drive 'on air'.
- Accelerate with the gradient.

New Project: REDUCE
PDA Saves Fuel

Though Project TRANSMIT is over, another project has started, named REDUCE. For this, we'll continue with the same haulage rigs, drivers, and reference roads as we had in TRANSMIT. The new project will test regular PDAs that would show fuel consumption compared to an optimal value. An alarm signals when the driver exceeds a set variance. As well, the driver can see when driving is unnecessarily rough, where acceleration or breaking is too hard. The PDA can also recommend the correct gear.

Hauling in Sweden

n One of the 1,500 timber rigs, that transport a total of 70 million cubic meters of timber a year.

n The average haulage distance in Sweden is 80 km long.

n The max load for a timber rig is 60 tons and 10 tons axle pressure (with bogie, 18 tons). Max dimensions are length 24 meters, breadth 2.6 m, and height 4.5 m.

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CO_2 FIXATION IN POPLAR I-214 PLANTATIONS AIMED AT ENERGY PRODUCTION

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ABSTRACT

CO_2 fixed in two year rotation plantations of poplar I-214 for energy production is studied. The experimental site is located in Cabrerizos (Salamanca). Estimated productivity ranged from 18 to 26 odt/(ha·yr). The results obtained for the lowest estimate (18 odt/(ha·yr)) show that CO_2 fixed reaches 5,992 kg/ha and 234.64 kg/kWh produced.

INTRODUCTION

The Plan for the Development of Renewable Energy Sources in Spain (IDAE, 2000), passed by a Ministers Council on December 30th 1999, stresses on the so called "ligneous crops" as an energy source. The growing of I-214 is one of the crops to consider. In other countries willow trees (Labrecque *et al.* 1995, 1998) and other hardwood plantations (Stokes, 1993; McDonald and Stokes, 1994) are used.

In addition, the Kyoto protocol in 1997 intended to implement some measures so that the atmospheric CO_2 was fixed to the ground rather than ascending continuously to the atmosphere when fossil fuels are burned.

OBJECTIVES

The objective of this communication is to determine the amount of CO_2 fixed by the energy crop. In order to accomplish this objective, the methodology developed by Fernández (1998) and Lewandowski (oral communication) has been followed. This methodology has been modified by Marcos et al. (2000) and has been adjusted according to the data provided in the literature and consultations to experts. The experimental site is located in Cabrerizos (Salamanca) where a two year rotation crop for energy production with a density of 33,333 plants per hectare has been established (Marcos et al, 2002).

METHODOLOGY

The estimates of CO_2 fixed per electric kWh produced will be calculated on the assumption that the I-214 biomass is transported to a thermal power plant where it is burned to produce electric energy. Two stages can be identified in the calculation process:

Stage A: Growing + transportation to a thermal power plant.

- Dry matter production (odt/(ha·yr)). Following publications by San Miguel and Montoya (1984) and San Miguel et al. (1992), an initial production of 18 odt/(ha·yr) will be assumed.

- Amount of carbon per ton of dry matter: The figure of 500 kg (that is, 50%) will be considered based on the average data used by Marcos et al. (2000) after a thorough bibliographic review. Rueda (1997) also assumes a carbon percentage of 50% for *Populus tremula*.

- CO_2 fixation: Similarly to other agroenergy species (Fernández, 1997), it can be assumed that 1.25 grams of carbon are fixed per gram of carbon fixed in the wood. The remaining 0.25 is the amount fixed in the mineralization process, the floor humus and the roots attached to the stump. In this kind of crop, the stems are cut every two years along a six to eight year cycle. At the end of the 3rd or the 4th cut, the stumps must be crushed and incorporated to the ground.

- CO_2 emission: According to Fernández (1997), a total value of 0.77 tons of CO_2 per hectare and year are sent to the atmosphere as a result of the planting, fertilizing, maintenance, weed and pest control operations carried out in crops of thistle (*Cynara cardunculus*). This figure comes from the contribution of machinery (0.25 t), raw material including seeds, fertilizers, herbicides and pesticides (0.46 t), and biomass transportation to the power plant (0.06 t). In the case of poplar I-214, an accurate calculation should be done, but initial estimates in Spain and Chile have given values around 0.77 t. Irrigation has been considered at the end of the calculations as a reduction factor, since it strongly depends on the area where the I-214 plantation is carried out. The reference datum for irrigation is 76 grams of CO_2 per each MJ used in water pumping.

Stage B: Combustion and electrical energy generation.

- Anhidrous high heat value: A value of 4,200 kcal/kg = 17,556 kJ/kg has been considered. Following Gimeno (1989), the values of the high heat value for the wood of *Populus nigra L* range from 4,449 kcal/kg (Fabricius and Gross) to 4,601 kcal/kg (Feher), therefore the value of 4,200 kcal/kg seems acceptable according to published results of a series of laboratory analyses (Elvira and Hernando Lara (1989)) and the expected value taking into account the I-214 wood chemical composition.

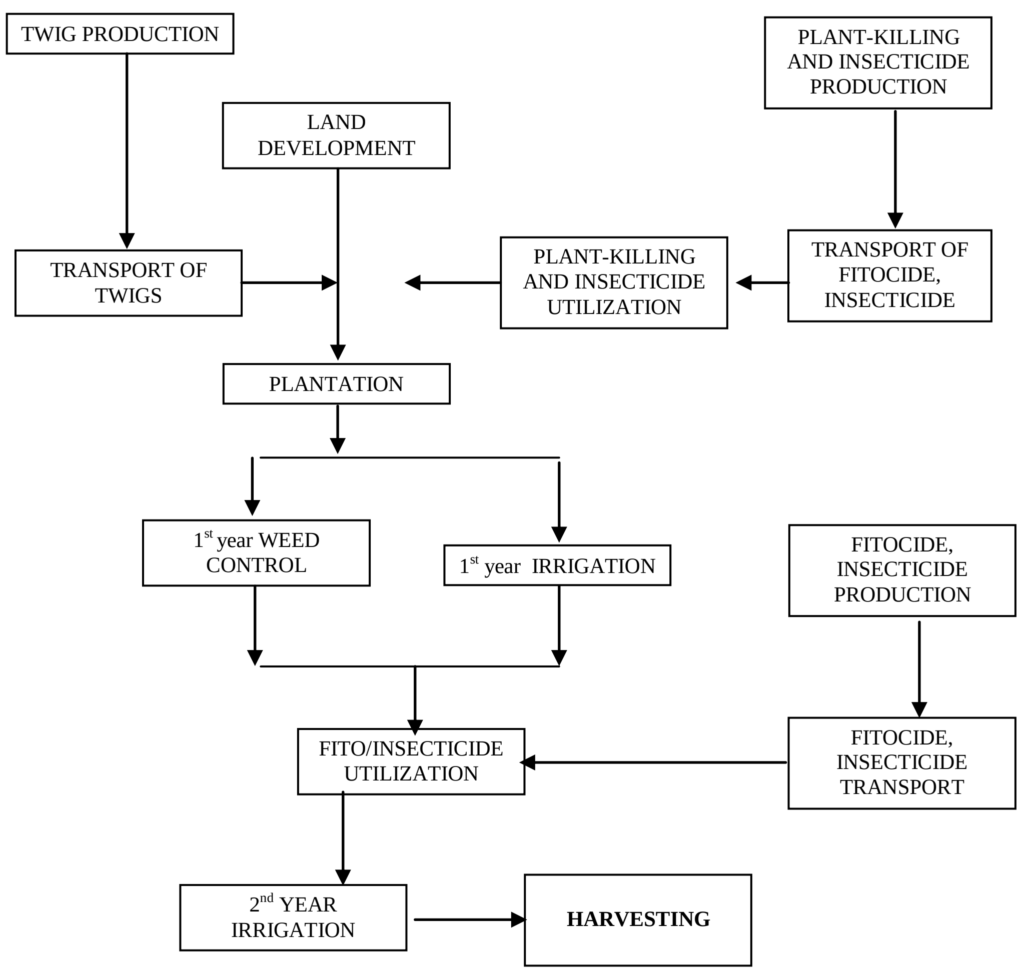
- Thermal plant working hours: The value of 6,750 hours/year has been selected according to data from the Spanish Atomic Forum and the International Energy Agency (IEA).

- Energy efficiency in terms of electrical energy is calculated as the quotient between the number of electric kilowatt-hour (kWh) and the product of the mass by the reference heat value of the proposed plant, and is equal to 30% because of the good combustion characteristics of the poplar wood. The ashes and the solid particles obtained in the combustion process are recycled in the same plantation site, thus closing the nutrient cycle.

- The unit conversion is given by: 1 electric MJ = 0.2777 electric kWh.

- Drying: It has been estimated that 3% of the available energy is spent in the drying process. Natural drying and a countercurrent drying place are used for that purpose.

The methodology used in the research is summarized in a flowchart as follows:



RESULTS

Balance of CO_2 fixed:

Since the CO_2 gram molecule weighs 44 g and contains 12 g of carbon, the amount of CO_2 fixed (FI) may be calculated as FI = 18,000 kg · 0.5 · (44/12) · 1.25 = 41,250 kg = 41.25 t of CO_2 .
The CO_2 emission during Stage A, growing + transportation, (E1) is equal to 0.77 t of CO_2.
The amount of CO_2 emitted during the combustion process (E2) is given by:

$$E2 = 18{,}000\ \text{kg} \cdot 0.5 \cdot (44/12) = 32.99\ \text{t of}\ CO_2/\text{ha}$$

The balance of CO_2 fixed per hectare (BA) is calculated as:

$$BA = FI - E1 - E2 = 41.25 - 0.77 - 32.99 = 7{,}490\ \text{kg}\ \ CO_2/\text{ha}.$$

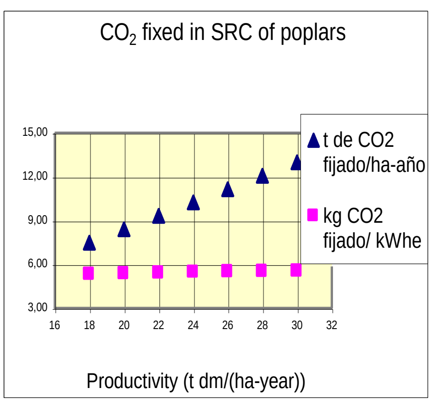
Electrical energy production: The electrical energy obtained is given by:

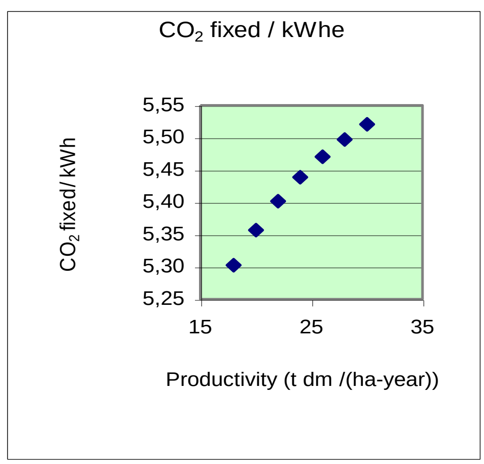
$$18{,}000\ \text{kg} \cdot 17{,}556\ \text{kJ/kg} \cdot 0.3 = 94{,}802.4\ \text{MJ} \cdot 0.2777\ \text{kWh/MJ} = 26{,}326.626\ \text{electric kWh}$$

Since 3% of the energy produced is spent in the drying process, the available energy (PE) is equal to PE = 26,326.626 kWh ·0.97 = 25,536.83 $kWh_{e.}$ The installed power can be obtained in the following way 25,536.83 kWh / 6,750 h = 3.78 kW.
The balance of CO_2 fixed in relation to the electrical energy produced (BAE) is given by:

$$BAE = BA/PE = 7{,}490\ \text{kg} / 25{,}536.83\ \text{kWh} = 293.30\ \text{g/kWh}$$

This figure is above the 214 g/kWh quoted for the thistle crops (Fernández, 1997), but it must be recalled that in this work two main assumptions have been made: there is enough water for irrigation and a dry matter production of 18,000 kg/(ha·yr) is attained. Assuming that 76 grams of CO_2 are emitted per MJ of energy used in water pumping, the latter values are cut down by 20%, that is BA = 5,992 kg of CO_2 fixed per hectare, BAE = 234.64 g of CO_2 fixed per electric kWh produced.This value is still slightly higher than the figure of 214 g/kWh obtained by Fernández (1997) in thistle crops. The relationship between biomass yield and CO_2 fixed is shown as follows:





REFERENCES

Elvira, L. y C. Hernando-Lara. 1989. *Inflamabilidad y energía de las especies del sotobosque.* INIA. Madrid.

Fernández González, J. 1997. La biomasa como energía alternativa para reducir el CO_2 atmosférico. *Homenaje a D. Angel Ramos Fernández*. pp. 1265-1286. E.T.S. de Ingenieros de Montes. Real Academia de Ciencias Exactas, Físicas y Naturales. Academia de Ingeniería. Madrid.

Gimeno, C. 1989. Poderes caloríficos de especies forestales españolas. *Tesis Doctoral*. Madrid.

Labrecque, M., T. I. Teodorescu and S. Daigle. 1995. Effect of wastewater sludge on growth and heavy metal bioaccumulation in two *Salix* species. *Plant and Soil*. 171: 303-316.

Labrecque, M., T. I. Teodorescu and S. Daigle. 1998. Early performance and nutrition of two willow species in short-rotation intensive culture fertilized with wastewater sludge and impact on the soil characteristics. *Canadian Joural of Forest Research*. 28:1621-1635.

Instituto para la Diversificación y Ahorro de la Energía. 2000. *Plan de Fomento de las Energías Renovables en España*. IDAE - Ministerio de Industria. Madrid.

Marcos Martín, F., I. Izquierdo Osado and J. Ruiz Castellano. 2000. Cultivos energéticos de chopos. *Revista Forestal Española*. 26:4-14. Madrid.

Marcos Martín, F. 2001. *Biocombustibles sólidos de origen forestal*. AENOR. Madrid.

Marcos Martín, F., S. Villegas Ortiz de la Torre, F. García Robredo, I. Izquierdo Osado and J. Ruiz Castellano. 2002. Two year - rotation plantations of poplar trees for energy. *Proceedings of the 25th Annual Meeting of the Council on Forest Engineering.* Auburn, Alabama.

McDonald T. P. and B. J. Stokes. 1994. Harvesting Costs and Utilization of Hardwood Plantations. *Proceedings of the IEA/BA Task IX, Activity 1.* USDA Forest Service. Auburn. Alabama.

Rueda, J. 1997. *La madera de chopo y sus aplicaciones*. Junta de Castilla y León. Valladolid.

San Miguel Ayanz, A. and J. M. Montoya. 1984. Resultado de los cinco primeros años de producción de tallares de chopo en rotación corta (2-5 años). *Anales del Instituto Nacional de Investigaciones Agrarias. Serie: Forestal*. 8: 73-91. Madrid.

San Miguel Ayanz, A., J. San Miguel Ayanz and S. Yagüe. 1992. Tallares de chopo a turno corto. *19ª Sesión de la Comisión Internacional del Álamo*. Zaragoza.

Stokes, B and Bruce R. Hartsough. 1993. Development and analysis of SRIC harvesting systems. In. *Proc. First Biomass Conference of the Americas, 1993;* August 30- September 2. Burlington VT. National Renewable Energy Laboratory , Golden, CO. 302-308.

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PRODUCTION ECONOMICS OF TWO MECHANICAL HARVESTING SYSTEMS

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Abstract

This study reviews the production economics of two mechanical harvesting systems in the Pacific Northwest of the United States of America. The first system was a Logmax 750 processing head on a Caterpillar 322 Forest Machine working in a Douglas fir dominated stand. The other system was a Valmet T500 cut-to-length system operating in a Ponderosa pine stand in Eastern Oregon. The results indicate that in both operations a stronger emphasis needs to be placed on looking at ways to increase value recovery as opposed to just trying to increase productivity. This is particularly true in high value stands.

Introduction

The use of mechanical harvesting systems is on the increase worldwide. In Scandinavia almost 100 percent of logging is carried out using mechanical harvesting systems (Chiorescu and Grounlund 2001). Within the last 10 years the number of harvesters and processors sold in eastern Canada increased from 200 to 900 (Godin 2000) and in North America 20 to 30 % of logging is done with cut-to-length systems (Gellerstedt and Dahlin, 1999). In Australia, mechanization has almost eliminated motor-manual felling in radiata pine thinning operations (Raymond 1988). Although there are a number of factors driving this trend, by far the most important driver is the increases in productivity that can be obtained from using mechanical harvesting systems.

There are numerous production studies in the literature that have been performed on mechanical processing systems, however few have considered both the revenue and cost sides of the production economics equation. Due to the high capital and running costs of these modern harvesters, maintaining high productivity is vital to the profitability of these machines. However, significant value can be lost and gain through log bucking decisions (Murphy 2003). For this reason it is essential to assess both the costs and revenues generated by these machines when calculating the production economics of a system.

This paper looks at the production economics of two mechanical harvesting systems; it investigates the relationship between productivity and value recovery.

Field Sites

The following is a description of the selected study sites and harvesters. The sites for this study were selected based on their logistics (location and crew willingness to be studied) and the number of log grades being cut.

Site 1 was a Douglas-fir dominated stand in southern Washington State. A Logmax 750 harvesting head was being operated on a Caterpillar 322 Forest Machine. The harvester essentially sat at one location processing stems brought to it using a shovel. The stand was clearfelled and had an average DBH of 46 cm and an average stocking of 273 stems per hectare. The average tree size was 2.35 m^3.

Site 2 was a ponderosa pine stand in Eastern Oregon. The site was located on the hills just outside John Day. At this site a Valmet T 500 harvester was operating in a cut-to-length thinning operation. The average DBH was 27 cm with an average stocking of 415 stems per hectare prior to thinning and 102 stems per hectare post thinning. The average tree size for the selected trees was 0.35 m^3

Data Collection and Analysis

The data collection and analysis procedures were similar for both sites; they can be divided into two sections; machine costing and productivity, and value recovery.

Machine Costing and Productivity

The percent utilization and mechanical availability of the harvesters was determined by surveying the literature for production studies of harvesters operating in similar situations to those described above. Detailed productivity was determined by recording at least 5 hours of video of each machine working under "normal" operations. The videos were then analyzed using activity sampling. Activity sampling was first developed in 1934 by Tippett. The technique involves taking snap-readings of the element or activity that is occurring at the time the reading is taken. These snap-readings can be taken at either set or random time intervals. Due to the semi random nature of these operations snap-readings were taken at set time interval of 15 second. The results of these time studies were used to calculate the productivity in terms of trees and cubic volume per hour.

The costs were calculated using standard costing procedures described in Bushman and Olsen (1988). The productivity and cost information was combined to come up with a cost per productive machine hour (PMH) for the whole system. It was assumed that the harvester would always be the machine that limits the productivity of the whole operation.

Value Recovery

Log specifications and prices that were being used at each site to merchandize each stem into logs were obtained from the forest owners. The Douglas fir market included nine log-types; individual log-types could have multiple lengths. Log lengths ranged from 3.6 to 12.2 m. The highest value log-type was an export grade saw log with an average stumpage value of US$157 per m^3. The lowest value log-type was pulp with a value of $22 per m3. The ponderosa pine market included three log-types; individual log-types also had multiple lengths. Lengths ranged from 2.4 to 6.7 m. The highest value log-type was a saw log with a value of US$ 62 per m^3. The lowest value log-type was a chip log with a value of $4 per m3.

At each site 100 trees were selected, they were felled and left on the ground. Detailed measurements were made of each stem. These measurements included; the total length, diameter at regular intervals up the stem, location of detects, the magnitude and location of changes in branch size and stem form. Once all the stems had been measured the operator of the harvester/processor merchandized the stem as he would have normally done. The length and grade of all the logs were recorded, the value of the logs cut was then determined.

An optimal bucking algorithm based on dynamic programming techniques was developed to calculate the optimal value for each of the stems measured. The algorithm used the log specifications, prices and the detailed log measurement for each log to find the combination of log grades and lengths that yielded the maximum value for each individual stem. The log volume was calculated using cubic foot scaling at the Washington site and eastern side scriber scale was used for the eastern Oregon site.

Results

Machine and Costing Productivity

The productivity data was collected for a total of 256 and 364 trees at the Washington site and John Day site respectively. At Washington the productivity was 145.98 m^3 per PMH which was considerable more than the John Day site where the harvester had a productivity of 23.94 m^3 per PMH. On average the harvester at the Washington site was processing 63 trees per hour compared to the harvester at the John Day site which was processing 68 trees per hour. Figure 1 gives the proportion of time spent on each of the activities involved in processing a stem. The difference in the productivity between the two sites can be attributed to the difference in tree size, operation (cut-to-length versus on-landing-processing), and tree species.

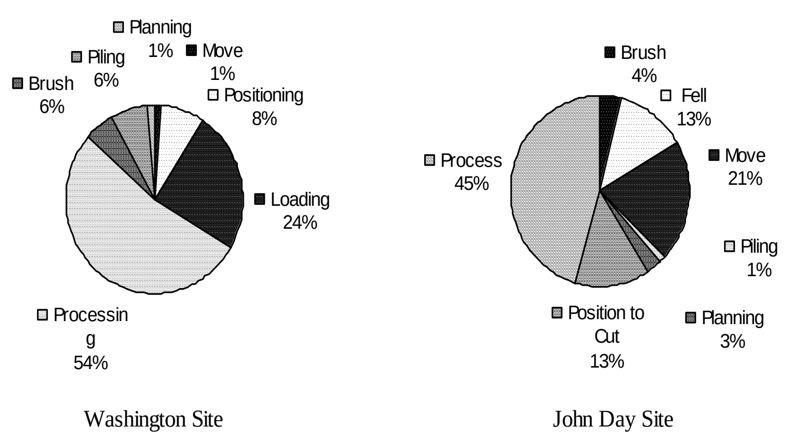

Figure 1. Productive time distribution for mechanical processing.

The graphs show that for both systems approximately half the harvester's time is spent processing the log.

The cost per PHM is given in Table1 for the two different systems. The costing assumes a 75 % utilization rate.

Table 1. Productive Machine Hour Costs.

Site 1 (Washington)		Site 2 (John Day)	
Machine	Cost ($/PMH)	Machine	Cost ($/PMH)
Harvester	$ 179	Harvester	$ 169
Shovel	$ 137	Forwarder	$ 118
Loader	$ 139	Loader	$ 79
Total	$ 455	Total	$ 364

Value Recovery

The value recovery studies gave the results outlined in Table 2. The value of the trees at the Washington site is over 20 times that of the trees being harvested at the John Day site. Based on the productivity calculated for each harvester the value of the tree processed per PMH equals $15926 for the Washington site and $673 for the John Day site.

Table 2. Theoretical Optimal and Actual Value Recovery

	Washington Site (Douglas fir)	**John Day Site (ponderosa pine)**
Total Optimal Value (100 trees)	$ 27613	$1185
Total Actual Value (100 trees)	$ 25367	$985
Percentage Value Recovery	92%	83 %

These results are above the average for mechanical harvester systems. A recent international survey of value recovery studies indicated that mechanical log making systems were losing on average 21 percent of the potential value and this compare with manual log making systems that were losing on average only 11 percent of the potential value (Murphy 2003).

Production Economics

These costing and value recovery results can be used to calculate either how much extra time can be spent processing each stem or the investment in the harvester that can be made to obtain the optimal net profit per tree. The calculation is a simple breakeven analysis using Equation 1.

$$R_{optimal}(\$/tree) - \frac{C_{optimal}(\$/hour)}{P_{optimal}(trees/hour)} = R_{current}(\$/tree) - \frac{C_{optimal}(\$/hour)}{P_{current}(trees/hour)}$$ **Equation 1**

where: R = revenue; C = cost and P = productivity

It is assumed that is made either the productivity can be reduced to increase the value recovery without effecting the hourly cost or additional equipment can be added to the harvester, hence increasing its hourly cost to increase the value recovery without effecting the harvester productivity.

The results from applying Equation 1 and the above assumptions are summarized in Table 3. The analyses show that both systems could significantly reduce their productivities in an attempt to increase their value recovery. An extra $1410 per hour can be spent on processing at the Washington site and a $132 per hour could be spent at the John Day.

Table 3. Breakeven Productivity and Costs assuming that the Theoretical Optimal Value can be Recovered

Site	Site 1 (Washington)	Site 2 (John Day)
Breakeven Productivity (trees/PHM)	15.3	49.7
Breakeven Hour Cost ($/hour)	1865	496

Conclusion

The introduction of mechanical harvester systems has dramatically increased the productivity of many harvesting operation. In many cases this increased productivity has come at a cost in terms of value recovery. This study investigated the production economics of two different mechanical harvesting systems. The systems differed in terms of: type of operation (cut-to-length vs. on-landing-processing), silviculture prescription (thinning vs. clearfell) and species (Douglas fir vs. ponderosa pine). Probably the most important difference in terms of the production economics of the two operations is in the value of the trees with the Douglas fir trees being worth 20 times that of the ponderosa pine trees.

The breakeven analyses indicate that either productivity can be reduced, significantly in the case of the Washington operation, or extra financial investment can be made in both the harvester and the harvester operator to achieve the optimal value recovery.

In reality, slowing a harvester's productivity down by the amounts indicated in Table 2 would probably cause an increase in the hourly system cost. Alternatively adding additional systems to increase value recovery will most likely reduce productivity.

The results do however give strong evidence for the need to put more emphasis on value recovery when using mechanical harvesting systems. The industry needs to continue to investigate ways of increasing value recovery such as training operators and implementation of scanning and optimization systems that do not seriously effect productivity.

Reference

Gellerstedt, S. and B. Dahlin 1999. Cut-to-length the next decade. Journal of Forest Engineering 10(2): 17-24

Murphy G, 2003, Mechanization and Value Recovery: Worldwide Experiences. In; Proceedings of the Woodfor Africa Forest Engineering Conference, July 2002. Pietermanitzbury, South Africa. College of Forestry, Forest Engineering Department, Corvallis, Oregon. Pp 23-32.

Godin, A.E. 2000. Logging equipment database: 1999, Advantage 20(1).

Raymond K. 1988. Mechanised Harvesting Developments in Australia, Project Report 37, Logging Industry Research Association. pp 45.

Chiorescu, S and Gronlund, A. 2001, Assessing the role of the harvester within the forestry-wood chain. Forest Products Journal 15(2): 77-84

Tipett,L.H.C 1934: "IV – Statistical Methods in Textile Research. Part 3 – A snap reading method of making time studies of machines and operatives in factory surveys:. Shirly Institute Memoirs, 13 73-93

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USE OF INFORMATION AND COMMUNICATION TECHNOLOGY IN WOOD PROCUREMENT MANAGEMENT IN FINLAND

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Abstract

Modern information and communication technology (ICT) is widely used in wood procurement management in Finland nowadays. Especially large Finnish worldwide operating companies like StoraEnso Oyj, UPM-Kymmene Oyj and Metsäliitto Yhtymä Oyj in addition to Metsähallitus (the Finnish Forest Service) have developed systems of their own to manage the forest operations. Many of the smaller companies are introducing these systems as well. The necessary condition for the use of these systems is well developed communication infrastructure of the country.

The basic data of the forests is continuously gathered and monitored through inventories both national, provincial, company and private woodlot owner's levels. The data is available in digital form which allows use of modern GIS systems. The data is based on satellite and aerial images as well as field surveys, so called multi source data.

Operational harvesting plans are based on this data. Maps and other relevant marked stand's information are shown on the screen of a on-board computer of a harvesting machine. The harvester optimizes the utilization of stems according to bucking-to-order scheme send wirelessly to the machine. Environmental aspects are monitored through on-line follow-up of the location of the machine alarming the operator of the hazards of exceeding the cutting area borders, protection zones etc. Forwarding follows many times immediately after logging, and the location information of the piles is send to the database. The performance record of the machine is stored in the memory automatically

After logging the information is sent to company's district office, which organize the optimal long distance transportation schedules based on this data. The truck fleet can be monitored on-line with GPS and rescheduled easily. There are several vendors for these systems in Finland.

These systems have intensified the use wood procurement resources and cut the costs of operations considerably. Another advantage is that environmental risks of traditional activity, harvesting, can be minimized and thus increase the acceptance of direct commercial use of forests.

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Modern Forest Operations

In modern wood procurement information and communication technology (ICT) plays an essential role. The tools provided by the ICT are geographic information systems (GIS), global positioning systems (GPS), world wide web (WWW), mobile phone or cellular phone networks such as NMT, GSM and UMTS to mention a few.

Activities of woodland division of a forest industry company or an independent wood procurement organization may consist of many tasks that have an effect directly or indirectly on the outcome of the operations and thus need to be taken into consideration when managing these activities.

Wood procurement is basically a logistic process which can be managed with the above mentioned tools. A proper and strong management requires measurement of the efficiency of the organization. This means that planning of activities as well as monitoring is needed on every level of management. Planning can be strategic, tactical or operative.

Management structure can be hierarchic, functional, matrix or team-work type organization. The modern solution seems to be in most cases functional, team work based organization.
When dealing with its interest groups different levels of partnership may be applied by the companies. This varies from purely owned operations to complete outsourcing.

In the following forest operations are dealt without the sustaining activities i.e. as wood procurement activity. This restricts public organizations working, say, on afforestation or road construction outside the scope of the presentation.

The wood supply chain forms the framework for the forest operations management. There are basic activities and auxiliary activities. Auxiliary activities are needed to help carry out the actual forest operation more cost efficiently. Such an activity is wood measurement, for instance.

There are basically four independent actors in the wood supply activity. They are forest owners, forest industry, contractors and public authorities as well as organizations of citizens.

Typical harvesting is carried out using shortwood or cut-to-length (CTL) systems in the Nordic countries. Of course, similar type of structures can be found in any wood supply systems in different countries.

The forest operations management starts with an annual strategic wood procurement plan based on pre-orders of the mills drawn from market development estimates for products. From that information a tentative wood purchase plan as well as preliminary transportation plan is being developed. These plans allocate the volumes of different assortments needed to the procurement districts and calculate the other resources required to carry out the task. At this stage just a small

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portion of the stands to be cut is known, most likely only the geographic area where they are supposed to come. This is due to the fact that the raw material needs to be bought from the free timber market in the form of pre-marked stands. Only a small portion comes from companies own forests.
In the countries where the state owns the forests and sell harvesting concessions the approach might be different as regards planning.

As time goes by these plans are revised quarterly to the tactical plans. At this stage the stands have been bought and the information is available. In the sales contract the forest owner and wood buyer agree upon the length of period during which the harvesting must be completed.

In the next step monthly and weekly operative plans are developed including the harvesting and transportation schedules for the stands to be harvested.

Wood purchase

Buying of timber from free market is the most important activity in conditions where the public supply of timber is insignificant. In a team based organization this activity is carried out by a specialist who knows the local conditions very well. In the wood procurement team there is also a substitute who can do the task if the specialist is not available at that moment. The information on the stand characteristics from sales contract is transferred into the information system of the company for further planning activities. The reliability of this information is crucial, because all the following management measures are based on this.
Forest owners' forest management plans are very important source of information for this purpose. However, they are confidential and controlled by the forest owner.

Own forests are a minor source of wood for Nordic companies but world wide this is rather common. However, companies have long term forest management plans for their own forests. These utilize nowadays modern planning tools such as GIS. From this data source the actual harvesting schedules can be defined and executed. Companies tend to use their own forest resource to balance the timber flow. One typical trend today is to outsource the forest property and forestry to separate companies due to the low return on investment expected from traditional forestry. Owing the forests would decrease the return on investment figures of the actual forest industry business.

Planning and management of operations

The raw material flows from the forest to the mills and management information basically to the reverse direction.
Strategic planning is carried out both at company's woodland division and district levels. Tactical planning concerns basically logistics, how to get the raw material most efficiently to the

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mills. These plans are made at districts' level except for imported wood which is handled at woodland department level. These plans are up-dated quarterly. Operative plans consist of the actual instructions by whom, how and when the operations must be completed.

Once the company has got the authority to cut the stand owing to sales contract, and the information is passed to the planning system, the operations management i.e. harvesting and transportation plans are prepared. These include the assortment to be made, the destinations for them, schedules of the actions and other necessary plans such as precautions for the environmental risks. These are then adjusted to the other stands' information purchased from the same area to optimize the use of resources available. The plans are then converted to day-to-day instructions for the contractors available for the task.
Monitoring of the operations produces daily and weekly reports of the progress of operations. If something goes wrong, the team can quickly interfere in the situation by smoothly adjusting instructions.

Harvesting of the stands is almost completely mechanized with harvesters and feller-bunchers in company operations in the Nordic countries. To some extent chain saws are used especially in thinnings and special wood logging as well as self-sufficient forest owners' harvesting. Regardless of the level of mechanization, shortwood system is applied.

Off-road transportation is carried out by forwarders, which carry the load to the road side. Skidding is very exceptional operation in the Nordic countries.

The companies have outsourced their forest operations to contractors almost to 100 %.

Role of information and ICT

Modern wood procurement relies heavily on quick and reliable transfer of information. Tools are GIS, GPS, mobile phones, text messages and wireless communication. There is a lot of information technology in a modern harvesting machine. They are equipped with an on-board computer that in addition to wood measurement functions also monitors the state of the machine operation itself.
From the operations management point of view the correct wood measurement and cross-cutting instructions are essential. At this point a wrong decision might destroy the value of the timber. This is because a customer oriented approach is used. Bucking instructions for individual trees are defined by the bucking-to-value tables or bucking to order tables from the saw mill or plywood mill using the logs. These tables are transferred to harvesting machines wirelessly almost daily, according to the need of the customer. Because of the variety of assortments and sometimes large need for special wood, a group control system for the management of a fleet of harvesters is developed.

Production and productivity figures can be followed continuously as well as the location of machine through GPS. Once the location of the next harvesting site and the stand characteristics

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in addition to the assortments to be made are known the contractors work independently. They only report daily to the team's office the state of the work end the finishing of the site. This information is used to define the transportation readiness of the assortments. Coordinates of the piles are also available for the route optimization routines of transport scheduling programs.

A well functioning mobile communication network is a must for efficient data transfer between the harvesting equipment and supervision of the work.

Literature cited

The Green Kingdom. Finland's Forest Cluster. Keuruu 1999. ISBN 951-1-15653-5.
Högnäs, Tore.2000. Towards Supplier Partnerships in Timber Harvesting and Transportation. *Forestry publications of Metsähallitus 37*. ISBN 952-446-257-5. ISSN 1239-1670.
Kumpula, Jussi and Leskinen, Jarmo. 2002. Forest Operational Planning and Supply Chain Management in Metsähallitus. *Forest IT 2002. Sept. 3.-4. 2002. Seminar proceedings*.
Mikkonen, Esko. 2002. Recent Developments and Research Needs in Forest Operations Management and Modeling. *Proceedings: International seminar on new roles of plantation forestry requiring appropriate tending and harvesting operations*. IUFRO. The Japan Forest Engineering Society.ISBN 4-99010493-0-0.
Mikkonen, Esko. 1999. Puunhankinnan organisointi. (in Finnish only) in METLA's report 720/99. Metsäteknologia muuttuvassa metsätaloudessa. ISBN 951-40-1666-1, ISSN 0358-4283.
Mäkinen, P, Rummukainen, A, Aarnio, J., 1997. Puunhankinnan organisointitavat. (Organizing wood procurement) in Finnish only. METLA report 647. ISBN 951-40-1574-6, ISSN 0358-4283

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A SURVEY OF WEST VIRGINIA LOGGER CHARACTERISTICS

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ABSTRACT - West Virginia licensed loggers were surveyed in 2001 and 2002 regarding their business, operational, and personal characteristics. They were also asked to rate their educational preferences from a supplied list of topics. An initial survey was mailed out in 2001 and a more intensive follow-up survey was mailed out to 1,055 licensed loggers in 2002. The survey was directed toward owners since West Virginia logging businesses must be licensed by law. In 2002, the total response rate was 10.2% with 6.2% submitting completed usable surveys. Results indicated that independent loggers of West Virginia averaged 47.8 years old with an average of 17.8 years in logging business. The firm size was between 1 and 80 employees with an average of 2.3 certified loggers. A firm of average size harvested 10 tracts with weekly production of 51.8 MBF and unit cost of $116.6/MBF.

INTRODUCTION

According to the West Virginia Division of Forestry (WVDOF), approximately 1,055 loggers were licensed by the state to operate in 2002. The Logging Sediment Control Act (LCSA) passed in 1992 by the state legislature, requires all logging operations to obtain a timbering license from the WVDOF, operate with a certified logger on-site at all times, notify the WVDOF of harvest operations, and be subject to the enforcement authority of the WVDOF (West Virginia Division of Forestry 2002). The results of BMP evaluations over a ten-year period indicate an increasing trend of compliance with state BMP's (Wang *et al*. 2003). State certification requirements include: completion of courses in tree felling safety, first aid / CPR, and silvicultural Best Management Practices. Loggers also receive Sustainable Forestry Initiative (SFI) Program training in a two-hour module during recertification training. Recertification training is required every three years. The SFI Program training topics includes: SFI awareness, regeneration, forest aesthetics, transportation safety, threatened and endangered species, and wildlife habitat management. This SFI Program training is conducted by industry foresters employed by companies following the American Forest & Paper Association (AF & PA) SFI Program requirements. New SFI Program logger training and education requirements will require loggers to have business management training. A one-day business management for loggers workshop is offered and co-sponsored by the West Virginia University Appalachian Hardwood Center and the West Virginia Forestry Association.

Preliminary year 2000 forest inventory data released by the WVDOF show timber removals of approximately 966,073,000 board feet with a favorable growth to removal plus mortality ratio of 1.39 (Murriner 2002). Oak and yellow poplar accounted for 68.9 percent of the sawtimber removals in the year 2000. The state has 11,791,700 acres of timberland with an average volume of 6,038 board feet per acre. Logging occurred on 225,939 acres in West Virginia in 2001

(American Forest and Paper Association, 2002). Type of cutting practices used included: diameter limit cut, 52%; selective cut, 39%; clearcut, 7%; and not specified, 1%.

Historically, West Virginia forest landowners focused on removing sawtimber due to its relatively higher value and the lack of markets for low-grade material (Fajvan *et al.* 1998). The lack of markets for lower-grade sawlogs and pulpwood limited landowner options in managing their forests. Diameter-limit sales were often used since markets for smaller lower-grade timber were limited.

Demand for logging services between 1990 and 1998 increased dramatically in West Virginia (Luppold *et al*. 1998). This was the result of two new oriented strand board plants, two parallel-strand lumber mills, and two rotary-cut hardwood plywood mills within or close to state lines. These new facilities used lower-grade sawlogs or small-diameter trees that were previously left in the woods or utilized by smaller sawmills. According to U.S. Bureau of Commerce, hardwood lumber production also increased, peaking at 798 million board feet in 2000. The last few years have been financially challenging for the entire forest products industry, especially loggers (Milauskas 2003). Profit margins and profitability have been at the lowest levels in years with many companies showing negative or depressed returns. West Virginia forest products industry employment decreased by approximately 5% from 2000 to 2002 (Milauskas *et al.* 2002).

A previous survey of West Virginia loggers (Luppold *et al*. 1998) found the annual production of logging firms to vary between 5 MBF to 24,000 MBF. Companies were divided into two categories with two subcategories representing size (small or large) and products produced. Producers were classified according to products produced: sawlog, veneer and peeler log (SVP) or sawlog, veneer, peeler log and other material (SVPOM). Years in business ranged from 10.4 for small producers to 15.9 for large producers. Most large contractors worked full time (SVP – 86.7%, SVPOM – 88.1%) while approximately half of smaller producers (SVP – 50.8%, SVPOM – 53.5%) worked full time. The authors had difficulty with survey responses representing the number of employees. They speculated this was due to West Virginia's relatively high state worker's compensation rates and the growing trend toward contract cutting, skidding, or loading in order to avoid these payments. The number of employees in the larger company categories ranged 2.9 to 5.9 per firm while responses from smaller firms were too few and incomplete for statistical analysis. Worker's compensation, regulation, and taxes in that order were found to be the greatest barriers to increased production. Smaller and larger companies cited skidder capacity as their most limiting production factor.

The current status of West Virginia logging companies, their needs, and how they are adapting to recent economic, regulatory, and technical challenges is of particular interest to researchers and the forest products industry. This study seeks to characterize and understand educational, operational, and profitability factors impacting West Virginia logging firms. Survey results will allow forestry educators, professionals and researchers to target areas that can maximize benefits to the logging industry. This information is critical in understanding how logging companies are operating in the present challenging environment and developing a database for the evaluation of future trends.

METHODS

A list of licensed West Virginia loggers was obtained from the West Virginia Division of Forestry. An initial survey was mailed out in 2001 and a more intensive follow-up survey was mailed out in 2002 to 1,055 licensed loggers. Included with the 2002 survey was a cover letter informing the potential participants of their rights regarding human test subjects. West Virginia University Institutional Review Board and the U.S. Department of Health and Human Services requirements were followed. Potential survey respondents were informed that the survey was voluntary and that the results from any individual would be kept confidential. Postage paid return envelopes were included with the survey.

The 2001 survey included 21 questions focusing on logger educational and training needs. This focus on logger training and education was deemed important in order to evaluate future logging extension programs. The 2002 survey included 33 questions developed by the authors. The questions sought to obtain more detailed information on West Virginia logger business, educational and operational characteristics. Some of the major question areas included: harvest locations, products harvested, employee characteristics, production, training needs, equipment configuration, owner characteristics, profitability, and employee benefits.

RESULTS

The 2001 completed survey response was 4.9% (52). In 2002, the total response rate was 10.2% (108) with 6.2% (65) submitting completed usable surveys. Survey responses were input into computer files for analysis. Data was analyzed statistically.

Table 1. Summary statistics of logging firms in West Virginia.

	Mean	Standard deviation	Minimum	Maximum
Owner's age (yrs)	47.8	8.9	27.0	67.0
Years in business	17.8	11.4	2.5	46.0
Work hours per week	41.2	8.8	8.0	60.0
Work weeks per year	46.8	10.0	6.0	52.0
Workers in the woods	4.8	6.7	0.0	45.0
Machine drivers	3.2	6.7	0.0	46.0
Total employees	8.0	12.4	1.0	80.0
No. of certified loggers	2.3	1.6	0.0	8.0
No. of crews	1.2	0.7	0.0	5.0

Independent loggers of West Virginia averaged 47.8 years of age and had been in the logging business for an average of 17.8 years (Table 1). Each firm had an average of 1.2 crews and the size of the firm ranged from 1 to 80 employees with an average of 2.3 certified loggers.

Two major types of harvesting systems were identified in the survey. Each firm has the capability of manual felling with chainsaws and skidding with cable skidders, farm tractors or other machines (Table 2). However, only 17% of them could perform mechanized harvesting of feller-buncher felling and grapple skidder skidding. Delimbing and topping were primarily done by using chainsaws while 43% of bucking was done by sawbucks on the landings. Knuckleboom loaders accomplished 73% of the loading while trucking was done with tractor-trailers (51%) and shortwood trucks and other types of trucks (49%).

Table 2. Logging equipment per firm in West Virginia.

	Mean	Standard deviation	Minimum	Maximum
Felling				
Chainsaws	3.8	3.6	1	25
Feller-bunchers	1.5	1.3	1	5
Skidding				
Cable skidders	1.5	0.8	1	4
Grapple skidders	1.6	0.8	1	3
Delimbing and bucking				
Chainsaws	3.3	2.3	1	10
Sawbucks	1.4	1.1	1	6
Loading and trucking				
Knuckleboom loader	1.3	0.9	1	5
Tractor-trailer rigs	1.8	1.3	1	5
Road building				
Bulldozers	1.5	1.3	1	9

West Virginia logging firms harvested about 10 tracts per year with an average tract size of 96.3 acres (Table 3). Weekly production averaged 51.8 MBF with an average unit cost of $116.6 per MBF.

Table 3. Production statistics of logging firms in West Virginia.

	Mean	Standard deviation	Minimum	Maximum
Tracts harvested per year	10.4	19.7	1.0	124.0
Average size of harvested tracts (acres)	96.3	86.4	5.0	400.0
Weekly production				
MBF	51.8	64.8	3.8	275.0
Break-even weekly production				
MBF	36.5	36.4	3.5	150.0
Cost				
$/MBF	116.6	35.1	40.0	190.0

LITERATURE CITED

American Forest and Paper Association. 2002. West Virginia's SIC 2001 annual progress report. Submitted by the West Virginia Forestry Association, Ripley, WV.

Fajvan, M. A., S. T. Grushecky and C. C. Hassler. 1998. The effects of harvesting practices on West Virginia's wood supply. Journal of Forestry 96(5): 33-39.

Luppold, W. G., C. C. Hassler and S. Grushecky. 1998. An examination of West Virginia's logging industry. Forest Products Journal 48(2): 60-64.

Milauskas, S. J. and F. A. DeGeorge. 2003. Taking the mystery out of financial ratios. Journal of Forestry 101(1): 4.

Milauskas, S. J., R. B. Anderson and J. McNeel. 2002. Hardwood industry research priorities in West Virginia: a 2002 industry survey. Published by the WVU Appalachian Hardwood Center for the West Virginia Development Office under a grant from the U.S. Department of Energy. 22pp.

Murriner, E. 2002. West Virginia 2000 forest inventory-preliminary results. Presented at the 2002 West Virginia Forestry Association Annual Meeting, Canaan Valley State Park, July 20, 2002.

Wang, J., McNeel, J. and S. Milauskas. Accepted for publication in 2003. Logging Sediment Control Act and Forestry Best Management Practices in West Virginia: A Review. Northern Journal of Applied Forestry.

West Virginia Division of Forestry. 2002. Best management practices for controlling soil erosion and sedimentation from logging operations in West Virginia. WVDOF-TR-96-3 (August 2002), Charleston, WV 29 pp.

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POTENTIAL USE OF SLASH BUNDLING TECHNOLOGY IN WESTERN US STANDS

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Abstract

Production studies, carried out in Finland, of slash bundling systems were used as the basis for determining production rates for three levels of treatment (bundle and leave at stump, bundle and remove to roadside, bundle and transport to an energy plant) for five representative stands types (lodgepole pine, ponderosa pine, western larch, Douglas fir, and spruce/fir) in the Western US. Slash was limited to trees less than 10cm DBH and to the limbs and tops of larger trees removed in a conventional thinning operation. These simulated production rates were combined with constructed hourly costs to determine unit costs on a green tonne and on a per hectare basis. Per hectare costs ranged from $250 for "bundle and leave" to $1090 for "bundle and transport". Costs depended on forest type.

Introduction

It has been estimated that well over 9 million acres of timberland in the Western United States consists of small-diameter, densely-stocked timber stands. For almost a decade there has been broad interest in harvesting/treating such small timber stands to promote ecosystem restoration and forest health, and to reduce forest susceptibility to insect infestation and stand-replacing wildfire. The 2002 summer fire season, where millions of acres of forest were consumed by wildfires, confirms the need to identify suitable stand treatment systems.

Two independent equipment developers in Scandinavia, Fiberpac and Wood Pac, have recently developed machinery that bundles harvesting slash (limbs, tops and very small trees) into composite residue logs that can be easily transported by forwarders and conventional self-loading logging trucks (Andersson 2000; Asikainen et al. 2001; Poikola 2002). (Figure 1). Residue from the tops of the stems, branches and small trees is placed either in continuous rows or in piles to the side of the extraction trail.

The tops of the stems and the small trees must be oriented in the same direction as the extraction trail to obtain the best productivity from the bundler. The bundler compresses the residue into "logs" about 70 cm in diameter and binds the bundles tight with a sisal cord. The Wood Pac bundler produces logs in a batch process (fixed length of approx. 3 m) while the Fiberpac bundler produces logs in a continuous process which are then cut into log lengths chosen by the operator (usually approx. 3 m).

Bundles of slash weigh from 300 to 600 kg depending on "log" length, equipment, species and how long the slash has been left to dry. Scandinavian operators prefer to use the slash bundling system in clearfell spruce stands since they get higher bundling productivity, lower costs per bundle and less stand damage in these types of stands. In general, clearfell produces more bundles per hectare than thinning and spruce produces more bundles per hectare and is easier to bundle than pine. Because of concerns about nutrient removal, along with practicalities of picking up all of the residue, Scandinavian operations typically remove about 70% of the residue from clearfell stands. Studies of clearfell stands in Finland found bundle densities of 45-88 per ha for pine, 106 to 157 per ha for spruce, and 240 per ha for "leafy" trees (Poikola 2002).

Figure 1. Composite residue logs produced by Fiberpac slash bundling technology. Courtesy of Dr. A. Timperi, Timberjack Oy, Finland.

Besides forest type and silvicultural system, bundling productivity is also affected by such factors as terrain, size of the harvest unit, the method used for harvesting the industrial roundwood prior to bundling, underbrush density, operator experience and how long the slash has been left to dry in heaps. For example, Asikainen et al. (2001) indicated that bundling productivity for spruce at 13% moisture content was only half that for spruce at 45% moisture content.

The bundles are transported to roadside by means of a normal forwarder. The main factors affecting forwarding productivity are forwarder size, forest type and extraction distance. Poikola (2002) indicated that forwarding of spruce bundles was about 40% more productive than forwarding pine bundles; probably because of more bundles per hectare in spruce.

The bundled slash is used in Scandinavia as an energy source. Storing the bundles at roadside for one to three months allows them to dry, without composting, if stored properly – as high and tight as possible – and improves their energy content. Transport to the power plant is by means of self-loading conventional logging trucks. No special containment is required for transporting the bundles in Finland although this may be required in the US. Depending on the species and moisture content, the energy content of 3 m composite residue log bundles is 1 to 1.5 MWh. It takes about 3% of the energy in each bundle to produce and deliver it to an energy plant.

Although the bundled slash is used in Scandinavia as an energy source the bundling technology could be used in a number of different ways in the US depending on costs, energy prices and the needs of the forest owner. In our paper we evaluate three alternative uses of the slash bundling technology: (a) densify the slash by bundling and leaving it on site, (b) bundle the slash and forward it to roadside where it can be "permanently" stored or put to alternate uses in the forest such as erosion control, and (c) bundle the slash and transport it off-site to an energy plant. We limited our evaluation to thinning treatments because of the need to reduce fuel loadings in many western US stands.

Methods

A representative stand from each of five forest types was chosen for the evaluation. The forest types were: lodgepole pine (LP), ponderosa pine (PP), Douglas fir (DF), western larch (WL) and spuce/fir (S/F) from Bailey's Ecoregions 34, M26, M24, M33 and M34 respectively. Table 1 shows information on the removed stems along with the stand conditions prior to thinning. We assumed that slash would consist of the total above ground biomass of removed trees below 10 cm DBH along with the branches and tops of all other removed trees. Biomass equations were selected from BIOPAK (Means et al. 1994) to estimate the potential weight (dry and green) of the material. The potential weight was reduced by 15% to allow for uncollected biomass left on site.

Table 1. Stand and biomass data for selected forest types.

Forest type	Pre-thin stocking (spha)	Pre-thin quadratic mean DBH (cm)	Removals (spha)	Removals quadratic mean DBH (cm)	Slash biomass (kg/ha green)	Slash biomass (kg/ha dry)
LP	1495	16.0	633	16.5	14210	8170
PP	1771	15.2	328	16.3	13170	7200
DF	1762	16.3	581	16.0	14520	8350
WL	2513	13.1	986	11.9	22190	12750
S/F	1618	16.4	561	15.5	32220	15950

An average bundle size of 410 kg green weight was used in our analyses to calculate the number of bundles per hectare to be removed (Figure 2). This is similar to the average bundle weights reported by Poikola (2002).

The cost to pile the slash during harvesting of conventional roundwood products was determined using STHARVEST software (Fight et al, 2003). For the extra work in piling the slash, 5% was added to the cost of felling and processing trees with a cut-to-length harvester for all stems greater than 10 cm DBH. For small trees less than 10 cm DBH a cost of $81 per scheduled machine hour (SMH) and a productivity of 150 trees per SMH was assumed, leading to a cost of $0.41 per tree.

Bundling productivity was based on a recent study of the Fiberpac bundler (Poikola 2002) and a long term machine utilization rate of 85%. Productivity (bundles per SMH) was determined to be equal to 22 + 0.03*Bundles_Per_Hectare. An hourly cost of $110 per SMH, inclusive of labor, was assumed.

We used a 350 m average extraction distance when calculating forwarder productivity and costs. Forwarder productivity estimates were based on estimates from STHARVEST software and Poikola (2002); 20 bundles per SMH for LP, PP and WL and 25 bundles per SMH for DF and S/F. An hourly cost of $63 per SMH, inclusive of labor, was assumed.

We used a 160 km one-way haul and 45 bundles per load in our analysis of transport productivity and costs for the self-loading conventional log truck. Productivity was determined to be 13.5 bundles per SMH. An hourly cost of $65 per SMH, inclusive of labor, was assumed.

Results

Results from the evaluations are presented in Figure 2 and Table 2. Bundle density ranged from 32 per ha for thinnings in PP to 79 per hectare in S/F. This compares with densities ranging from 50 to 250 in clearfell stands in Finland. Bundling productivity was between 23 and 24 bundles per SMH. Productivity for the Fiberpac operating in Scandinavia was reported to be between 25 and 30 bundles per hour under optimum conditions.

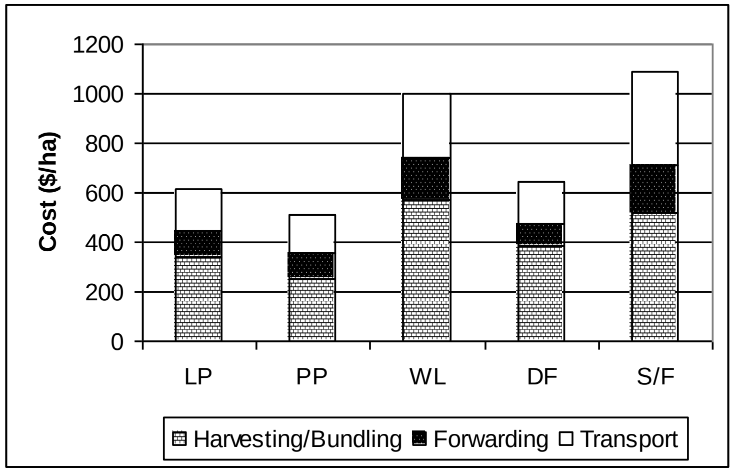

Figure 2. Slash bundling costs for five forest types – lodgepole pine [LP], ponderosa pine [PP], western larch [WL], Douglas fir [DF] and spruce/fir [S/F].

Costs for harvesting ranged between $2 and $ 6 per bundle. Bundling costs were about $5 per bundle. Forwarding costs ranged between $2 and $3 per bundle. Transport costs were about $5 per bundle.

Table 2. Activity costs for harvesting, bundling, forwarding and transport to energy plant.

Forest type	Bundle density (bundles per ha)	Harvest cost ($/bundle)	Bundling cost ($/bundle)	Forwarding cost ($/bundle)	Transport cost ($/bundle)	Total cost ($/tonne green)	Total cost ($ per ha)
LP	34.7	$5.00	$4.77	$3.15	$4.81	$43	$615
PP	32.1	$3.04	$4.79	$3.15	$4.81	$39	$505
DF	35.4	$6.04	$4.77	$2.52	$4.81	$44	$645
WL	54.1	$5.85	$4.66	$3.15	$4.81	$45	$1000
S/F	78.6	$2.05	$4.52	$2.52	$4.81	$34	$1090

Discussion

Slash bundling technology is attractive because it can be used to densify the slash, thereby reducing the fire risk. Since it is in a "log" form, it can also be easily handled as "roundwood" throughout the supply chain and transported with conventional forwarders and trucks.

We found that the cost of

- A "harvest, bundle and leave" treatment ranged from \$250 per ha (\$100/ac) for PP to \$570 per ha (\$230/ac) for WL,
- a "harvest, bundle and forward to roadside" treatment ranged from \$350 per ha (\$140/ac) for PP to \$710 per ha (\$290/ac) for S/F, and
- a "harvesting, bundling and transporting to an energy plant" ranged from \$510 per ha (\$200/ac) for PP to \$1090 per ha (\$440/ac) for S/F.

The per unit area costs for each of these treatments were affected by bundle density per ha. It is also important to look at the costs of the whole system if a stump to energy plant alternative is planned. In our analyses the cost of bundling the slash constituted only 25 to 35% of the total costs of delivery to the plant.

A more useful figure for the bundle and deliver to an energy plant alternative is probably a cost per tonne. These costs ranged between \$34/t and \$45/t of green material. Since hogfuel prices are currently below \$15/t for chipped green material this alternative is not economically viable without some form of subsidy.

At the time of preparing this paper there were no slash bundling systems operating in the Western US although a system is expected to be operational in late summer 2003. Although these findings are based on the best information from Scandinavian studies available at the time further research is needed to quantify the production and costs of slash bundling technology under a wider range of forest types and silvicultural treatments than we have reported on here.

Literature Cited

Andersson, G. 2000. Technology of fuel chip production in Sweden. In: Nordic Treasure Hunt – Extracting Energy from Forest Residues. VTT Symposium 208. pp 113-125.

Asikainen, A., Ranta, T., and Laitala, J. 2001. Large-scale forest fuel procurement. In: Wood Biomass as an Energy Source – Challenges in Europe. (P. Pelkonen, P. Hakkila, T. Karjalainen, B. Schlamadinger (eds)) EFI Proceedings 39. pp 73-78.

Fight, R., Zhang, X., and Hartsough, B. 2003. Users Guide for STHARVEST: Software to estimate the cost of harvesting small timber. USDA Forest Service. General Technical Report PNW-GTR-582. 18pp.

Means, Joseph E.; Hansen, Heather A.; Koerper, Greg J.; Alaback, Paul B; Klopsch, Mark W.. 1994. Software for computing plant biomass--BIOPAK users guide. Gen. Tech. Rep. PNW-GTR-340. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 184 p.

Poikola, J. 2002. The prerequisites of the bundling method in large scale wood procurement. Year Book of Wood Energy Technology Program 2002. VTT Symposium 221. pp 141-150.

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SYNTHETIC ROPE USE IN LOGGING WINCHING APPLICATIONS

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ABSTRACT - The use of ultra high molecular weight polyethylene (UHMWPE) fiber rope as a replacement for steel wire rope shows beneficial properties with the use of synthetic ropes in static line applications such as guylines. The promise shown establishes the basis for expanding its use to running lines for improvements in logging safety, worker ergonomics, and economic efficiency. Research is investigating the applicability of synthetic ropes to dynamic applications including winch lines on crawler tractors and rubber-tired skidders, a carriage dropline, and a mainline winch on a Koller K-300 cable yarder. Required rigging connection modifications are discussed. Observed durability and wear of the synthetic rope are reported. Subjective evaluations by machine operators and researcher observations are briefly summarized. Future research ideas are outlined.
KEYWORDS: fiber ropes, cable harvesting, line logging

INTRODUCTION

The potential of rope constructed of ultra high molecular weight polyethylene fibers (UHMPWE AmSteel Blue 12 strand braided rope[1]) to replace wire rope in logging applications has been shown at previous COFE meetings (Garland et al., 2001) and elsewhere (Pilkerton et al., 2001). The rope's strength is similar to steel wire rope of the same nominal diameter but it weighs only about 1/9th as much. Current research is continuing into the specific static line applications in cable logging (Leonard et al., 2003). Designed experimental trials on various potential end-connectors are underway to assess connections of synthetic rope to machines, winches, and wire rope. This paper describes experiences with winching applications on ground-based equipment and in cable logging.

Three research and development projects funded by Oregon's Occupational Safety and Health Administration Worksite Redesign Grants show potential ergonomic improvements for workers using synthetic rope in place of steel wire rope (Garland et al., 2002). In addition, the research was designed to place synthetic rope in the hands of logging contractors to evaluate its potential applications, specific problems and opportunities for improvements. The nature of the research and development efforts with contractors diminishes the opportunity of designed studies in favor of identifying problems across novel uses and subjective assessments by users. Only one type of synthetic rope was selected for our studies of dynamic uses on winches with potentially different type rope applications likely to be suggested from our pilot trials. Economic potentials are always of high interest when synthetic ropes may cost from 2-4 times comparable wire ropes,

[1] AmSteel Blue is a product of Samson Rope Technologies, Ferndale, WA (samsonrope.com). Mention of trade names is not an endorsement by Oregon State University.

and our studies begin such documentation but await further designed studies on economic benefits.

The comparison of synthetic rope to steel wire rope is hampered by the lack of research on wire rope in logging applications, especially related to wear and damage. Serviceability of wire rope in logging is often estimated from manufacturer's guidance (Williamsport Wirerope Works, Inc. 2000) or guidance provided by safety codes (Oregon Admin. Rules, Forest Activities Code, Division 7: www.orosha.org/standards/div_7.htm). It turns out wire rope is not homogenous and strength and service vary by design, manufacturer (domestic versus imported), and specific applications. Torgersen (2002) recently experimentally evaluated selected wire ropes for their endurance over cyclic loadings and their service life related to varying sheave diameters and found significant differences. Earlier work with synthetic ropes as yarder guylines (Takumi 1998) and as ground-based winch lines (Lapointe 2000; Golsse 1996; Dunnigan 1993) were not so positive as to stimulate further trials; however, the rope types and applications were different from those we report on in this study.

Our trials include: a large, crawler tractor operation in eastern Oregon; two western Oregon operations using a mid-size crawler and skidder; a Boman carriage operation using synthetic rope as the dropline; and use of synthetic rope as the mainline on a Koller K-300 yarding operation (mention of trade names is not an endorsement). All trials used AmSteel Blue synthetic rope in sizes from 3/8 to 7/8-inch diameters to replace wire ropes of comparable diameters and strengths. Our observations and subjective assessments describe these applications and suggest potential economic benefits and future research needs from the trials.

Figure 1. Operator pulling synthetic winch line and chokers to ponderosa pine logs.

CASE STUDY DESCRIPTIONS

Eastern Oregon Crawler Tractor Trial: A logging contractor performed sanitation thinnings in mixed ponderosa pine (*Pinus ponderosa*) and western juniper (*Juniperus occidentalis*) stands affected with Black Pineleaf Scale (www.fs.fed.us/r6/nr/fid/fidls/fid191.htm) to remove dead, dying, and severely compromised ponderosa pines. The terrain was broken, and slopes exceeded 30 percent in some areas. The prime mover was a Caterpillar D6C-10K crawler tractor (140 horsepower, 30,600 pounds) outfitted with a Carco F50 integral arch winch. The contractor typically spooled 75 feet of 7/8-inch swaged steel wire rope. For this trial, 120 feet of 7/8-inch AmSteel Blue rope was installed. The operator typically drove to logs, pulled winch line and set pear-ring and toggle chokers to the logs (Figure 1). Turns were usually of 3-4 logs.

Western Oregon Crawler Tractor Trial: Contract operations consisted of clearcut harvest of a 40-year old Douglas-fir (*Pseudotsuga menziesii*) stand. The terrain was uniform, with slopes to 30 percent. The crawler was a John Deere 650G crawler tractor (90 hp, 19,000 pounds) with a JD 4000 series integral arch winch. One hundred twenty feet of 5/8-inch AmSteel Blue rope was installed with a pear-ring and toggle choker system. The operator drove to the logs and collected 3-4 logs per turn.

Western Oregon Skidder Trial: The OSU Forest Engineering department Student Logging Program utilized a John Deere 540 B rubber-tired skidder (90 hp, 16,800 pound) to thin 40-50 year old Douglas-fir stands on slopes less than 20 percent. One hundred twenty-five feet of 3/4 –inch AmSteel Blue rope was used with a round-ring and toggle choker system. The skidder operator set his own chokers or had preset turns of 3-4 logs hooked by a choker setter.

Skyline Carriage Dropline Trial: A logging contractor operated a standing skyline system with a Madill 071 yarder and Boman Mark IV carriage (3800 pounds) in a modified seed tree (six trees per acre for wildlife) harvest unit of 100-year old Douglas-fir. Cable corridors ranged from 15 to 60 percent. The carriage used a powered (106 hp) winch for pulling logs into the carriage. The 2-speed winch also powered out (rotationally "pushed") the steel wire rope from the carriage for lateral slackpulling. While the contractor utilized a 5/8-inch swaged steel wire rope dropline, a 5/8-inch AmSteel Blue rope was installed for this trial. Chokersetters set 2-4 logs per turn and controlled carriage winching operations by radio signals.

Cable Yarder Mainline Trial: The OSU Forest Engineering department Student Logging Program utilizes a Koller K300 two drum yarder and SKA-1 carriage for standing skyline yarding operations (Figure 2). Thinnings on steep slopes (greater than 45 percent) of 40-50 year old Douglas-fir stands are typical; however, our trial included a 1-acre patch clearcut of larger stems. The original 3/8-inch steel mainline was replaced with a 3/8-inch AmSteel Blue rope. A round ring and toggle system is utilized to preset 2-4 logs per turn.

Figure 2. Koller K300 yarder, SKA-1 carriage, and yarded turn at landing.

FINDINGS

The owner-operator skidding in the ponderosa pine was pleased with the ease of line pulling, especially on difficult uphill pulls. Operational times were decreased, sometimes remarkably. The operator stated that on one difficult uphill pull, a turn would have taken him 30 minutes with steel, but he did it in about 10 minutes with the synthetic line. The operator also had occasional pulls over rimrock outcroppings and around residual juniper stems -- both are abrasive materials. The synthetic skidding line failed (broke) late in the trial period. We did not see this failure and do not know the failure mechanisms. The operator said the turn was normal size. The operator was able to eye splice the line onto the toggle and continue operating. This line has now been removed for residual strength testing. The operator requested a 50 percent longer synthetic line to continue the trial. He now uses a synthetic winch line twice as long as the previous steel line.

The employee operating the JD 650 crawler tractor had similar positive experiences. The pear-ring chokers however occasionally twisted 180 degrees and make a bight on the skidding line winch hindered slackpulling. The operator also encountered two failures due to rope breakage. These failures were not observed by us and we do not know the failure mechanisms. We think the sharp casting edges of the pear-rings may create cutting edges. Subsequent rings have been smoothed with a grinder prior to use. The next trial will substitute round-ring chokers (with smoothed casting edges) and changed operating procedures.

The student skidding trials have been more successful in terms of duration. No operational failures have been encountered. Tufting of the rope due to broken exterior filaments of the strands is the only visible degradation of the rope during use. However, the synthetic rope will not sustain abuse as steel wire rope. A student worker wrapped the synthetic skidding line over sharp grab hooks to attempt to pull an artificial earth anchor. The rope was severed. This rope had 2.5 years of use prior to this event and is now scheduled for residual testing.

The carriage dropline trial provided information on the failure modes. Sharp edges on the used carriage cut the trial rope on a low deflection corridor with perpendicular lateral pulls. The adage "you can't push a rope" was confirmed in application of this winch design for spooling off the skidding line. The two-speed winch created back-spooling hang-ups on the drum. When the rigging crew applied minimal, constant pulling tension during lateral slackpulling, the backspooling was eliminated. The rope failed once on the drum as the yarder engineer spooled and unspooled the drum to release the dropline. In spite of the problems, the owner would like to again try the rope in the near future.

The mainline trial has been successful to date. One rope failure has been encountered near the load hook. A "strand interchange" (knotting of old and new spool for a strand) during manufacturing was located near the break and suspected to be the failure mechanism. While our early lateral pulls are not substantially different (due to minor differences in unit line weight with 3/8-inch steel rope), there is a noted difference in the reduced sag which develops with the synthetic mainline. This reduces the pulling effort required. Spooling capacity increased on the drum due to better layering of the synthetic line. The K300 mainline drum capacity is rated at 1150 feet of steel line. We installed approximately 1300 feet of synthetic rope and still have additional drum capacity.

DISCUSSION

Our efforts to put the synthetic rope in the hands of the users have provided significant information on failure and wear mechanisms. Treating synthetic rope as steel rope has provided future operational changes and/or rope configuration and materials changes for improvement. None of the failures were so different than similar steel wire rope failures as to give concern about using synthetic rope. In fact, some synthetic rope failures were similar to "expendable" failures in steel wire rope winch lines.

Wear and Replacement Issues: Wire rope and synthetic rope are most often evaluated for replacement by visual indicators or simple measures on the rope itself (element counts, diameter measurement, etc.). While wire rope standards may exist for allowable wire breaks for some industries (elevators, material lifts over personnel, etc.), they do not apply to logging where work practices call for personnel to be in the clear when loads are on the lines. Some rope elements in logging are considered "expendables" because of the wear they receive such as chokers or the end sections of winch lines and drop lines. Similarly, existing retirement guidelines for arborists' use of synthetic ropes are not applicable to logging applications. Visual evidence from abrasion, corrosion, crushing, diameter reductions, stranding, bending and shock loading for wire and synthetic ropes differ as follows.

Abrasion -- Abrasion in wire rope causes broken wires and replacement is based on a specified number of broken wires. Synthetic rope initially fuzzes up from broken filaments that produce a protective cushion but when braided rope is worn 25% from abrasion it should be replaced. Powder inside the rope indicates internal abrasion (The American Group 1997).

Corrosion – With wire rope, pitted wire surfaces and breaks indicate corrosion and corrosion is difficult to assess for interior damage. AmSteel Blue synthetic rope is not affected by corrosion for the chemicals typically encountered on logging operations.

Crushing – With wire rope, flattening of strands from poor spooling and other causes damages it and reduces its strength. Synthetic rope may flatten and glaze due to tension around pins and sheaves but will return to a round shape when worked by hand.

Diameter reductions -- Wire rope diameter reduction is a critical retirement factor due to excessive abrasion, loss of core support, inner wire failure and so forth. Synthetic ropes may actually increase in apparent diameter from abraided filaments and material inside the rope itself. Localized diameter reductions, flat areas, and lumps and bumps in the synthetic rope are of concern for replacement as well as ropes built up with dirt and debris.

Stranding -- Wire rope stranding occurs from various causes including kinking, twisting, or tight grooves leading to broken wires and "jaggers" (exposed broken wires) to such a degree the rope is unusable. Synthetic rope will have broken filaments and strands but no jaggers.

Bending – Wire rope manufacturers' recommended ratios of bending to rope diameters have seldom been met for wire rope in logging. Synthetic rope ratio recommendations are also larger than those found in logging practice.

Shock Loading – In wire rope, birdcaging (core protusion) is evidence of shock loading and seriously degrades rope strength. Synthetic rope is less subject to shock loading but fibers may have memory and may retain effects of shock loading during normal loads. We are continuing to assess wear criteria for synthetic ropes.

Economic Issues

Early research and development have identified economic potentials (Garland et al., 2001) but detailed results will need to come from designed studies and perhaps over long term trials. For example, a study with the dropline carriage where the crew pulls the skidding line along the ground may show differences. Ground skidding in difficult (steep, slippery, etc) terrain and/or on long pulls may show synthetic rope advantages. Plus, some of the economic benefits from synthetic rope accrue from a reduction in crew fatigue allowing additional production at the end of the day or important safety benefits from reductions in slips and falls. It is always a problem with safety improvements to show the accident that <u>did not happen</u> was the result of reduced fatigue.

Designed studies should be conducted to relate the circumstances under which synthetic rope shows advantages, is neutral, or is a disadvantage depending on the operating conditions. We now have information from our contractor trials to organize such studies.

FUTURE RESEARCH

The obvious question for running line research would be trials using synthetic rope as a skyline where the weight advantage could be significant in low deflection circumstances. The question of how a carriage might affect the skyline is still open for trial; however, the use of synthetic rope as a skyline extension not involving carriage passage is not a problem. The other obvious research trial would be as a rigging line (strawline) for a larger cable system. To date, we have not tried either of these possibilities.

Carriage designs that allow use of synthetic rope are needed besides those carriages that use a dropline winch arrangement. Clamping the carriage on the skyline presents a problem for carriage designers to avoid rope damage. Another intriguing prospect would be the use of synthetic rope with a self-propelled carriage which eliminates requirements for a yarder. Current models have small radius sheaves and damage the wire rope more than what synthetic rope might experience.

We look forward to future research trials.

REFERENCES

Dunnigan, J. 1993. Braided Kevlar^{tm} cable: Trials in skidding wood with an ATV. Forest Engineering Research Institute of Canada Field Note. No. 22. Pointe-Claire, Quebec. 2p.

Garland, J.J., Sessions, J., Pilkerton, S. and B. Stringham. 2001. Synthetic rope used in logging: Some potentials. Council on Forest Engineering Annual Meeting, held July 16-19, 2001, Snowshoe, West Virginia. Council on Forest Engineering. Corvallis, OR. 5p.

Garland, J.J., Sessions, J., Pilkerton, S. and B. Stringham. 2002. Using synthetic rope to reduce workloads in logging. Final report Worksite Redesign Program Oregon Occupational Safety and Health Administration. Forest Engineering Department, Oregon State University. Corvallis, Oregon. 28p. plus appendices.

Golsse, J-M. 1996. Initial tests of synthetic fiber mainlines for cable skidders. Forest Engineering Research Institute of Canada Field Note No 33. Pointe-Claire, Quebec, 2p.

Lapointe, M. 2000. Development of methods to minimize the breakage frequency of synthetic-fibre rope mainlines used on cable skidders. Bachelor of Science thesis, Forestry and Environmental Management, University of New Brunswick, Fredericton, Canada. 32p.

Leonard, J., Garland, J. and S. Pilkerton. 2003. Evaluation of synthetic rope for static rigging applications in cable logging. Council on Forest Engineering Annual Meeting, held September 7-10. Bar Harbor, Maine. Council on Forest Engineering. Corvallis, OR. 7p.

Pilkerton, S., Garland, J., Sessions, J. and B. Stringham. 2001. Prospects for using synthetic rope in logging: First look and future research, in Proceedings of the International Mountain Logging and 11th Pacific Northwest Skyline Symposium. 2001-A Forest Engineering Odssey. Eds. P. Schiess and F. Krogstad, College of Forest Resources. U. Washington. Seattle, WA. Dec. 10-12, 2001. CD ROM Media. 289p.

Takumi, U. 1998. Application of super fiber rope as a guyline for a mobile tower yarder. Proceedings of the IUFRO/FAO Seminar on forest operations in Himalayan forests with special consideration of ergonomic and socio-economic problems. Heinimann, H.R. and J. Sessions (eds.). Kassal University Press, GmbH. ISBN 3-933146-12-7. 160p.

The American Group. 1997. Marine and industrial ropes. MIRC-1097 (general catalog). Ferndale, WA. 39p.

Torgersen, H. 2002. Service life of compacted steel wire ropes on varying block sheave diameters. Int. J. For. Eng. 13(1):51-56.

Williamsport Wirerope Works, Inc. 2000. General purpose catalog (Bethlehem Wire Rope). Williamsport. PA. 40p.

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EVALUATION OF ROLL-OFF TRAILERS IN SMALL-DIAMETER APPLICATIONS

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ABSTRACT

Concern about wildfire in overstocked forests of the western U.S. has led to increased emphasis on extraction of small-diameter material. Removing this material improves forest health, reduces fuel loading, and may generate value that can be used to offset the costs of operation. However, the cost of small-diameter operations (both in-woods and secondary processing) are often prohibitive due to handling and transport. This is a particular problem with small-volume niche markets that cannot absorb the productive capacity of conventional forest products transportation systems. This project studied the performance and costs of an innovative wood transport system using roll-off pallet racks to facilitate handling of small-diameter thinning material. Elemental studies defined the transport cycles and cost analysis compared the economics of the new system with conventional transport technology.

Introduction

A recent assessment of biomass in western forests of the U.S. (USFS, 2003) estimates that about 570 million bone dry tons of material could be removed through fuel reduction treatments to address high-risk stands. While much of the volume can be processed into conventional forest products, there is also interest in promoting diverse and specialized utilization. Small-volume niche markets can increase value-added by careful selection and merchandizing of the raw material. For example, logs for carving, rustic furniture material, log home components, post-and-rail, and specialized sawlogs are higher value niche products that can be recovered from fuel thinning projects. Although these niche products will not consume large quantities of forest biomass, they may make fuel reduction projects more cost-effective in some local areas.

A key problem for small producers is finding economical methods for harvesting, handling and transport of material when daily production levels are low. Conventional logging and transport equipment operates efficiently at high volumes. A drive-to-tree feller-buncher, for example, may be able to cut and pile 50 tons per hour. A conventional grapple skidder can produce 30 tons per hour. High production is essential to reducing harvesting and transport costs. However, when the total wood flow for a small-scale producer is less than potential productivity of conventional equipment, costs increase due to under-utilized capacity.

This objective of this project was to examine transportation alternatives for a case study of a small-volume shavings factory. Total woodflow through the mill is about 30 green tons per day. Because of a lack of conventional harvesting activities in the area, reliable wood delivery required the mill to develop an appropriately scaled harvesting and transport system. Trees were felled manually and skidded tree-length using either a skid-steer multi-purpose machine or a small cable skidder. At the landing, trees were manually bucked into 100" bolts and loaded with a front-end loader attachment on the skid-steer. The transport system had to integrate with this low-capital harvesting operation as well as the shortwood unloading equipment at the millyard. A prototype shortlog transport system based on roll-off wood racks was developed and tested and preliminary performance and cost estimates are presented in this report.

Prototype Roll-off System

Over the years, there have been various iterations of roll-off (RO) type log transport systems. The pallet system used in the southern U.S. from the 40's to the 60's was an early design that reduced handling and loading time. Pallets set at ground level could be manually loaded more easily than racks on a truck (Bromley 1949). Trees were bucked into shortwood at the stump and collected on the pallets for unitized extraction. The loaded pallets were then winched onto straight frame trucks for transport to the woodyard or mill. Improved mechanization in skidding, bucking, and loading functions eventually eliminated the advantage of palletized shortwood.

Sinclair (1985) revisited the unitized load concept to collect woody biomass from cable logging operations in Canada. Like the old pallet trucks, the Canadian system winched loaded transport containers onto a highway truck. The cost of the roll-off container system was considerably less than an alternative approach using conventional trucks and skidders to recover low-value biomass. Sinclair noted that use of an up-to-date RO truck configuration would improve the performance of the container system even further.

Current RO designs are typically a straight frame 300-hp class tractor with dual rear axles. The RO modification consists of a tilting frame that is elevated by hydraulic cylinders. A cable winch pulls a loaded RO container onto the truck. This transport system is commonly used for waste collection with solid bin containers. The Village of Ruidoso, New Mexico has an ongoing contract with a waste disposal firm to collect municipal and residential woody debris in RO containers.

For the small-wood thinning project, special wood racks were designed that were compatible with the local waste truck configuration. The wood racks hold approximately 5 cords (22,500 lbs) of 100" bolts loaded crosswise (Figure 1). While there is some additional space for load, this truck has a maximum legal weight of 46,320 lbs and a tare of about 24,000 lbs. In operation, when the trucker is notified that a loaded rack is ready for pickup in the woods, the truck takes an empty rack to the woods and drops it on the landing. The truck winches the full rack onto frame and the load is secured for highway travel. At the woodyard, a sling-type loader unloads a bunk at a time and the empty truck is returned to the truck staging yard or to the woods.

Figure 1. Roll-off wood rack for shortwood bolts.

System Evaluation

An initial elemental production study was conducted after the contractor had used the system for several months. The truck made 2 trips per day and Table 1 summarizes elemental data from 6 loads. Each load was followed to the millyard to measure average travel speeds on the various types of roadways (Table 2).

Table 1. Elemental cycle time summary for roll-off wood rack transport system.

Productive Element	Mean	Max	Min
In-woods			
Position to unload (min)	1.02	1.73	0.32
Unload rack (min)	3.33	4.25	2.40
Position to load (min)	4.48	7.06	2.04
Load rack (min)	3.99	5.27	2.44
Bind down load (min)	6.61	10.19	2.69
Millyard			
Unbind load (min)	2.15	3.31	1.65
Unload with sling loader (min)	12.98	16.45	10.12

Table 2. Average travel speeds for the roll-off truck.

Road Type	Mean Empty (mph)	Mean Loaded (mph)
Woods road	4.2	4.1
Gravel road	30.3	26.0
Paved, in-town	33.7	28.2
Paved, out-of-town	44.7	41.5
4-lane highway	50.9	45.1

The initial cycle time and travel speed estimates were combined with a standard machine rate based on a new $100,000 truck and $15/hour labor. A spreadsheet template was created with a constant haul route of woods, gravel and in-town mileage combined with an increasing amount of highway mileage to estimate the effect of total haul distance on wood transport cost (Figure 2).

Two other wood transport configurations were modeled in the spreadsheet. The first was a conventional 5-axle logging truck with a shortwood trailer operating at 85% utilization. This would reflect potential wood transport costs if existing harvesting and utilization operations were able to keep the trucking system busy. One load per day would be delivered to the shavings mill while additional loads would be taken to other wood-consuming facilities. The second configuration estimated transport costs for the conventional shortwood trailer system operating at 30% utilization, reflecting the limited woodflow needed by just the shavings mill. Figure 2 shows the results, with the underutilized conventional system having the highest cost line, the RO wood rack system in the middle, and the conventional fully utilized system having the lowest costs.

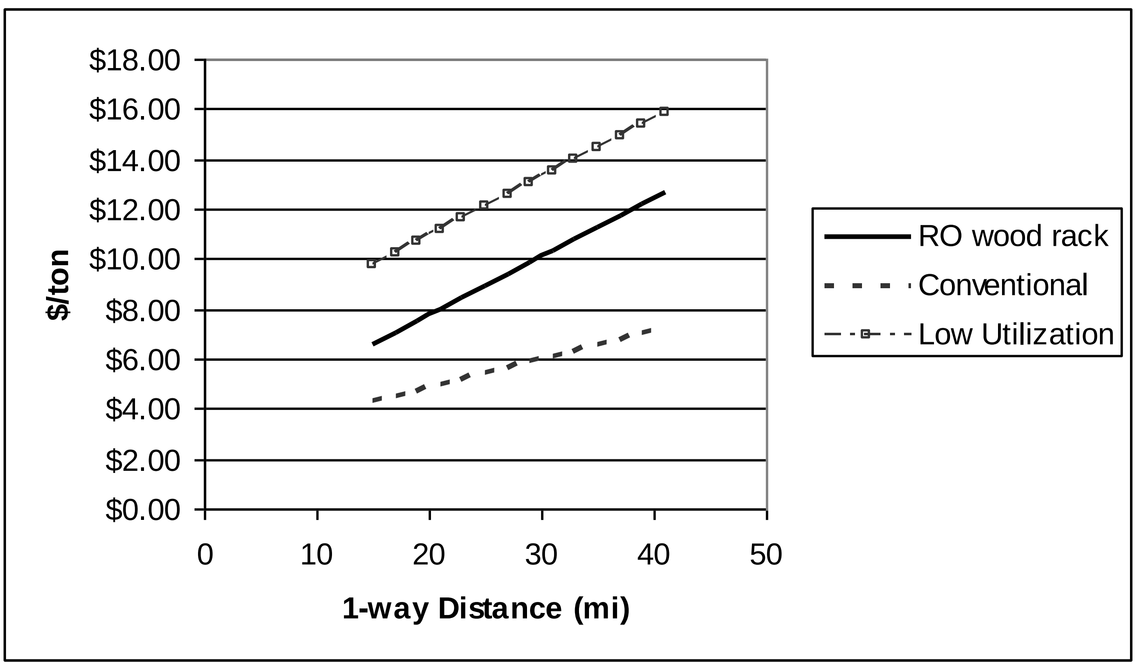

Figure 2. Estimated costs for three alternative transportation scenarios.

Summary

Small-volume wood consumers may not be able to take advantage of the economies of scale offered by conventional wood harvesting and transport systems. If the small consumer is the only delivery market, it is important to find an appropriately-scaled system to avoid the cost penalties of underutilized equipment. The shortwood transport system using roll-off wood racks shows the value of matching transport system capacity to woodflow requirements. This analysis also suggests that additional cost savings can be realized if multiple markets are available to share a transportation system. For example, two small facilities may be able to fully utilize a single conventional trucking operation reducing wood costs for both consumers. However, multiple markets must be able to have some consensus on product form and wood-handling system requirements in order to use a common trucking system.

As new utilization opportunities are developed for small-diameter wood products it is important to understand the economies of scale in wood transport. Markets that require less than 50 green tons per day will likely pay a premium in transport and handling compared to larger utilizers.

References

Bromley, W.S. 1949. Dixie pulpwood pallets for crosswise loading. Release 46. New York: American Pulpwood Association. 3 p.

Sinclair, Alex. 1985. Development and testing of a container system for the recovery of roadside biomass in mountainous terrain. Special Report SR-27. Vancouver, BC: Forest Engineering Research Institute of Canada. 23 p.

USFS. 2003. A strategic assessment of forest biomass and fuel reduction treatments in western states. http://www.fs.fed.us/research/infocenter.htm (5/31/03)

A REPEATABLE REGIONAL BMP MONITORING METHODOLOGY

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Abstract:
The Northeastern Area Association of State Foresters, Water Resources Committee initiated a project to develop, test and implement a standardized Best Management Practices (BMP) monitoring protocol. The project addresses the need for information regarding the implementation and effectiveness of BMP's on timber harvesting operations throughout the Northeastern Area and potentially beyond. A phase 1 version protocol was developed in the fall and winter of 2001 and training and data collection in nine states in the summer of 2002 produced 97 samples and 21 quality control re-samples. The BMP monitoring protocol analysis demonstrates the approach and methodology of the protocol produces repeatable results across a diverse geographical area.

Background:
The term, Best Management Practice (BMP) was originally defined in the 1987 Clean Water Act (CWA) to refer to precautionary activities designed to protect water resources during timber harvests.

Timber harvesting activities are exempt from the permitting requirements of the CWA when BMP's are used to protect water resources. The Environmental Protection Agency (EPA), has been required, as a result of litigation, to show evidence that the requirements of the exemption are being implemented. As a result, the EPA has long sought a standard BMP monitoring protocol that would provide measurable data that is reliable and comparable among states.

The National Council of Air and Stream Improvement (NCASI) agrees as stated in Technical bulletin #820, January 2001: "Most states recognize the potential for water quality impairment from timber harvesting, especially soil erosion and sedimentation caused by roads and stream crossings. The states repeatedly report a serious lack of monitoring information, and generally fall back on widely accepted generalizations about the impact of timber harvesting on water quality."

State Forestry agencies have sighted manpower, time, cost, differences in their individual BMP specifications, and monitoring team makeup as barriers to a common protocol.

Importance of Consistent Methodology in Environmental Monitoring
"Measurement inconsistency is unfortunately a serious problem in environmental monitoring. At the very least it throws doubt on the results of an analysis and opens the door to criticism of any interpretation. Continuity and reliability of information is only assured if it is gathered or produced in a consistent and well, documented manner. This facilitates comparison with results from other related contemporary studies. Deviation

from the method or its components will often compromise the outcome and adherence to specification is therefore critical for ensuring reliability of results." Beard, et al 1999.

Beard et al identified critical sources of data collection errors which influence the consistency of monitoring results and suggest the following guidance for data collection;

Need for a detailed protocol
Need for a detailed recording methodology
Need for quality control and assurance
Need for an overlap period for changes in methods
Need for Measurement synchronization

This project addressed the above concerns by:

- ✓ Developing a detailed protocol with a recording methodology;
- ✓ Initiating a quality control and assurance component through blind re-sampling to ensure validity of protocol questions and answers;
- ✓ Encouraging each participating state to conduct their sample collection on sites which are currently monitored utilizing their own protocol in order to make comparisons between the protocols;
- ✓ Setting a time frame for data collection relative to the harvest.

Pilot Phase Participants

During the pilot phase of this project 9 states and 1 Industrial landowner were trained in the use of the protocol and the GPS data collection equipment. The participants included: New York City Watershed Agriculture Council; New York, DEC; New Hampshire, DRED Division of Forest and Land; Maine, DOC Maine Forest Service; Maryland, DNR, Forest Service; West Virginia, BUC, Division of Forestry; Pennsylvania, DCNR, Bureau of Forestry; Ohio, DNR, Division of Forestry; Indiana, DNR, Division of Forestry; MeadeWestVaco, Maine; Wisconsin, DNR. Participants who collected data for testing of the protocol were primarily the same individuals who also collect data for their state BMP monitoring programs.

How This Protocol Differs

Major hurdles which have impeded the development of a regional monitoring protocol have been the variability of BMP practices among states, selection of practices to be monitored, activities monitored, and the method to be used to analyze the data.

This protocol differs in that it does not evaluate individual practices but evaluates only the use of BMP principles based on their designed functionality. The premise is; it does not matter which practice is used to slow and disperse water flow, but that practices were used and they were effective, based on the intended function of the practice. We only evaluate the intended function of a BMP not the impact on water quality. We all recognize the overall intent of a BMP practice is to protect water quality but we are assessing how well a practice or group of practices are functioning to meet the designed functionality of "how" the practice protects water quality.

The BMP principle approach permits the evaluation of data from a variety of practices or a combination of practices across a region. An example of this approach is the science and research behind cross drain spacing. Many BMP guidelines for cross drain spacing are based on the concept that "the distance that water flows down a road surface from a cross-drain to the point where rills are (1) inch deep (erosive cutting distance) defines the average spacing required between cross-drains." Packer 1967.

Determining if a BMP practice is implemented is typically less complex and less time consuming than determining BMP effectiveness. One major goal of effectiveness monitoring is to identify effectiveness of successful BMP applications. Therefore it becomes important to initially identify any discernable deviation of effectiveness for BMP principles applied. Since there are various degrees of acceptable effectiveness among states, due to inherent differences with in the resources and expectations of BMP practices, we need to set a common standard when evaluating effectiveness of BMP principles. This approach, which is similar to the Forest Inventory and Analysis (FIA) program, ensures there is consistency in site evaluation and data collection and that all data, which is analyzed, has the same parameters and definitions. This approach allows individual states to set their own acceptability benchmarks that meet their needs and objectives versus creating a generic regional or national standard which may not account for important differences among states or regions.

In addition to evaluation of BMP principles this protocol strives to minimize the subjectivity of results by requiring the presence of physical evidence to substantiate decisions in the field.

Sampling

The protocol focuses monitoring on the following logging, road construction and road maintenance activities:

At haul road water crossings.
At skidder water crossings.
At haul roads or landings within riparian or buffer zones.
Within state specified riparian or buffer zones.
Slope distance out side the riparian or buffer zone.

Focusing on activities within these specific locations will improve efficiency as well as focusing efforts in locations that typically have the highest potential to impact water quality.

To ensure consistency in monitoring a harvest operation or a harvest operation with multiple skidder or road crossings and to eliminate averaging the evaluations of large harvest sites a "sample unit" definition was defined.

The BMP monitoring protocol consists of a series of questions with an array of answer choices which functions much like a dichotomous key. The questions and related answer choices were then programmed into a Trimble GEO III, GPS unit where they are referred to as a data dictionary. The intent is to collect field data in fairly large amounts, transfer the data across a wide geographic area, as well as simplifying the data entry responsibilities. A data dictionary was developed specifically for this project that allowed for answering the associated questions directly into the GPS unit.

This phase of the project was not intended to determine how BMP's are being used or their effectiveness but to test the protocol under a variety of site conditions throughout the USFS Northeast area. The diversity of sample units was based on soils, topography, geography or other characteristics that were identified as important to the individual state or company. Since the goal was to test the protocol, sampling was neither random nor unbiased. Re-sampling was conducted on approximately 30 percent of the total samples.

Analysis of Repeatability of Protocol Questions

The purpose of this analysis is to determine how well 2 different individuals at different times evaluated the same site without prior knowledge of either site evaluation. The evaluation is broken into 4 components;

(1) The percent of matching answers for "all questions" answered excluding the general section and site attributes. The general section and site attribute section would normally be shared information between evaluators therefore we did not want to bias the results by using these questions.
(2) The percent of matching answers for questions answered with in each "feature" such as haul road, skidder crossing, buffer, haul road in the buffer and Hazmat.
(3) The percent of questions by feature answered which were classed as "critical questions" versus questions which may be more descriptive and informative.
(4) We will also use the comparison between initial and repeated sample data to guide us in improving questions and answers during phase 2 of this project.

The results of 21 sample units with a blind repeat sample are in table 1.

Table 1. The results of repeat blind samples.

Feature	All Questions with Matching answers	n	Critical questions with Matching answers	n
All features	71%	620	78%	263
Haul road crossing	75%	202	83%	98
Skidder crossing	68%	176	73%	60
Buffer	68%	218	75%	101
Hazmat	100%	24	100%	4

Having a monitoring system that is repeatable should add credibility to monitoring results from the professional aspect as well as the general public and interested stakeholders. A repeatable protocol will also improve and increase efficiencies of a Quality Control and Quality Assurance program which is essential for any monitoring program. Replication of a site evaluation is important but more important is that the repeatability results match professional opinions to ensure common sense and experience is not lost in the process.

Summary

A survey of "Data Collection Participants" was conducted after data was collected to ensure participants had the opportunity to work with the monitoring protocol as well as comment on the effectiveness of the training as it relates to the data collection.
Three very encouraging points are revealed by the survey.

1. 90% of the data collection participants feel the monitoring protocol, with some edits, is applicable to their state.
2. 70% of the participants feel the protocol supports their professional opinion of the site evaluations.
3. All feel subjectivity was minimized to various degrees for the site evaluation using the monitoring protocol.

The approach to BMP monitoring using this BMP protocol appears to account for most of the topographic, soil, and geographic differences in the test area. Evaluation of BMP's based on their principles and desired functionality appears to be a key component allowing for the development of a regional BMP monitoring protocol.

Since all the data collected was done using the same method and process a test of a regional analysis was conducted. The consistency of data collection was very conducive to a regional analysis.

The repeatability (71% all questions) and (78% critical questions) of sampling was reasonable and improvements on repeatability can be improved by editing the protocol, follow up by QAQC teams and more training.

Since the data was collected electronically in a compatible data base format there was no data entry other than the initial electronic entry in the field. This greatly reduced costs of data entry and allows the data to be transferred easily by e-mail and entered directly into the main data base.

Based on the data, participant comments and committed funding this project will progress to the next phase which is to expand the utilization of an edited version of the current protocol.

References;

Beard, Scott and Adamson; 1999, The value of consistent methodology in long term environmental monitoring. Environmental Monitoring and Assessment 54:239-258)

Packer 1967, Criteria for designing and locating Logging roads to control sediment; Forest Science Volume 13, number 1).

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LIDAR-BASED TOPOGRAPHIC MAPS IMPROVE AGREEMENT BETWEEN OFFICE-DESIGNED AND FIELD-VERIFIED ROAD LOCATIONS

Peter. Schiess and Finn T. O. Krogstad

ABSTRACT:

Existing photogrammetricly derived topographic maps are good for general planning of road and harvest activities. Sub-canopy topographic variation however is not identifiable by photogrammetry, necessitating field evaluation and often field design of marginal activities. The advent of airborne laser scanning (LIDAR) promises the possibility of detailed sub-canopy topography. This paper presents an evaluation of the utility of LIDAR topography for road and harvest design. In general, LIDAR allowed avoidance of 'difficult' areas, identification of areas in need of field validation, and confidence in the validity of map-based designs. Confidence however was limited by the tendency of some LIDAR mapping techniques to smooth over areas in which LIDAR was unable to penetrate the canopy and map the ground below.

PROBLEM

Topography can be a crucial element in assessing the utility of alternate road and harvest plans. In the past, photogrammetric mapping has been the most cost effective way to build topographic maps of forested areas. These maps provide good preliminary guidance for laying out roads and harvest units, unfortunately the trees that draw us to these areas also obscure the underlying topography. In difficult topography, planned skyline profiles and road alignments are frequently rendered unworkable by topographic 'details' that were not represented in the photogrammetric topography that was used to plan them.

Recent technological advances lead to a rapid spread in airborne laser mapping known by the acronym LIDAR. Just as in photogrammetry, forest canopies can intercept most of the laser pulses, but any stand in which sky can be seen from the ground will allow some LIDAR penetration to the ground. Wherever the LIDAR pulse density can overcome canopy density, the resulting ground points can be interpolated into a topographic map.

The resulting sub-canopy topography can display considerable topographic detail. In Figure 1, the microtopography of stream draws, landslides, and even abandoned road prisms are clearly visible. The photogrammetricly derived contour lines for this area either misrepresent or totally fail to represent these microtopographic features that can be difficult to design around. While LIDAR topography can not identify non-topographic design issues such as excess water and weak soils, it can frequently identify these problems when they produce even minor slumps or hummocky topography.

It is not initially obvious however, whether this superior topographic detail necessarily translates into better harvest and road planning. The cost of LIDAR mapping must somehow be justified by some combination of improved designs, reduced field work, and/or increased confidence in our plans. Ideally, LIDAR should provide enough detail to:

- Guide activities away from 'problem areas'
- Identify areas most in need of field investigation
- Identify options that are most likely to be validated in the field
- Estimate the level of confidence in field validation of a design

It might be imagined that LIDAR, in combination with GIS-based road and harvest design tools might allow office-based road and harvest planning, without the need for costly field-based design and verification. As the above list suggests, the main benefits of LIDAR is not in replacing fieldwork, but in making it more efficient.

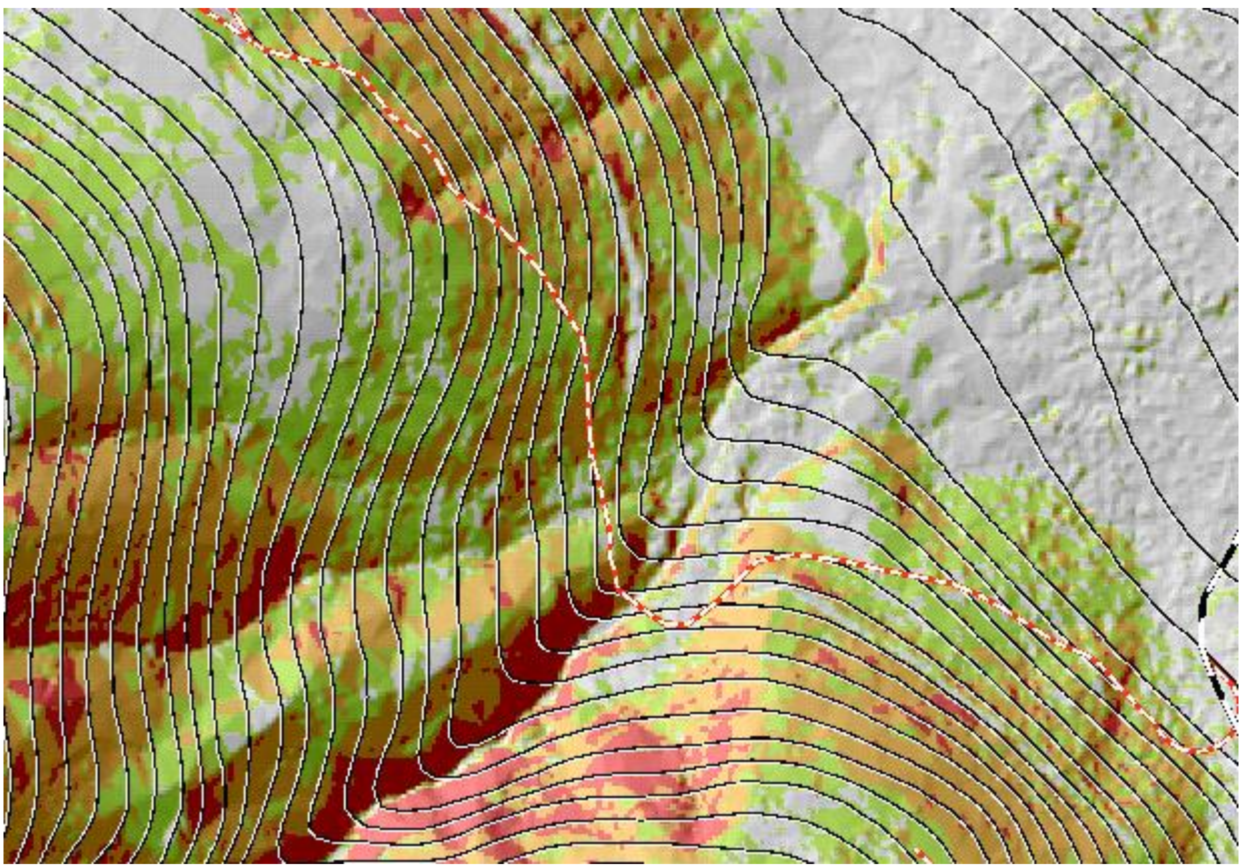


Figure 1. LIDAR topography (hillshaded image) provides a realistic and detailed topography. Photogrammetricly produced contour lines capture the general shape of the landscape. However, complex features such as incised streams**,** draws, abandoned road

beds and sharp ridges are not recognized**.** Superimposed on the map is a traversed road centerline that is profiled in Figure 2.

EVALUATION

This new mapping shows considerable promise in a range of design activities. While some might choose to evaluate the root-mean-square error or some other measure of accuracy, the true measure of LIDAR's utility in road and harvest planning is whether we have confidence that a road or cable profile that is planned using LIDAR topography can actually be executed in the field. Small discrepancies can always be fixed with minor earthwork or alignment changes. Larger discrepancies however can require extensive redesign and often a whole new approach.

In order to evaluate the design benefits of LIDAR topography, the students in the University of Washington, Forest Engineering Capstone Design course (in cooperation with the Washington State Department of Natural Resources) have begun using LIDAR topography in their landscape scale harvest and transportation planning. This paper outlines some of our most recent finding in our evaluation of the utility of this LIDAR topography for forest engineering.

As part of the planning and design work the UW Forest Engineering Seniors traversed about 2.4 miles of a road centerline (P-Line shown in Figure 1). The traversing was done with a "Criterion 400" instrument, measuring slope distance, slope angle and compass bearing. The horizontal and vertical data points in Figure 2 were derived from slope distance and slope angle. The overall precision of the survey was about 1:700.

As shown in Figure 2, the elevations inferred from LIDAR topography agree well with profile elevations taken in the field Elevations from older photogrammetricly derived topography generally agree with the field data, except around draws and stream crossings where topographic accuracy is most important. Figures 1 and 2 show that a small draw (identified in the LIDAR and field data) was totally missed by photogrammetric topography, and that the topography of a large stream crossing was dramatically simplified, and showed an error of as much as 50 vertical feet.

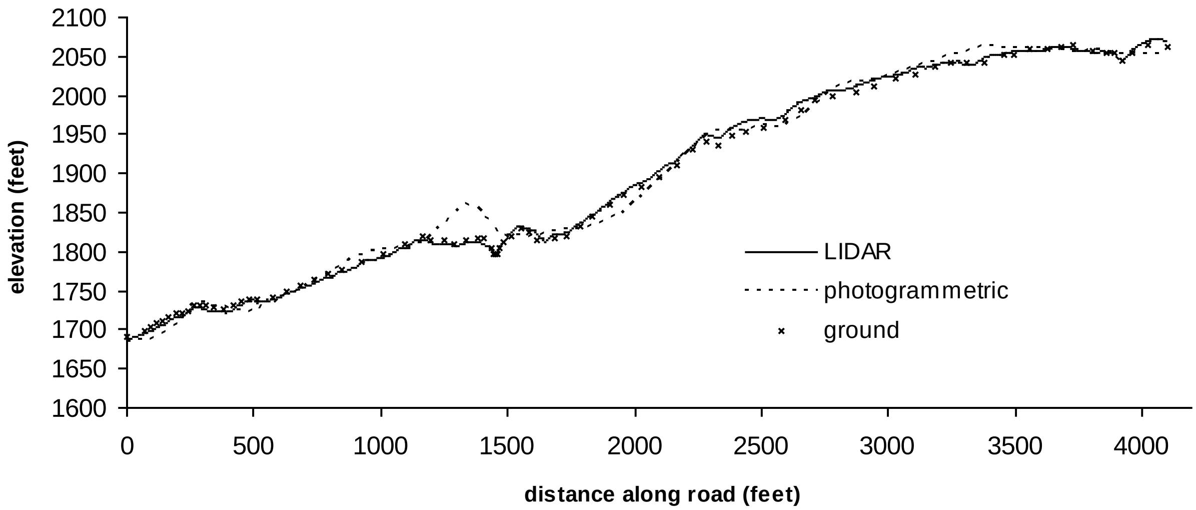


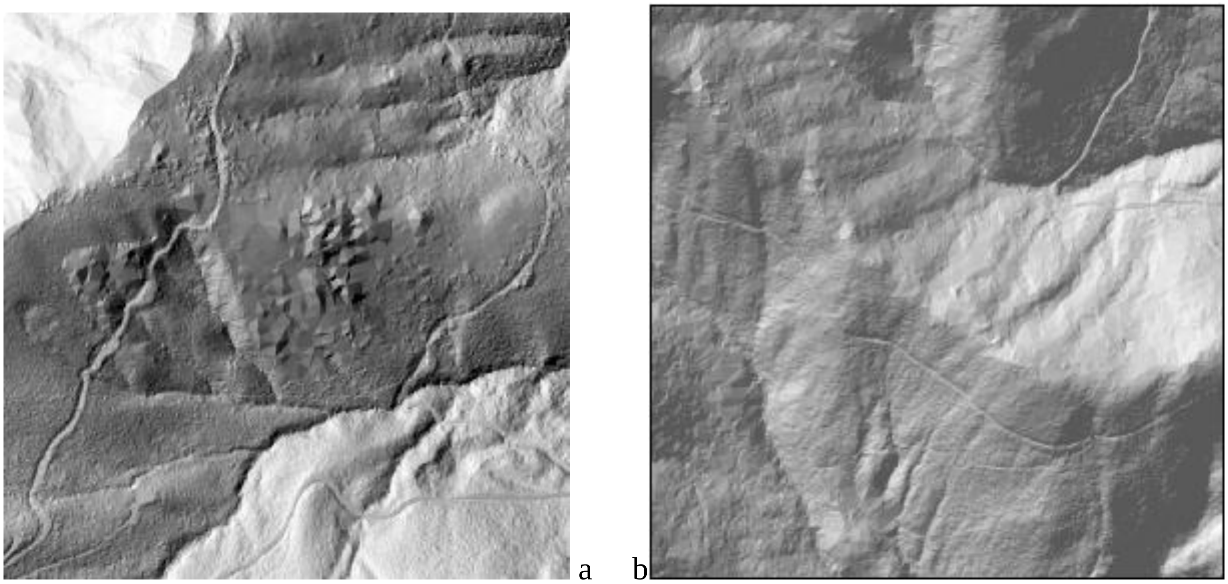
Figure 2. The topographic simplification of photogrammetric mapping becomes significant at incised stream crossings, just when exact elevations become most significant for road design. The traversed road elevations of the road shown in Figure 1 agrees almost exactly with the LIDAR surface, but the topographic smoothing of the photogrammetric topography totally misrepresents the stream crossing, and does not even identify the smaller gully further up the road.

As part of a different project a DNR forestry crew spent eight man-days traversing five profiles with clinometer, stringbox and handcompass. Establishing the field profiles was deemed critical to prove the viability of cable-yarding this particular harvest unit. Based on the results of the road traverse and its agreement with LIDAR-generated road profiles we conclude that the same five skyline profiles could have been generated in eight minutes from LIDAR maps with comparable, if not higher certainty about their accuracy

LIDAR PROBLEMS

The impressive accuracy and detail of LIDAR topography however can still be inhibited by the forest canopy. Where young stands are so dense that it is difficult to see the sky, LIDAR systems are similarly prevented from penetrating to the ground. In such cases, LIDAR can provide no guidance to engineering design, and we must fall back on field methods for mapping and design.

Depending on the mapping technique, these areas of minimal canopy penetration can either be easy or difficult to identify. If the lowest LIDAR return in an area is assumed to be a ground return, then the resulting topographic surface will be easily identified since it won't look like a real ground surface (Figure 3a). From past experience, we know that the area could contain gullies, earth slumps, or hummocky topography. And we know that we may need to field evaluate any design passing through such areas.



a b

Figure 3. Where a dense canopy prevents all LIDAR pulses from reaching the ground, LIDAR can not provide useful information for planning. Depending on the mapping system however, it can provide misleading information. While both images provide excellent detail of streams and abandoned roads, the first image shows these as areas that clearly are not ground topography. The second image is more dangerous however, in that it provides no hints that there may be massive outcrops along the top of the ridge that were only identified in the field.

An alternate mapping approach would be to interpolate topography across these no-data areas to create a more realistic looking ground surface. But realism and reality are not the same. In creating a realistic interpolated topography, we hide the fact that we don't really know what is under those dense canopies. Unrealistic topography at least tells us that we don't know what the topography of an area is, so field validation/design may be required. Realistic smoothed topography however gives no clue that our plan may be invalidated by problem areas that are not shown on the map. Making areas of unknown topography look like areas that really do have smoothed topography will necessarily make us suspicious of all areas of smoothed topography. This will necessitate field validation of all areas that look smooth, eliminating the benefit of having LIDAR topography.

The problem of the smoothing away of real topographic problems is exemplified in Figure 3b. The ridge running through the middle of the image was the preferred road alignment in an otherwise steep area. When running grade lines in the field however, several large rock outcrops were found along this ridge top that invalidated this entire ridge road option. They were not identified on the photogrammetric map or the orthophotos, and they had been smoothed off by the LIDAR mapping, so there was no warning that this entire ridge road might be unworkable. Had the outcrops been left as an anomalous topographic bulge, then they might have been investigated on the detailed aerial photographs (in which the outcrops were visible) and planning could have shifted to other alternatives. Instead, significant design and field time was wasted on a road option that could have been invalidated in the office.

These experiences might be taken to suggest a fundamental flaw in using LIDAR for engineering design. After all, why pay for mapping if you still have to validate and/or design in the field? Perhaps a more correct lesson is that when engineers are requesting LIDAR topographic mapping, they should request mapping techniques that sacrifice topographic 'realism' in favor allowing anomalies (whether outcrops or no-data regions) to express themselves.

CONCLUSION

Initial experience with LIDAR-based DEM's showed their usefulness in improving the reliability of "paper" or map-based designs. However, surface expressions such as wet soils, are not yet identifiable, still requiring field verification. Engineers should also be willing to accept maps with segments of anomalous topography so as to reduce the risk of false confidence in their maps and designs**.** Given these inherent problems, engineers need to be suspicious of LIDAR generated topographies in which the problems are not easily identifiable. LIDAR providers who smooth over data gaps to make topography 'look good' are not helping engineering design. Areas with clearly identifiable problem can always be flagged for field inspection. If these problem areas can not be identified however, engineers will face the same uncertainties that they face with today's lower quality mapping.

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Putting Environmental Engineering into Forestry's Engineers

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Increasingly, the annual timber harvest in the United States comes from private, industrial forestland. In Oregon, over 80 percent of the annual harvest comes from the 22 percent of commercial forestland that is owned and managed by private, industrial landowners. If an increasing proportion of society's demand for wood products is going to be supplied from a decreasing proportion of the commercial forestland available to be managed, then that forestland must be managed very intensively.

The constraints on contemporary intensive forest management on private industrial forestland are, increasingly, environmental. Many of these constraints are associated with: landslide potential on steep lands, concern for the impact of timber harvesting on non-fish-bearing, headwater streams [both water quality and riparian habitat], cumulative impacts of forest management, and the management of existing forest road systems.

The common solution to these environmental constraints is recognition and avoidance. Two historic examples of this type of solution are fixed width buffer strips for riparian area management and harvest unit size limits and adjacency constraints for cumulative impacts. Proposed solutions for contemporary problems follow the same pattern. For landslide- prone terrain the solution is recognition of high hazard areas and avoidance of these areas. For headwater streams the solution is recognition of the feature and either buffering of the stream or managing at a lower spatial intensity. For road systems the solution is recognition and removal of high hazard and high-risk roads, and seasonal road use restrictions. All of these solutions limit the ability of private landowners to intensively manage their forestland either by removing more forestland from production or reducing the intensity of management allowed on the forestland. These limitations can be economically debilitating.

There are a number of ways to address contemporary environmental constraints while allowing private landowners to continue to intensively manage their land. One way involves a more spatially explicit approach to the recognition of high hazard or high-risk landslide sites/headwater streams/road segments – this amounts to more refined definitions of "high hazard" or "high risk". For example, (1) of the total population of high-hazard landslide sites only about 10 percent of them ever fail during a rotation, (2) of all the headwater streams only a minority of them have the capacity to efficiently transport thermal pollutions downstream, and (3) of the total population of forest road segments only a minority of them carries sufficient runoff to cause problems with watershed hydrology or chronic sediment delivery.

We believe that the forest engineer should be a key contributor to any refined process of hazard definition. Forest engineers are forestry's environmental engineers. For too long the process of solving these environmental problems has been relegated to other disciplines, most notably earth scientists trained to use surficial descriptions and inductive thinking for problem solutions. This robs the solution process of the strength of engineering, which is site-specific data collection and deductive reasoning. Instead of blanket recognition and general avoidance of a class of terrain for solving potential environmental problems, we suggest that site-specific data collection, more refined definitions of hazard followed by spatially explicit recognition of high hazard sites or features, all carried out in the context of a problem solution is a highly desirable path. The outcome will certainly include avoidance of some areas, but should allow environmentally acceptable management of others.

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LOGGING COST CALCULATOR,
a tool to aid the planning and estimation of logging rates

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Introduction and Abstract

The benefits of logging planning have been well documented (Rodgers, et al COFE 2002). The potential for cost improvements through logging planning have also been well documented (Mayo, et al COFE 2002). Logging planning involves making a map of the developments required to harvest, the operational limitations of the harvest, and estimating the costs to develop and harvest. The Logging Cost Calculator (LCC) is a tool developed to simplify the task of estimating logging and development costs.

Logging planning can compare various harvesting alternatives to determine the alternative with the most desirable cost and impacts. There are numerous commercially available mapping programs that can be used to depict logging systems, developments, and operational limitations. These programs most readily accept cost effective recreational grade gps data collected to identify and locate various existing roads, landings, and other developments needed to implement logging plans. They also can be used in reverse, to take coordinates of planned developments, input them into a gps, and navigate to them in the field. Another benefit of using mapping programs is that they can be used to measure the length, area and number of various items in order to determine quantities for costing and impact analysis. The selection of which particular program to use for logging planning is mostly a matter of personal taste, and has greatly reduced the map based efforts needed to effectively accomplish logging plans. However, no logging plan is complete without estimating the cost of logging and developments. Costing of logging plans usually involves a lot of separate manual calculations, and as a result does not lend itself to rapid determination. The author has identified this costing process as the greatest barrier to the development and use of logging plans. Overcoming this barrier will help the industry to achieve the cost efficiencies of better planning that have been previously identified (Planning and Communication; WSRI 2002). A Logging Cost Calculator (LCC) has been developed in order to facilitate the estimation of these costs as rapidly and easily as possible. The LCC can be used to estimate logging costs at the strategic, tactical, and operational levels. Different logging systems can quickly be compared for cost effectiveness. This effectiveness comparison would help to overcome the greatest barrier, planning, in implementing specialized logging systems (Sloan, COFE 2001). The purpose of this paper is to explain the rationale used to determine logging costs in the LCC and to demonstrate the applicability of the LCC in development of logging plans. LCC is a script-based program that can be run on most platforms that can operate a web browser program such as Internet Explorer. It will run on a pocket PC, enabling the user to estimate costs in the woods, as well as PC's of any operating system with a web browser.

Logging Cost Rationale

What does it cost to log? This simple question plays a dominant role in Forest Management today, as logging is a major part of the cost in Forest Management. It is also a very complex question to answer. Complex because it involves so many variables, all of which play a role in establishing what it costs to log. These variables can easily lead to logging rates that vary by over 100%.

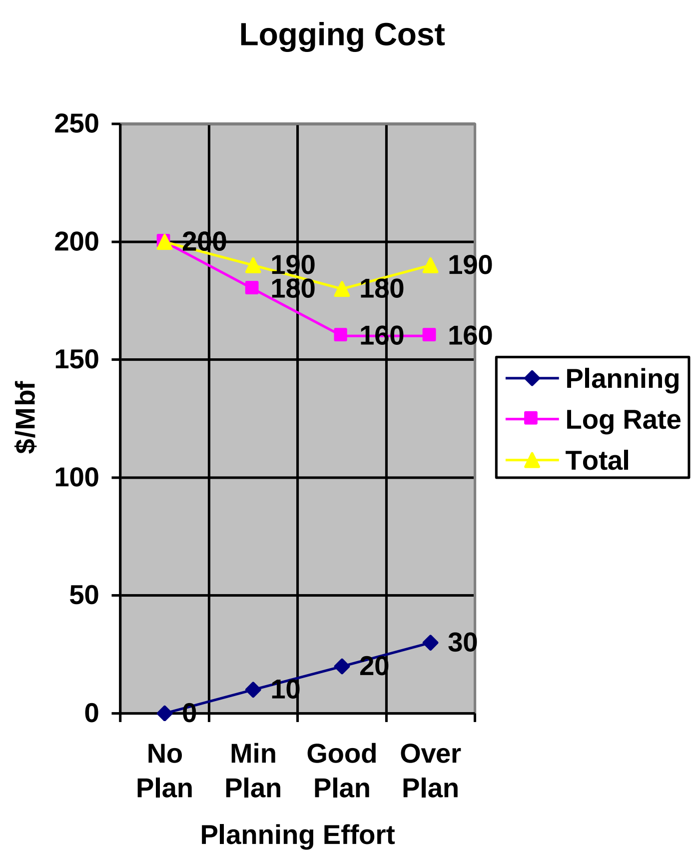
The variables involve people, culture, equipment, tools, location, weather, terrain, timber species, soils, size of tract, size of timber, methods of cut, markets or lack thereof (quotas), merchantability specifications, road construction and maintenance, time of year, performance standards (damage to residuals), planning effort, logging patterns, logging systems, and there are many, more detailed, variables not listed. Many of these variables can be determined with a good logging plan, others cannot. For example, tract size, tract volume, tree size, species, road construction and maintenance, landings, yarding distances, slopes, haul routes and times to various markets, time of year for harvest, and the selected logging system can be determined from a logging plan.

Other variables, such as people, work culture, and condition of equipment cannot be specifically determined, but can be reasonably assessed. Some equipment is maintenance heavy (i.e. lemon) and some equipment seems to run forever. Some loggers are highly motivated to optimize their production and others are content with standards that permit survival. Loggers have a tendency to self compensate their production efforts, clouding further the effect of the true variability in logging costs. For example working longer days in order to compensate for more difficult chances, and/ or loosing money on a tract and making money on the next to dilute the true variability of logging costs.

What does it cost to log? The answer to this simple question also depends on the scale and scope of the question. For example, what did it cost to log your mill last year should be a fairly simple question to answer by totaling the costs and volume logged and dividing. Answering the question, what should it have cost to log your mill is a difficult question to answer and involves analysis of all of the variables listed above. The best question to ask is: Are my logging costs reasonable?

When looking at logging costs and productivity it is important to remember that in this mix of loggers there are "star" performers as well as "also ran" performers. When answering the question, it would be a mistake to establish either one of these extremes as the performance standard. What is important about a logging cost performance level is that it is **reasonable**. In this manner the "stars" are rewarded and the "also rans" are penalized. This is one of the problems with using productivity and cost from most classical time and motion studies, they just give a snapshot of an operation and invariably it is of a "star" or an "also ran" performer, in conditions that are particular to the tract being harvested. In 1997 the World Forest Institute developed a logging cost estimator in which the productivity of a particular operation was presented as a range for the user to reasonably estimate (Wilbrect, 1997). This program presents a production range of what could be considered reasonable, and permits the user to evaluate logging costs over that range. While this program does not contain enough detail to evaluate a wide range of logging conditions, it does recognize the difficulty in estimating productivity. Virtually every logging cost method I have ever used has required me to "customize the results" with judgment gained through experience. The productivity levels in the LCC are based upon experience in what is reasonable to achieve given all the particulars of a logging job. This judgment can be easily be adjusted to account for being smarter tomorrow than one is today, as we are constantly learning about logging productivity.

It has been my experience that actual contract logging rates do not accurately reflect the work that is involved with logging a particular tract. The typical logging rate structure is flatter than what reasonable estimates would conclude. This flatness involves under estimating contract rates on poor tracts and over estimating contract rates on good tracts. When it comes to sealed bid timber sales, this flatness leads to underbidding on the good tracts and overbidding on the poor tracts, of course at the loggers expense! This is a loose - loose situation where there is obviously an incentive to more accurately estimate the true range of logging costs.



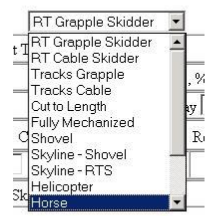
What does it cost to log? The answer to this question should include the cost of planning for logging. So the answer has two parts, 1) planning cost and 2) contract logging rate. The total of these two is the answer to the question. Opportunities for increased productivity through better logging planning have been identified through extensive study funded by WSRI (Rodgers, 2002). A relationship between planning effort and logging costs is: as more effort is put into optimizing and developing logging plans, the more efficient logging becomes. As one can see in the chart, with increasing amounts of planning, the reasonable contract rate for logging decreases. At some point in planning effort, the logging efficiency in maximized and any further investment in logging planning will result in an overall increase in total logging cost. This effect of increased planning leading to decreased logging rate works at both a strategic scale as well as a tactical scale. Strategic logging planning is not site specific, but is a broad based consideration of timber and terrain resulting in optimal logging system selection and that systems application guidelines. Strategic logging planning pays off by putting the right tool on the job. Tactical logging plans are site-specific development plans for a particular logging system. Tactical logging planning pays off by making the most efficient use of the tool.

How much planning effort is optimal? Depends on all the aforementioned variables, but spending somewhere around 10 – 15% of the Logging Rate would be a reasonable place to start. Generally the lower cost the logging, the less opportunity to reduce overall costs by improved planning, however there are exceptions, such as helicopter logging which has a high unit rate but relatively easy to plan and optimize. A good starting point is 10 – 15%, which can be refined by actual experience in the area.

<u>The LCC – what it is</u>

The LCC is a tool which calculates road and logging costs on a per unit of volume and weight basis, taking into account all of the variables which can be determined or estimated for a particular logging chance and making a reasonable estimate of system productivity.

Having completed many strategic and tactical logging plans, I was frustrated by the time involved and organizational skills needed to go to many different places in order to estimate costs of each plan. The objective of developing the LCC was to produce a one-stop shop for costing logging plans. With the idea of using a popup window to be used concurrently with a mapping program, and portability outside of laptop environment, I decided to use Internet Explorer and code pages with JavaScript. LCC will run on Pocket PC's. The script is written to be easily updated or tweaked as more experience is gained. The script was written to take advantage of costing methods and principles the author has learned from years of experience in developing logging costs. LCC includes on a drop down menu to select from 11 different logging systems and 4 swing applications, truck roads including culverts, skid roads, revegetation costs and other developments. The logging systems are: 1) Grapple Skidder, 2) Cable Skidder, 3) Grapple Tracks, 4) Cable Tracks, 5) Cut to Length, 6) Fully Mechanized, 7) Shovel, 8) Skyline – Shovel, 9) Skyline – Skidder, 10) Helicopter, 11) Horse and for swing only 12) Forwarder, 13) Tracks Grapple, 14) Tracks Cable, and 15) Shovel. Full description of each system is provided through an extensive help system. System productivity is limited by either hauling capacity or logging capacity, and requires manual adjustment to balance. Use of the LCC is designed to be self-explanatory.

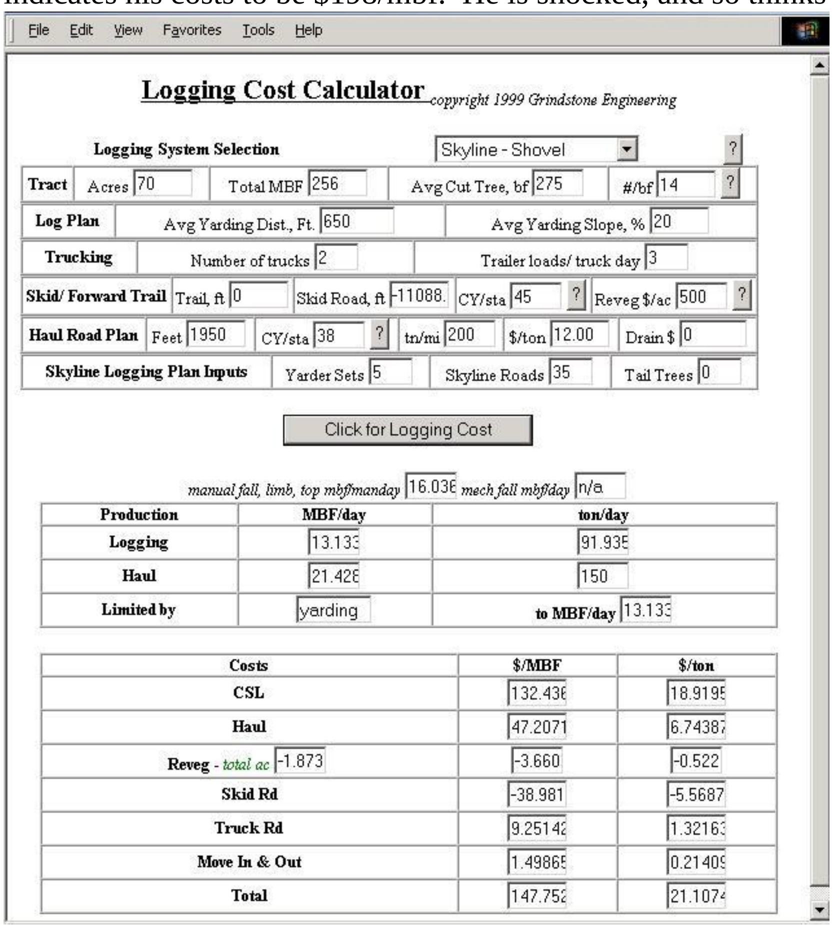


<u>Instructions on how to use</u>

Select the logging system that you are planning for from the drop down listing. 2) Fill in the data variables for the logging plan you are costing. 3) Click the button and logging cost and production is listed in the boxes at the bottom. The page may be printed to document your costs and variables. If the window is not big enough to view the results, go to view – text size – and change to smaller. Since this process is so simple, it encourages comparisons between alternative logging plans for the same system as well as comparison between logging systems. Help is available by clicking the question mark button located beside the variable being asked for. Note that logging costs are determined for the limiting production of either hauling or cut skid and load (CSL). Balancing this production will result in the lowest cost logging. The best way to explain how the logging cost calculator works is by showing some example applications.

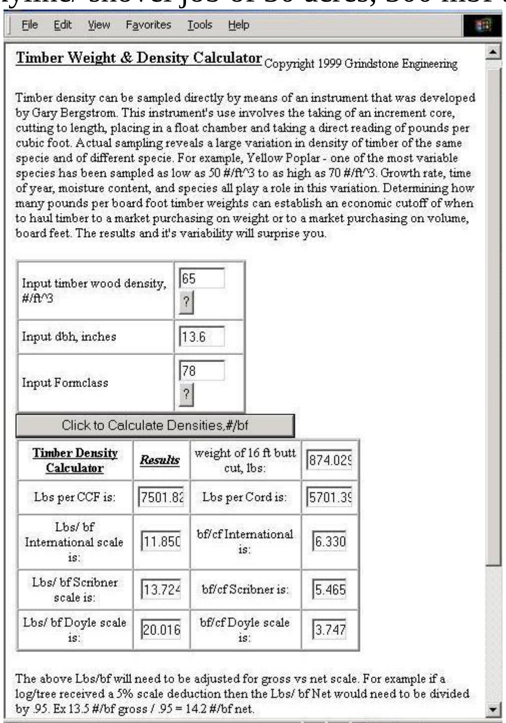
Example 1) Tactical optimization on a system. The logging system planned for is a cable skidder with manual falling and 2 haul trucks. The logging plan indicates that the tract is 40 acre has 320 mbf with an average tree of 200 bf, typical hardwood mix. The plan is to skid to the edge of the tract with an average skid of 900 feet on pretty gentle ground (15% adverse skid), and each truck can haul 2 loads per day. It is estimated that 1600 ft of skid trail will need to be revegetated and the average side slope at the roadside landing is 25%. The LCC calculates total logging costs to be $193/mbf. If the logger builds a road to the middle of the tract, about 600 feet, will he be better off? The logging plan indicates the road average side slopes are 25%, will need spot surfacing, and it will have 2 ea 18" culverts at a cost of $360 ea. The average skid is reduced to 550 feet. The LCC calculates total logging costs to be $170/mbf, including the $4.90/mbf for the road. Since this was such a good deal, the logger thinks he can save even more by building 300 feet more of road and reducing his average skid to 400 feet, working 2 landings. The LCC calculates $172/mbf, so the logger decides to not spend the extra on the road, and negotiates for a $180/mbf rate (5% profit).

Example 2) Logging System Selection. An eastern hardwood sawmill owner has seen a skyline logging operation out west during his Elk hunting trip. He liked the skyline system because it can produce logs when the weather is adverse to his normal logging operations. He is trying to figure out if it would be cost effective against his normal skidder crews on some of the ground he is logging. He has taken a sample of several of the tracts he is logging and completed a logging plan for both his skidders and for a skyline – shovel operation. From these plans he has determined the following strategic information. The average tract size is 123 acres, needs .93 miles of truck road on average side slope of 30%, needs 3.2 miles of skid road on average side slope of 50+%, needs 4 landings, and has 3.6 mbf/ acre cut common hardwoods (14#/bf), average tree is 275 bft, and cable skidding mainly downhill on a modest road grade of -15% average 900 feet is normal. Each of the 2 assigned trucks can haul 3 loads/day. The LCC indicates his costs to be $198/mbf. He is shocked, and so thinks immediately about getting a grapple skidder and keeping the same logging plan. The LCC indicates his cost drop to $171/mbf, so he orders one, but then starts to think about all the uphill pulling and how the cable skidder comes in handy being able to winch. So, wondering where the uphill skidding limit for his new grapple skidder is, he consults the LCC and figures that somewhere around a 20% adverse and steeper grade the cable skidder is cheaper. He vows to keep his new grapple skidder on grapple skidder ground and moves on to his real problem, to figure out how much is it going to cost to skyline log? Back to those strategic logging plans he developed for a skyline – shovel on the rougher ground and has determined the



following: On the typical 123 acre tract, about 57% (70 acres) of it lent itself to skyline an average of 650 feet uphill, needed 1.3 miles of truck road, needed 1.1 mile of skid road, and needed 5 landings with 7 corridors per landing and no planned tail tree rigging. So by adding in the skyline, truck road construction went up by 36% (1950 ft), skid road construction went down by 65% (-11088 ft), and landing construction went up by 25% (+1 ea). Consulting the LCC he finds that a skyline – shovel system would cost an average of $190/mbf for the increased truck road and logging, but it would also save $43/mbf on saved skid roads and revegetation, leaving the net cost impact of $147. This cost is less than current costs, so he decides to pursue getting a skyline – shovel system. He also figures that his skidder production will get better by keeping it on ground more suited to it.

Example 3) Merchantability – Markets Logger is trying to decide how small should he merchandize to a sawtimber market. Sawtimber market is 50 miles away, or a 3 load/day haul. Pulpwood market is 30 miles away and is a 4 load/day haul. Sawtimber market pays $200/mbf Doyle scale and pulpwood pays $26/ton after stumpage is taken out. The logging plan is for a skyline/ shovel job of 30 acres, 300 mbf total (heavy to Yellow Poplar), 275 bf/tree, and an average yard of 700 feet and 2 landings and 20 skyline roads. It will take 1000 ft of road on 35% side slopes and no culverts. The LCC to the pulpwood market is $17.30/ton (110.71/mbfeq) and $114.01/ mbf ($17.81/ton eq) to the sawtimber market. Gross revenue pulpwood is $26 - $17.30 = $8.70/ ton, gross revenue sawtimber is $200 - $114.01 = $85.99. The breakeven is ($85.99/mbf) / ($8.70/ton) = 9.9 ton/mbf. If the timber weights 10 tons per mbf or heavier then pulpwood brings more revenue. What trees should be merchandized as pulpwood? Using the LCC density calculator one can determine that the heavy hardwoods of good form (65# & FC80), 12.9" dbh and smaller should go to pulpwood; in the light hardwoods of good form (52.5# & FC80), 11.1" dbh and smaller should go to pulpwood. If the timber is of poor form, FC78, this breakeven changes to 13.6" for the heavy hardwoods and 11.7" dbh for the soft hardwoods. What happens if logs have a scaling deduction of 20%? Then I am looking for a log whose size is such that 120% of it tons/ bf is 10, so 10/1.2 = 8.3 tons/bf. The breakeven for the heavy hardwoods with poor form and a 20% scaling deduction is 16.1"dbh



Conclusion

One of the greatest improvements to the cost and impacts of forest management can be made through better logging plans. Generating logging costs for a mapped out logging plan is a significant barrier to developing logging plans. Awareness of alternatives to conventional logging systems is a first step towards better matching the timber and terrain with the proper logging system. The LCC can assist foresters, loggers, and forest management people to make better decisions.

Wilbrect, S. 1997. A Guide to Estimating Logging Costs in the Pacific Northwest (PNW). *World Forest Institute publication*.

Rodgers, B et al 2002. Opportunities for Increasing Productivity in the Industrial Wood Supply Chain through improved Planning. *COFE 2002 Auburn Al*

Mayo, J.H. et al 2002. Causes and Costs of Unused Logging Production Capacity. COFE 2002 *Auburn AL*

Sloan, H 2001. Appalachian Hardwood Logging Systems: Managing Change for Effective BMP Implementation. COFE 2001 *Snowshoe WV*

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COMPARING STRATEGIES FOR SKYLINE CORRIDOR LAYOUT

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Abstract

In the steep terrain of the Pacific Northwest, thinning has been widely used as an effective management tool for young Douglas-fir stands (McNeel and Dodd 1996). Skyline systems and pre-designated corridors are typically utilized for timber removal. The corridors are marked and profiled prior to harvesting to determine any potentially limiting factors for an operation's productivity. Historically, those profiles have been completed using a one-person crew, string box, hand-held compass, and clinometer. However, recent developments in electronic distance-measuring (EDM) devices have prompted land managers to investigate whether the improved efficiency of those instruments can reduce operational planning costs and increase accuracy of estimates.

This study compared two techniques for collecting profile data, as well as assessing the associated costs and design payloads for 20 corridors on the Siuslaw National Forest in western Oregon. The first technique used measurements made with a traditional string box, clinometer, and hand-held compass; the second employed an EDM device, digital compass, and digital data recorder. These two survey methods were then statistically compared with the results obtained from benchmark data collected by a total station. In additional, a time study was conducted to determine the overall efficiencies of each technique. The results from this project may assist harvesting contractors in making informed decisions on the use of alternative surveying tools for collecting spatial data.

Introduction

In the the Pacific Northwest, many governmental forestland managers are attempting to mimic mid-to late-successional forests by structuring younger, second-growth forests on steep slopes (Thompson et al. 2002). To expedite this process, commercial thinning is being widely applied to increase tree spacings and open the forest canopy (McNeel and Dodd 1996). Private land managers are also implementing this strategy to gain periodic returns on their investments (Curtis and Marshall 1993). Because a large amount of the timber removed from these stands is of marginal value, all aspects of the harvesting must be efficient (Kellogg et al. 1996b). Therefore, more accurate spatial data-collecting devices are being investigated for their potential in improving operational planning and layout.

Layout and profiling of harvesting corridors for thinning operations varies substantially from the preparations made for clearcutting (Kellogg et al. 1996b). The planning of skyline-thinning operations is usually more expensive because of the added requirement for marking and profiling the corridors. This is in addition to the costs incurred for laying out and surveying the harvest unit boundary. Many of these planning steps add to the time and expense for the harvesting contractor, and directly affect the profitability of the operation.

Several studies have focused on the potential benefits of using electronic devices to traverse forest stand boundaries (Liu 1995), low volume road surveys (Moll 1992), and millyard woodpile volumes (Turcotte 1999). These studies reported mixed results for the usefulness of the EDM devices. The distance- and vertical angle-measuring capabilities of the lasers generally met the survey requirements, but the azimuth measurements with the compass did not due to offsets in the magnetic field. Gains in efficiency were noticed of up to 60% by using the EDM devices.

Wing and Kellogg (2001) also assessed the use of a laser range finder and digital compass for traversing skyline corridors and harvest boundaries. In several pilot studies, these instruments required less time and provided greater accuracy than conventional methods, apparently because of the rangefinder's rapid capture ability. However, measurements with this highly precise technology were more difficult to obtain in thick understory vegetation.

Little research has been done to assess the potential benefits, e.g., precision, accuracy, and cost, of using electronic techniques for corridor layout and profiling. Therefore, the objective of this study was to compare the associated costs and calculated skyline payloads for three survey methods: 1) a string box, hand-held compass, and clinometer; 2) a laser, digital compass, and digital data collector; and 3) a benchmark system that used a total station for data collection.

Methods

Study Site

The study tract was a 55-acre unit located in the Oregon coastal mountain range on the Siuslaw National Forest (Fig. 1). The site was a 35-year-old mixed stand, comprising primarily Douglas-fir (*Pseudotsuga menziesii)*, bigleaf maple (*Acer macrophyllum*), and red alder (*Alnus rubrus*). Minor shrub vegetation included vine maple (*Acer circinatum*), salal (*Gaultheria shallon*), and salmonberry (*Rubus spectabilis*). The slope percent within the unit ranged from 0% to 96% (average ~45%).

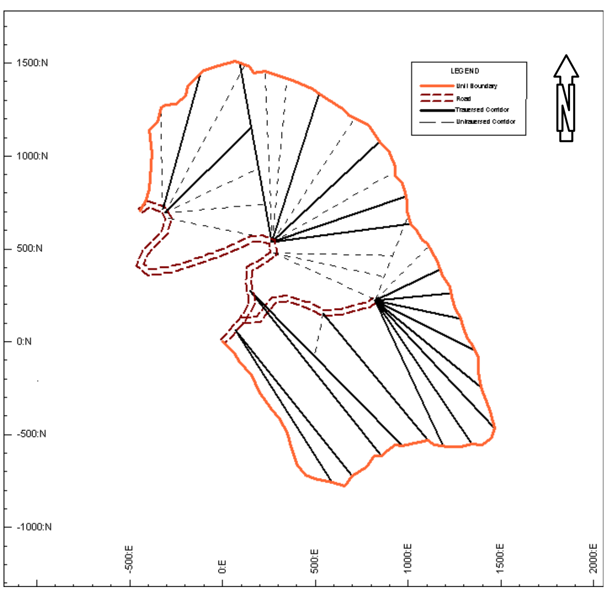

Figure 1 Harvest unit with access roads, unit boundaries, and skyline corridors.

Data Collection

Data were gathered on 20 skyline corridors, using two survey methods, and were entered into LoggerPC4, the skyline payload-analysis program. Each corridor was measured consecutively by the two techniques. Information was also collected on the amount of time required to flag corridors, travel to and from the site, traverse profiles, and complete the office work.

The first method involved one person traversing the profile, working away from the landing and toward the tail hold. Slope distance and vertical angles were measured with a string box and clinometer; azimuths, with a hand-held compass.

The second method utilized a two-person crew to gather profile information along the traverse. The lead traverser ribboned the station as the rear traverser completed field notes. An Impulse 200 laser and MapStar digital compass were used to gather horizontal and vertical distances, as well as horizontal angles. These data were then downloaded to a digital data collector.

After harvesting was completed, a final survey of each corridor was conducted. For this benchmark, total-station method, a two-person crew used a Nikon DT-310 total station and Senco prism to gather horizontal and vertical distances.

Results and Discussion

Time Study

A total of 392 hours accrued during the completion of the layout and planning of the unit. Included within this time was travel, reconnaissance, corridor layout, profiling, and mapping. In all, layout and profiling consumed 64% of the entire study period, with values based on the times required to complete corridor profiling and ribboning using the string box, clinometer, and hand-held compass.

The time spent in completing the same surveys differed significantly between the string-box and laser methods (Fig. 2), probably because of a number of anomalies between the survey equipment and data-collection processes. For example, of the 20 corridors studied with the laser, only five (2, 23B, 26, 31, and 33) were profiled with the digital compass because more time was needed to keep the lead traverser on bearing. The laser method for these five corridors was an average of 21 minutes greater than the string box method. Multiple shots had to be taken and necessary adjustments were made to maintain the angle, a process that differed from the manual-compass technique, in which the traverser could back-sight on the ribbon line without numerous shots. In addition, the use of the digital data collector meant that measurements had to be downloaded to a database and reformatted to x, y, and z coordinates for analysis by LoggerPC4. The direction in which the corridor was traversed may also have contributed to these discrepancies. Two of the laser corridors that were traversed from the tail hold to the landing had >60% slopes, so that walking uphill increased the time spent on the survey.

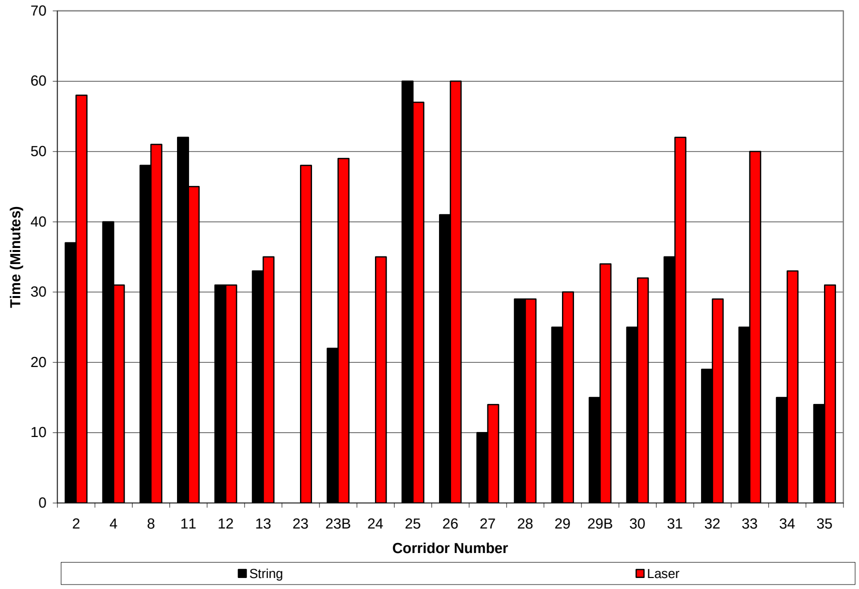

Figure 2 Time-study comparison of corridor measurement techniques.

Costing Information

Costs (Table 1) were calculated based on the hours required to complete each task and the initial purchase price of the survey equipment (depreciated over two years). This rate of depreciation varied according to the operation, with two years serving as an estimate for turnover of the technology. Information on hourly wages, including benefits, was obtained from the 2001 Associated Oregon Loggers Annual Wage Survey (Salem, OR, USA).

Table 1 Costs incurred per survey method for layout, traversing, and associated office work.

Method	Crew size	Labor cost ($/hr)	Equipment cost ($/hr)	Total time (hr)	Total cost ($)	Cost per mbf
String Box	1	18.90	0.05	10.8	192.95	0.47
Laser*	2	37.80	0.51 or 1.18	13.5	557.95	1.36

***Equipment costs are for either the digital compass plus data collector or for the laser plus hand-held compass.**

The volume harvested from the unit, ~411.7 mbf, was used to calculate the total cost for 14 corridors. The laser survey proved to be almost three times more expensive than the string-box technique. Costs associated with the former combined the values obtained for corridors measured by manual compass ($0.51/hr) and those using the digital compass and digital data collector ($1.18/hour). The two-person crew needed for the laser survey doubled the labor costs, and was the main contributing factor to the large difference in costs.

Payload Determinations

Payloads were calculated for both methods along each corridor (Fig. 3). Analyses within LoggerPC4 were completed using a Linkbelt Yarding Crane with a 50-ft boom and a motorized slackpulling Eagle Eaglet carriage.

Although seven corridors were not surveyed with all three techniques, they remained within the data set for comparative purposes. An example of this is Corridor 29B, which was not traversed with the total-station but was used to compare the laser and string-box methods.

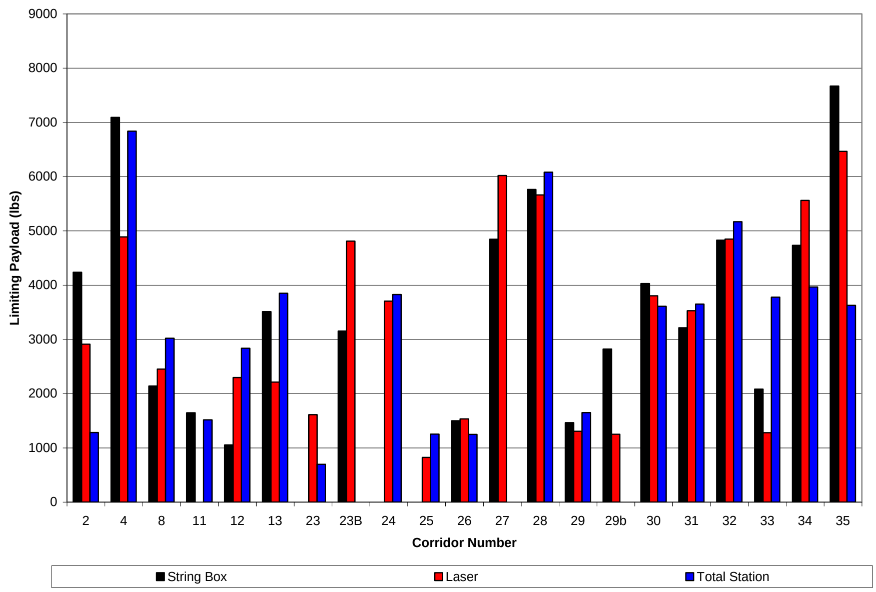

Figure 3 Limiting payloads (lbs) per corridor and method.

Payloads differed greatly among a number of corridors for two reasons. First, the critical point of the profile may have been altered because of the accuracy of the survey technique. The critical terrain point limits the skyline deflection thus affecting the amount of wood that can be yarded on the skyline. For example, the critical point for Corridor 29 was located approximately 400 ft from the landing. Although each method located the tail tree at approximately the same location, a difference in payload of over 10% resulted from small changes in the elevation of the corridor and a different terrain location for the critical point from each survey method.

The second reason for the difference in calculated payload may have been the apparent change in elevation or horizontal distance of a lift or tail tree from the landing due to differences in the survey methods. Therefore, the magnitude of this effect was partly a function of the total difference in distance among methods. Another factor contributing to the large variation in elevations generated by the laser was the fact that one survey was conducted from tail hold to landing. This made it more difficult to stand upright and hold the target at eye level. If the target was held away from the body, however, the corridor appeared steeper than it actually was.

A statistical analysis was completed on 14 of the corridors that had been traversed by all three methods. For each corridor, the limiting payloads for the string-box and laser methods were subtracted from that for the total station. Based on t-tests, the resultant differences were non-significant (P-Value = 0.57), thereby showing that survey method did not seriously affect the payload estimations. Although fluctuations in some corridors' limiting payloads were substantial (e.g., a 4042-lb. deviation between string-box and total-station methods for Corridor 35), the total differences were insignificant among methods. This was perhaps a result of the sample size not being large enough to account for the amount of variation. That, combined with the sensitivity of the critical-point calculation, may have outweighed the difference in payloads. Average total-station payloads were 440 lbs greater than those computed with the string-box data; that difference ranged from an under-estimate of 1781 lbs to an over-estimate of 4042 lbs. Moreover, the laser payload was approximately 130 lbs heavier than that calculated with the total-station values, with the differences ranging between -1636 lbs. to +2839 lbs.

Another aspect of the study examined the mechanical feasibility of using an intermediate support; specifically the forces on the jack and jack passage angle (Brantigan 1978). Angular, distance, and force differences were found within the five corridors that required intermediate supports, and were based on the magnitude of apparent differences in distance and elevations of lift trees among survey methods. Although none of the techniques resulted in infeasible conditions at the intermediate support, the large variations that resulted could mean greater challenges in more difficult terrain when viable analyses are not physically possible due to introduced surveying errors.

Conclusions

This study investigated the magnitude of difference in costs and calculated payloads when three separate survey techniques and tools were used to complete the layout and profiling of 20 skyline corridors in the Siuslaw National Forest. Corridor layout and profiling costs were lower for the string-box survey than the laser. This was mostly due to the difference in crew sizes between the survey methods. When small changes occur in the location/elevation of the critical point, payload calculations can vary substantially. Although the variations identified in this study were case-specific and not statistically significant, forestland managers can be confident that the less labor-intensive and lower-cost string-box method will provide data similar to those produced by a total-station or laser method.

Literature Cited

Curtis, R.O., and D.D. Marshall, 1993. Douglas-fir rotations - Time for reappraisal. Western Journal of Applied Forestry 8(3): 81-85.

Brantigan, R.T., 1978. Critical Conditions for Carriage Passage at the Support Jack for Uphill Yarding. Master of Science thesis, Department of Forest Engineering, Oregon State University, Corvallis, OR, USA. 111 p.

Kellogg, L.D., Milota, G.V., and M. Millar Jr., 1996b. A Comparison of Skyline Harvesting Costs for Alternative Commercial Thinning Prescriptions. Journal of Forest Engineering 1: 7-23.

Liu, C.J., 1995. Using Portable Laser EDM for Forest Traverse Surveys. Canadian Journal of Forestry Research 25: 753-766.

Moll, J.E., 1992. Development of an Engineering Survey Method for Use with the Laser Technology, Inc. Tree Laser Device. Master of Science thesis, Department of Civil Engineering, Oregon State University, Corvallis, OR, USA. 74 p.

McNeel, J.F., and K. Dodd, 1996. Trends in commercial cable thinning in western Washington. Forest Products Journal 46(11-12): 33-39.

Thompson C., Olsen, D., Chan, S., and J. Tappeiner, 2002. The density management studies of western Oregon. P. 1 In Proceedings of Silvicultural Options for Sustainable Management of Pacific Northwest Forests Symposium, Corvallis, OR, USA.

Turcotte, P., 1999. The Use of a Laser Rangefinder for Measuring Wood Piles. Forest Engineering Institute of Canada Field Note 76, Pointe Claire, Quebec, Canada. 2 p.

Wing, M., and L.D. Kellogg, 2001. Using a Laser Range Finder to Assist Harvest Planning. P. 147-150 *In* Proceedings of the First International Precision Forestry Cooperative Symposium, Seattle, WA, USA.

2003 Council on Forest Engineering (COFE) Conference Proceedings:
"Forest Operations Among Competing Forest Uses"
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PRODUCTIVITY OF A TREE LENGTH HARVESTING SYSTEM THINNING PONDEROSA PINE IN NORTHERN ARIZONA

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ABSTRACT - In the fall of 2002 a productivity study was performed on a tree length harvesting system thinning a Ponderosa pine stand in Flagstaff, Arizona. This study was a component of a Joint Fire Sciences Program project investigating opportunities to lower the costs of fire hazard reduction treatments in over stocked stands. The harvesting system consisted of a Hydro-Ax 421 E rubber tired feller-buncher with a shear head, a Caterpillar 528 grapple skidder and a Denharco 4400 stroke delimber mounted on a Caterpillar 320C base. Detailed time study was used to gather productivity data for all machines in the harvesting system. This paper presents the results of the study including a description of the stand, study methods and productivity equations for each machine.

INTRODUCTION

The Joint Fire Science Program (JFSP) is a partnership among six federal agencies to address wildland fire and fuels issues confronting land managers. Some estimates suggest that there are over 40 million acres of forest in the United States with high fuel loads making them vulnerable to wildfire. The spate of catastrophic wildfires over the last several years has confirmed the need for research into the causes of wildland fire and management options to control it. The JFSP focuses on four main areas: fuels inventory and mapping, evaluation of fuels treatments, scheduling of fuels treatments, and monitoring and evaluation (National Interagency Fire Center, 2002).

This paper documents a component in a JFSP project to look at ways of lowering costs of fire hazard reduction treatments in overstocked stands. The overall objectives of the project are to assess the economic costs and benefits of different harvesting practices and regionally based utilization opportunities in fuel reduction treatments (Lowell et al, 2002). The component of the project being reported here is the productivity study of a tree length harvesting system thinning a Ponderosa pine (*pinus ponderosa*) stand.

The study was conducted in the Coconino National Forest on the outskirts of Flagstaff, Arizona during October 2002. Detailed time study techniques were employed as the harvesting system thinned two 20-acre units. The data was used to determine productivity of the individual machines and to allow the development of regression equations to predict performance under varying stand conditions.

DATA COLLECTION

A video camera was used to record the feller-buncher working. The machine cycle was broken down into four elements: *Move-to-tree*, *Fell*, *Move-to-dump* and *Pile*. Tree data consisted of dbh and height. Video was also used to record the stroke delimber working. The following elements were used to describe the machine cycle: *Reach, Process, Stack* and *Clear*. Butt diameter and number of pieces processed per tree was recorded. DBH was calculated using a regression equation developed from the relationship of butt diameter to dbh obtained from the skidding data. A digital stopwatch was used to record elemental times for the skidder. The machine cycle was broken down into *Travel-empty, Load, Travel-loaded* and *Deck*. Data collected included skid distance and bundle data. Bundle data consisted of the number of trees, butt diameter, and dbh and height where possible. Data for all machines was analyzed to extract elemental cycle times, calculate productivity and develop regression equations.

HARVESTING SYSTEM AND STAND DESCRIPTION

The harvesting system represented the most common system working in Northern Arizona. The tree length system consisted of three machines; a Hydro-ax 421E rubber tired feller-buncher with an 18" shear felling head, a Caterpillar 528 rubber tired grapple skidder and a Denharco 4400 stroke delimber mounted on a Caterpillar 320 excavator base.*

After scouting the harvest unit the contractor flagged the unit into smaller areas to limit skidding distance and volume of wood to each landing. The feller-buncher began felling by clearing the landing area and then felling a path to the rear of the harvest area and working towards the landing. This method allowed the operator to be better oriented as to the location of the landing. Bundles were placed with the butts facing the landing to facilitate easier skidding. The skidder was moved on site a day after the feller-buncher in order to avoid machine interaction. The skidder skidded bundles from the landing outwards until the area was completed. The stroke delimber was the last machine moved onto the site. The machine processed all trees at the roadside landing. Two lengths of saw logs (16 ft and 12 ft) and firewood logs were processed from the trees. The firewood logs were left tree length.

The harvest units consisted of natural stands of ponderosa pine (*pinus ponderosa*). Age and size ranged from younger "blackjack" trees to large "yellow bellies". The terrain was flat with occasional rock outcrops. The average number of trees per acre was 196 and average basal area was 119 ft^2. Both harvest units were classified as Class III fuel hazard.

RESULTS

<u>Hydro-ax 421E</u>

A total of 409 cycles (935 trees) were videoed during the detailed time study of the feller-buncher. Tree data was recorded for 157 of the 409 cycles. Data analysis was performed on these 157 cycles (385 trees). The average number of trees per cycle was 2.45 with an average dbh of 8.58 inches. The average total cycle time per tree was 16.43 seconds, which equates to 220 trees per hour. Table 1 reports the summary of cycle elements and tree data for the feller-buncher. The regression analysis indicated that the number of trees per cycle and the basal area per cycle best modeled time per tree. Figure 1 illustrates how time per tree varies with the number of trees per cycle.

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* The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

Table 1: Summary of time study data for Hydro-Ax 421E.

Elements	*Mean*	*Minimum*	*Maximum*
Move-to-tree (sec)	13.49	3.10	40.9
Fell (sec)	10.02	1.10	37.20
Move-to-Dump (sec)	9.81	1.00	38.40
Pile (sec)	2.96	0.70	10.70
Total Cycle Time (sec)	36.04	11.60	79.50
Trees per cycle	2.45	1.00	5.00
DBH per cycle (inches)	8.58	6.20	16.00
Basal Area per cycle (sq. ft.)	0.89	0.28	1.73
Volume per cycle (cubic ft.)	13.98	3.88	35.49

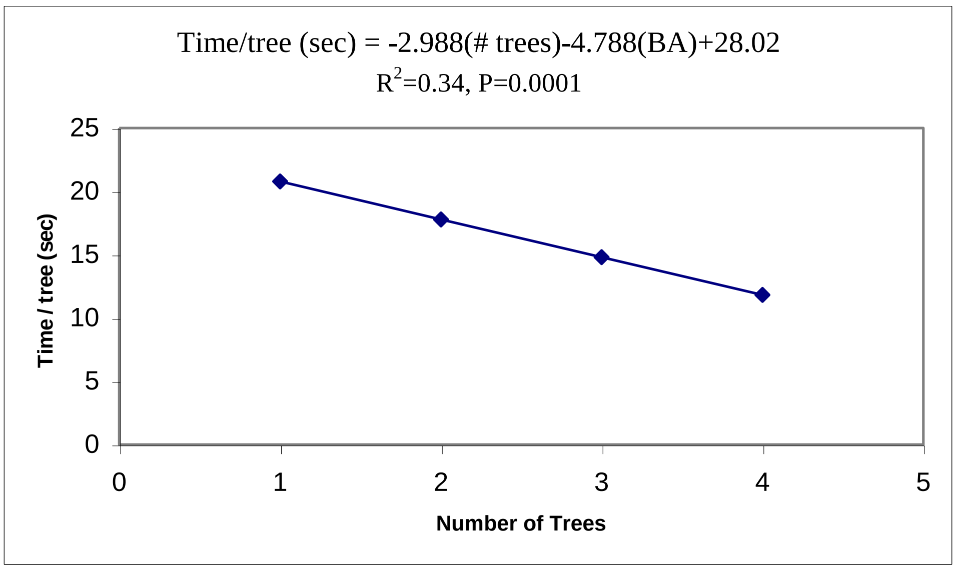

Figure 1: Time per tree vs. number of trees per cycle for Hydro-Ax 421E (BA=0.89ft^3)

Caterpillar 528

The detailed time study of the grapple skidder resulted in 100 cycles (525 trees). Table 2 contains a summary of the time study data. The average skid distance was 98 yards and the average number of trees per turn was 5.25. With an average time per tree of 36.5 seconds productivity was calculated to be 108 trees/hr. From the results of the regression analysis the log of the number of trees per cycle and the distance were found to best model time per tree (Fig. 2).

Table 2: Summary of Time Study Data for Caterpillar 528.

Elements	*Mean*	*Minimum*	*Maximum*
Travel-empty (sec)	29.96	8.88	59.58
Loading (sec)	23.86	5.40	118.92
Travel-loaded (sec)	31.99	8.16	71.04
Decking (sec)	77.96	23.04	206.76
Total Cycle (sec)	163.77	45.48	456.30
Trees per cycle	5.25	1.00	11.00
Distance (yards)	97.75	24.00	200.00

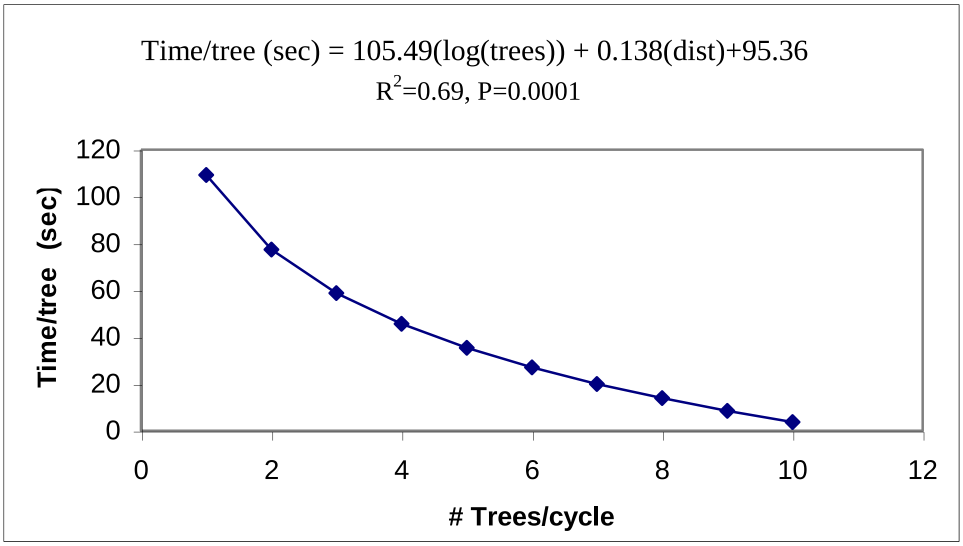

Figure 2: Time per tree vs. number of trees per cycle for Caterpillar 528 (@100 yards).

Denharco 4400

The stroke delimber was videoed processing 218 trees. See Table 3 for a summary of the time study data. The average dbh was 10.5 inches with a maximum of 19.6 inches. The number of pieces processed from each tree ranged from 1 to 4 with an average of 1.43. The average total time per tree (per cycle) was 40.83 seconds, which yields a productivity of 88 trees/hr. The results of the regression analysis to model time per tree indicated that the number of pieces per tree and the square of dbh accounted for most of the variability in the data (Fig. 3).

Table 3: Summary of time study data for Denharco 4400.

Elements	*Mean*	*Minimum*	*Maximum*
Reach (sec)	9.78	2.20	30.30
Process (sec)	16.02	0.50	77.70
Stack (sec)	6.89	0.30	28.10
Clear (sec)	15.95	5.30	60.50
Move (sec)	26.80	18.50	41.40
Total cycle (sec)	40.83	12.26	155.33
DBH (inches)	10.49	4.93	19.65
Number of pieces per tree	1.43	1.00	4.00

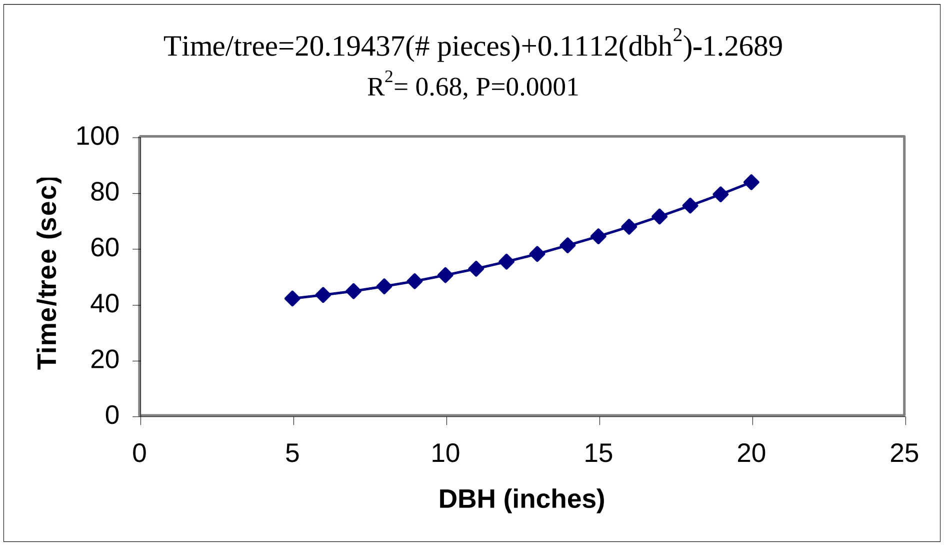

Figure 3: Time per tree vs. DBH^2 for Denharco 4400 (2 pieces).

DISCUSSSION

The feller-buncher handled the range in timber size (6"– 16" dbh) well. The low R^2 value for the regression equation is attributed to a couple of factors. First, the marked trees that were videoed for the time study were marked for the product recovery component of the JFSP project and were handled separately from the other trees harvested. We did not anticipate that the feller-buncher operator would treat the trees differently. Second, it is possible that another factor not measured during the study accounted for a significant amount of the variability in the data. Distance between trees (tree density) is the most probable factor.

The skidder performed well in the study conditions. The layout of the landings kept the skid distance short with a range of 26 to 200 yards. The time study revealed that the machine spent almost half (47%) of each cycle on the landing. A majority of this time was spent pushing up logs and building the height of the log pile.

The stroke delimber proved to be the limiting machine of the system with a production rate of just 88 trees/hr. Observations showed that the delimber double handled 10% of the trees. This occurred because the operator cut saw logs starting from the butt end. If there was a second log in the tree or the remainder of the firewood bolt needed additional processing the operator had to re-handle the tree to cut the second piece.

REFERENCES

National Interagency Fire Center, United States Government. 2002. Science & technology: joint fire sciences program. http://www.nifc.gov/joint_fire_sci/

Lowell, E., R. Rummer, and D. Larson. 2002. In-woods decision making of utilization opportunities to lower costs of fire hazard reduction treatments. Project proposal. 24.

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THE MAGNITUDE AND TIMING OF RUNOFF FROM FOREST ROADS RELATIVE TO STREAM FLOW AT LIVE STREAM-CROSSING CULVERTS IN WESTERN OREGON

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ABSTRACT. Forest roads alter the pathways of water through a watershed by intercepting and redirecting subsurface flow, along with road surface runoff, down the roadside ditch. At live-stream-crossing culverts, water from the ditches flows directly into the stream. This research investigated the effect of road runoff on the magnitude and timing of peak flows at stream-crossing culverts, by monitoring discharge at the culvert and in the corresponding roadside ditches in the headwaters of Oak Creek, Corvallis, Oregon. The effect of runoff from the road on peak flows in the stream depended on the interaction of the road with the hillslope. Where the road intercepted subsurface flow from the hillslope, the peak flows and flow volumes were affected more greatly than for those road segments where the ditch flow was primarily road surface runoff. These effects were highly variable and could not be predicted using traditional topographic indicators. For live stream-crossing culverts high in the watershed that had small contributing areas, the effect of road runoff on peak flow and volume was more pronounced than for those lower in the watershed where the contributing area was larger.

Introduction

Forest roads have come under increased scrutiny in recent years because they have been linked to deleterious impacts on water quality and aquatic habitat. Forest roads have slower infiltration rates and hydraulic conductivities than the surrounding soil and thus can be source areas for overland flow (Ziegler and Giambelluca 1997). Bilby *et al.* (1989) describe forest roads as potential chronic sources of fine sediment and other researchers define methods to predict sediment production from roads (Luce and Black 1999; Elliot *et al.* 1999; Ketcheson *et al.* 1999). The greatest opportunity for water quality impacts is at stream-crossing culverts where the road runoff drains directly into the stream. Wemple *et al.* (1996) suggests that road segments connected directly to streams are the road segments that are most likely to cause changes in watershed hydrology and water quality.

Roads not only direct surface runoff to the streams but may redirect subsurface flow as it is intercepted by the road cut-bank (Wemple 1994). In this way, forest roads have the ability to act as extensions of the natural stream network. At live stream-crossing culverts this may produce increases in volume and instantaneous maximum discharge. Also, as road related response involves a different mechanism for delivery of water to the stream, peak flows at the culvert due to the road might not be synchronized with peak flows in the stream at the culvert.

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The objective of this study is to observe and quantify how the timing and magnitude of peak flows at live stream-crossing culverts are altered by runoff from forest roads.

Study Area

We conducted this research in an 824 ha watershed in the headwaters of Oak Creek, Corvallis, Oregon on the McDonald-Dunn Research Forest, the school forest for the College of Forestry at Oregon State University (**Figure 1**). Elevations in Oak Creek range from 150 m to 650 m. The average annual precipitation is 140 cm that occurs primarily between November and April as rain. Hillslope gradients within the forest range from 20 to over 60 percent. The soils are predominantly silty clay loams with an average soil depth of 125 cm.

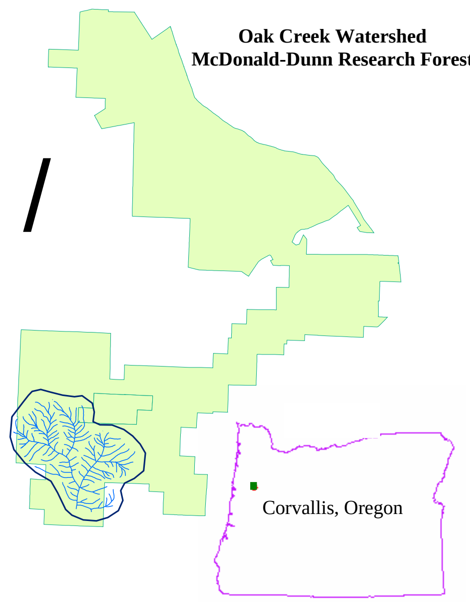

Figure 1. Location map for the Oak Creek headwaters basin.

There are 4,877 meters of stream within the basin resulting in a stream density of 5.92 m/ha. Oak Creek is a fish-bearing stream with measured flow rates as high as 2.0 L/s/ha (18.9 csm). The 4,572 meters of road (5.55 m/ha) were constructed primarily during the 1950's and 1960's, however significant upgrading of the drainage on the road system has occurred in recent years. The road system has 99 drainage structures installed and 24 of them are live stream-crossing culverts.

Sixteen stream-crossing culverts were chosen for this study. They varied in elevation from 150 m to 500 m and were located along actively traveled road segments with contributing ditches averaging 90 m. Data from two of the sites was not complete and was not used in all of the analysis.

Instrumentation and Monitoring

We instrumented the sixteen stream-crossing culverts with water height recorders at the culvert inlet and trapezoidal flumes in the contributing ditches. The trapezoidal flumes were each equipped with a stilling well and water height recorder. Between September 2002 and May 2003, the recorders in the flumes and at the culverts logged stage height at 10-minute intervals and were downloaded monthly. Four tipping bucket rain gauges recorded precipitation. We calculated stream discharge from water height at the culvert entrance using:

$$Q = 0.432\sqrt{g}\,(h - z)^{1.9}\,d^{\,0.6}$$

where Q is discharge (m^3/s), g is the acceleration of gravity (m/s^2), h is the water surface elevation above a datum (m), z is the culvert entrance elevation minus the datum elevation (m), and d is the culvert diameter (m) (Henderson 1966). We computed discharge in the ditch using an equation for large 60° V trapezoidal flumes:

$$Q = 1.55h^{2.58}$$

where Q is discharge (ft^3/s) and h is the water surface elevation within the stilling well (ft) (Robinson and Chamberlain 1960).

We analyzed data from an eight-day March 2003 storm. Total precipitation for the storm was 9.5 cm with a maximum intensity of 5.4 mm/hour. Discharge measurements from the stream at the stream-crossing culverts were matched in time to the road runoff discharges from the corresponding roadside ditches. We subtracted ditch discharge estimates from discharge at the stream-crossing culvert to give an estimate of what discharge in the stream would have been without the influence of the road. We compared instantaneous maximum discharge in the streams to the corresponding values in the ditches. For example, stream flow at site four was increased over 15% by the influence of the road when the ditch flow peaked (**Figure 2**).

Results

Surface road runoff was observed in the ditches of all the study road segments in response to the March 2003 storm. However, the runoff response was highly variable. At four road segments (27%) the instantaneous maximum discharge was less than 0.25 L/s and at eight road segments (53%) it was less than 1.0 L/s. The instantaneous maximum discharge ranged from 0.09 to 9.6 L/s for the ditches and 1.5 to 231 L/s for the streams at the stream-crossing culverts.

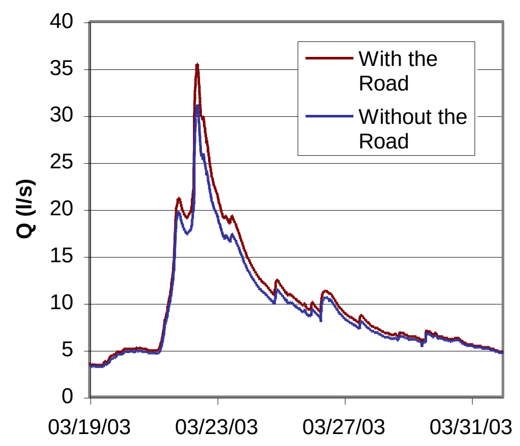

Figure 2. Storm hydrograph for site four.

Lag to peak, as described by Montgomery and Dietrich (2002), is characterized by the time elapsed from when half the storm rainfall has fallen to the peak discharge. For streams at the stream-crossing culverts, lag to peak estimates ranged from 5.0 to 51.9 hrs with a mean value of 10.2 hours. The lag to peak for the ditch response ranged from 3.3 to 13.0 hrs with a mean value of 5.9 hours. On average, the peak discharge from the ditches occurred 4.6 hours before the peak discharge at the corresponding streams.

At one particular site, the road caused almost a 640% increase in stream discharge. The stream had a baseflow of 0.3 L/s and an instantaneous maximum discharge of 1.5 L/s. The flow in the adjoining ditch peaked at 9.6 L/s. If this site is excluded, the peak flows of the streams were increased on average by 11.5%.

The interaction of the roads with the hillslope is highly variable and not all road segments appeared to intercept subsurface flow during this storm. At over half of the sites the roadside ditch flowed only in direct response to intense precipitation, and for the remaining road segments ditch flow responded throughout the storm and continued after rainfall had stopped. At eight road segments we classified the ditch flow as ephemeral, which means that ditch flow is assumed to come primarily from road surface runoff. At the remaining seven road segments the ditch flow was classified as intermittent, which means that the ditch flow is assumed to come primarily from intercepted subsurface flow (see Gilbert 2002) (**Figure 3)**. The hydrographs of the road ditches with ephemeral flow had quick responses to rainfall. The road segments that had intermittent flow had greater maximum instantaneous discharges, greater storm flow volumes, and hydrographs with attenuated falling limbs. At road segments with intermittent ditch flow, intercepted subsurface flow dominated the hydrograph. The maximum instantaneous discharge for road segments with ephemeral ditch flow averaged 0.49 L/s and 5.3 L/s for road segments with intermittent ditch flow.

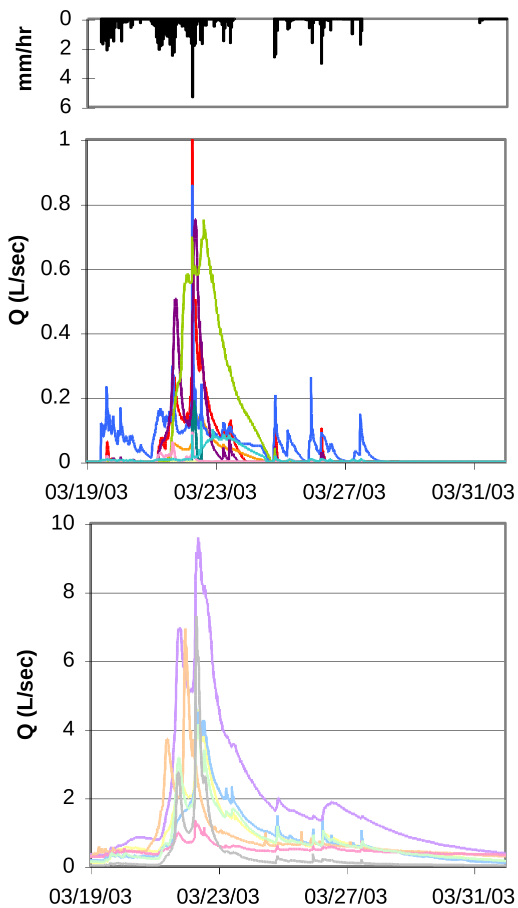

Figure 3. Precipitation and ditch discharge for a March 2003 storm event. The middle panel shows eight ditch hydrographs that appeared to predominately respond to surface runoff. The bottom panel shows seven ditch hydrographs that seem to measure surface runoff as well as subsurface interception.

The interception of subsurface flow was highly variable throughout the watershed. For example, sites 31 and 35 are on the same road at similar elevations but had different responses to precipitation. The intercepted subsurface flow and surface runoff at site 35 increased the maximum peak discharge at the stream by 42%. At site 31, ditch flow was primarily road surface runoff and increased the maximum peak discharge only 4%.

Discussion and Conclusions

The influence of forest roads on the magnitude and timing of peak flows at the streams they intersect was dependent on the interaction of the road with the hillslope. At all road segments flow at the stream-crossing culvert was increased by ditch flow. When the road segment intercepted subsurface flow this increase in peak flow was on average 10 times greater than when the road segments captured only surface runoff. At half of our study sites the roads intercepted subsurface flow. These sites were located throughout the watershed and were not predicted by elevation, cutbank height, or contributing area.

Peak flows in the ditches occurred, on average, 4.6 hours before their corresponding streams. At some sites this could contribute to reduced lag times and/or more volume of water on the rising limb of the storm hydrograph.

Small streams are much more likely to be affected by road crossings. These occur at higher elevations where streams have smaller contributing areas. Site 35 is an example of a small stream high in the watershed where the road influence substantially increased stream flow at the stream-crossing culvert. The ditch flow at this site, which appeared to consist of intercepted subsurface flow and surface runoff, peaked 30 minutes before the stream and at the peak of ditch flow, increased stream flow by 54%.

Along with increased sediment entering the streams, increased peak flows from ditch flow at the stream-crossing culvert are a forest management concern for sizing culverts. Increases in flow from subsurface interception and surface runoff could increase the return interval of flow at the culvert outlet.

This research suggests that it is not possible to predict the increase of stream flow from topographic indicators. Further research in this area is required to help us better understand how roads influence stream flow.

References

Bilby, R.E., Sullivan, K. and S.H. Duncan. 1989. The generation and fate of road-surface sediment in forested watershed in southwestern Washington. *Forest Science*. 35(2): 453-468.

Elliot, W.J., Hall, D.E. and S.R. Graves. 1999. Predicting Sedimentation from Forest Roads. *Journal of Forestry*. 97(8): 23-28.

Gilbert, E. 2002. M.S. thesis, A Characterization of Road Hydrology in the Oregon Coast Range. Department of Forest Engineering, Oregon State University, Corvallis.

Henderson, F.M. 1966. Open Channel Flow. Macmillan Publishing Co., Inc., New York. 522 pp.

Ketcheson, G.L., Megahan, W.F. and J.G. King. 1999. "R1-R4" and "Boised" sediment prediction model tests using forest roads in granitics. *Journal of the American Water Resources Association.* 35(1): 83-98.

Luce, C.H. and T.A. Black 1999. Sediment production from forest roads in western Oregon. *Water Resources Research.* 35(8): 2561-2570.

Montgomery, D.R. and W.E. Dietrich. 2002. Runoff generation in a steep, soil-mantled landscape. *Water Resources Research.* 38(9): 1168-1175.

Robinson, A.R. and A.R. Chamberlain. 1960. Trapezoidal Flumes for Open-Channel Flow Measurement. *Transactions of the ASAE.* 3(2): 120-128.

Wemple, B.C. 1994. Potential hydrologic effects of logging-access roads in forested landscapes of the western Cascades, Oregon. M.S. thesis, Dept. of Geosciences, Oregon State University, Corvallis.

Wemple, B.C., Jones, J.A. and G.E. Grant. 1996. Channel network extension by logging roads in two basins, western cascades, Oregon. *Water Resources Bulletin.* 33(6): 1195-1207.

Ziegler, A.D. and T.W. Giambelluca. 1997. Importance of rural roads as source areas for runoff in mountainous areas of northern Thailand. *Journal of Hydrology.* 196: 204-229.

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PRODUCTIVITY OF A SMALL CUT-TO-LENGTH HARVESTER IN NORTHERN IDAHO, USA

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Abstract
The application of small harvesters in harvest operations in forest stands composed of small-diameter trees is of increasing interest to natural resource managers; this interest is due to the efficiency and cost effectiveness in harvesting of small diameter trees. This paper presents research regarding the productivity of a Neuson 11002 HV harvester in a clearcut/restoration treatment of a Douglas-fir tussock moth damaged stand, and the investigation of the influence of tree branch characteristics upon harvester productivity. Tree heights, diameter at breast height (DBH), species, branch size and branch interval data were collected, to investigate the effect of these characteristics on productivity. A detailed time study was conducted on video footage of the harvest operations, to determine machine productivity. Production for the clearcut is estimated at $5.43/m^3. Analysis suggests that branch characteristics are influential upon tree harvest time, with branch size of high statistical significance.

Keywords: small harvester, branch size, branch interval, branch characteristics, Neuson 11002 HV, Logmax 3000, clearcut, restoration cut.

Introduction
While small harvesters have been in use in the forests of Europe and the North east of North America for some time, their use in the Western US is relatively new. The interest in the application of such machines has been initiated by the need to thin second growth forests (Kellogg and Bettinger 1994), and by the identification of 12 million hectares of high density/ high stem count forest stands as high priority for fuel abatement treatment in the western states of the US (Vissage 2003).

Small harvesters, designed to harvest smaller diameter trees, offer the natural resource manager a machine of lower capital cost. The work of Ewing (2001) on a series of small, tracked harvesters confirmed that these machines offered reasonable efficiency, lower capital cost, and cost effective operation. Ewing observed a production rate of 67 trees per productive machine hour (PMH), with a volume production of 14.1m^3/PMH, with direct operating cost of C$96/PMH, and unit production cost of C$7.00/m^3 in a 34% volume removal thinning of a mixed-wood forest stand with 1340 stems/ha, 161m^3/ha and 16cm mean diameter at breast height (DBH). Rummer (2002) investigated the use of the Neuson 11002 HV in a lodgepole pine thinning trial. The results were a productivity of 4.2m^3/ SMH, with a cost per unit production of $16.60/m^3, in a stand of 10cm mean DBH (Rummer 2002).

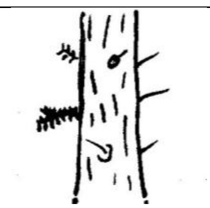
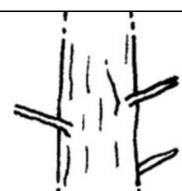
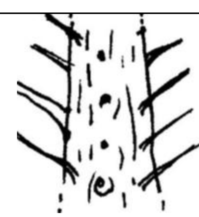
The researchers noted that tree branch characteristics are highly influential upon tree processing times. The influence of branch size and interval were identified by Drolet *et al.* (1971) in their investigation of the effect of branch characteristics of jack pine (*Pinus banksiana*), black spruce (*Picea mariana*) and balsam fir (*Abies balsamea*) on mechanised delimbing. Drolet *et al.* (1971) found that delimbing of 95% of all trees studied would be possible with a machine capable of removing branches with a branch stub area of 51.6cm^2 (8.1cm diameter branch) at a 7.6cm interval, and a 77.4cm^2 branch stub area (9.9cm diameter branch) at 30.5cm interval. In contrast to the substantial machine suggested by the results of the above study, the small harvester design imposes design limitations on dimensions, machine weight and horsepower, resulting in reduced power at the harvester head, diminished delimbing capabilities and ability to handle large trees. Thus, it might be hypothesised that the contributing effect of branch size and interval upon the processing time of the harvester will increase with decrease in harvester size (in terms of available horsepower, hydraulic systems etc.).

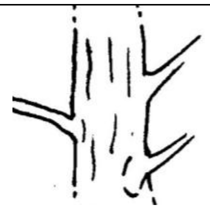
The objective of this research was to investigate the productivity and cost effectiveness of the Neuson 11002 HV harvester, and the influence of branch size and branch interval upon the time taken to process harvested trees.

Study Methods

The Neuson 11002 HV harvester is a purpose built, tracked-based harvester, manufactured in Austria. The harvester undercarriage is derived from a D4 caterpillar carriage, on which is mounted the leveling harvester body and 76 kW (102hp) engine. The harvester is equipped with a Patu parallel action crane (9.1m reach), and mounts a Logmax 3000 harvesting head, and is capable of harvesting trees up to 50 cm diameter at the base. Machine slope capabilities are specified by the manufacturer to 50% (Rocan 2003).

Figure 1: Harvester branch assessment key.

Branch size code	**Description**	**Appearance**		**Branch interval code**	**Description**	**Appearance**
0	Fine Branches < 1.2cm (½ inch) diameter (Includes brittle dry branches and fine live branches.			**1**	0.9m (3 feet) or greater branch interval	
1	Light Branches 1.2 to 2.5 cm (½ to 1 inch) diameter			**2**	0.45 to 0.9 m (1 ½ to 3 feet) branch interval	
2	Sturdy Branches 2.5 to 5 cm (1 to 2 inch) diameter			**3**	< 0.45m (1 ½ feet) branch interval.	

3	Heavy Branches > 5cm (2 inch) diameter				**How to use branch assessment key:** Branch size code and branch interval code are added to give total branch score; e.g. branch size code 2 and a branch interval code 1, total branch score of 3. (Exception: branch size code 0, default total branch score of 0.)	

To examine the effect of tree branches upon harvester productivity a branch classification key was developed that would allow rapid assessment of branch characteristics (Fig. 1).

Prior to the start of harvesting operation 500 trees within the trial were assessed for tree species, DBH, tree height, proportion of clean bole, proportion of dead crown, proportion of live crown, branch size, branch interval (Fig 1.), and tree form (sweep, crook, fork etc.). All trees were marked with a unique number, for reference by the observer. Tree details were entered into a spreadsheet, and analysed in that format. Tree volumes were calculated using formulae prescribed by Wykoff *et al.* (1982).

The Neuson Harvester was studied in operation in the University of Idaho Experimental Forest, in a 3.25 ha clearcut unit. The stand was composed of 66% Douglas-fir (*Pseudotsuga meziesii* var. *glauca*), 16% grand fir (*Abies grandis*), 16% ponderosa pine (*Pinus ponderosa*), and 2% western larch (*Larix occidentalis*). Harvest was scheduled to salvage trees severely defoliated by Douglas-fir tussock moth (*Orgyia peudotsugata*). Stand volume was estimated as 253 m^3/ ha, 23cm estimated mean DBH, and a harvest DBH range of 12.5 to 45cm. Stand density was approximately 710 stems/ha of 12.5cm DBH and greater. Slopes on the clearcut site varied from 5 to 36%, with a mean of 18%. The silvicultural prescription for the clearcut was the harvest of the unit, retaining stems of ponderosa pine and western larch for aesthetic/stand structural reasons.

Logging operations were video taped using a video camera equipped with a telescopic lens, mounted on a light tripod. Tree numbers were reported to the observer by the harvester operator via a two way radio equipped with a voice activated microphone, the number then being repeated into the video camera microphone. A time study was then conducted on the recorded operations using a Husky *feX*21 field computer, equipped with a time study program (Wang *et al.* 2003). During the time study, density of brush treated by the harvester at each tree was assessed, being described as nil, light, moderate or heavy, and a nominal brush code allocated (0 for nil, 1 for light brush, 2 for moderate brush, up to a score of 3 for heavy brush).

Machine owning and operating costs were calculated using standard machine rate analysis (Miyata, 1980); assumptions being U$290,000 delivered cost, 2000 Scheduled Machine Hours (SMH), estimated salvage price of 20% after five years, fuel consumption of 13.25 litres/hour, maintenance and repair at 70% of depreciation, interest rate of 11%, insurance cost of 4%, taxes estimated at 1%, fuel cost estimate $0.27/litre, labour cost of $25/hour with benefits of 40%.

A non-parametric statistical analysis, using the Mann-Whitney test, was conducted on the effect of branch size code, branch interval code, and total branch score on tree process time, to assess the significance of these factors on process time. Stepwise analysis of the dependent (travel time and head placement, brushing, felling, and processing) and independent variables (travel distance, brush density, clean bole, DBH, tree height, tree volume, branch size code, branch interval code, total branch score) was conducted, to assess the significance of the independent variables in the operation, and to construct a predictive equation for tree harvest time.

Results and Discussion

Mean productivity of the Neuson was 68.5 trees /PMH or 19.17m^3/ PMH. Mean tree size harvested was 0.28 m^3. Cost of machine operation was $94.82/ SMH. Estimated production of 17.45m^3/ SMH resulted in a calculated production cost of $5.43/$m^3$. Utilisation was noted as 91% over the duration of the study. Delay free cycle time components were summarised as: 11% brushing, 37% machine movement and locating the harvester head on the tree, 11% cut and fall, and 47% processing (delimbing and bucking).

Machine operation per unit production is relatively competitive. Data for a large harvester (Valmet 500T) in a commercial thinning estimated production as 21.1m^3/SMH, $104.54/SMH owning and operating cost, and cost per unit production of $5.47/$m^3$, for a thinning with trees of 0.63m^3 mean volume (Turner and Han 2002). When compared to the data generated by the study, the costs for the operation of the Neuson are quite favourable, given the smaller trees which the Neuson was harvesting.

The unit production cost for this study was notably low when compared to the results of the study conducted by Rummer (2002). It might be argued that the very high proportion of small diameter trees in Rummer's study, and the desire to recover the greatest proportion of material from these smaller diameter classes, had an adverse impact upon the productivity of the harvest operation.

*Delay free cycle time (seconds) = -3.4968 + 2.5398*Travel distance (m) + 1.7892*DBH (cm) + 19.0512*Brush code + 4.2932*Branch size code*

Adjusted $R^2 = 0.529$, $n = 397$

Average delay free cycle time to harvest a tree was 52.6 seconds, with mean values of 2.28m travel distance, 21.6cm DBH, 0.3 brush code, and 1.3 branch size code. The effect of travel distance, brush code, DBH and branch size code were all found to be highly significant ($\alpha = 0.05$, $p < 0.05$). The results of the Mann-Whitney test revealed that the branch size code had high statistical significance, branch interval code showed no significant effect on process time. Total branch score, which accounts for both branch size and branch interval, demonstrated marginal significance, due to insignificance of branch size code upon process time.

The potential cause of low statistical significance of the total branch score is the relatively low proportion of trees with short branch interval (high branch interval code) and large branch sizes (high branch size code) were observed to account for much of the variance noted in the analysis. Thus the trees that were observed to take the longest time to process impacted the correlation between total branch score and tree process time, and also impacted the tree harvest time.

A large amount of variation in processing method was noted by the researchers during the time study, and this too might be suggested as a cause of variance in tree harvest cycle time. This variation was caused by the operator making use of the full rotation of the harvester, and reach of the parallel action crane, in the handling of unprocessed and processed trees. This amount of movement was greatest with smaller, lighter, trees, and diminished with increase in tree size. In addition, the desire of the operator to optimise the product from the trees harvested was observed to cause increased handling during processing.

It must be noted that the harvester operator in this study was not employed full time in logging activities, though he was experienced in the operation of the machine. As such, the observed productivity of the harvester in the operation might be considered an underestimate of the full productive potential of the machine, an observation supported by the findings of Ewing (2002) in his study of small harvesters

Conclusion

Analysis of the data generated in this study suggests that the productivity of the Neuson harvester is significantly affected by the harvester travel distance (as a function of harvest stem density), tree DBH, and brush density (as an effect on time spent in brush clearance). Where these factors combine to adversely affect harvester productivity, such as the study conducted by Rummer (2002), productivity of the harvester is diminished, and financial viability of the operation is impacted. However, the rate of production observed with the Neuson 11002 HV harvester in this study suggests that this machine can be a competitive and financially viable harvester when used in stands composed of smaller trees. This would allow the conclusion that similar forest stands in North America might be successfully harvested using this machine.

The investigation into the effect of branch characteristics upon tree processing and total harvest time strongly suggests that branch size is of significant influence upon tree process and harvest time, and branch interval has no statistically significant effect. This result indicates that further investigation of the effect of branch characteristics is merited.

Literature Cited

Drolet, J.C., R.M. Newnham and T.B. Tsay. 1971: Branchiness of Jack Pine, Black Spruce, and Balsam Fir in relation to mechanized delimbing. *Inform*, FMR-X-34, Report to Forest Management Institute, Ottawa. 34 p.

Ewing, R.H. 2001. Four evaluations of compact tracked harvesters and forwarders in commercial thinning. *Advantage*, 2(37), Forest Engineering Research Institute of Canada, Pointe Claire, Quebec, Canada. 8 p.

Kellogg, L.D. and P. Bettinger. 1994**.** Thinning productivity and cost for a mechanized cut-to-length System in the Northwest Pacific Coast Region of the USA. *Journal of Forest Engineering*, 5(2): 43-54.

Miyata, E.S. 1980. Determining fixed and operating costs of logging equipment. *USDA Forest Service General Technical Report* NC-55, USDA Forest Service, St. Paul, Minnesota. 16 p.

Rocan 2003. Technical sales information, Neuson 11002 HV harvester. www.rocan.com/Neuson3.html

Rummer, R. 2002. Smallwood logging production and cost study summary; Medicine Bow – Routt National Forest. *Draft document*, Southern Research Station, Auburn, Alabama, USDA Forest Service. 17 p.

Turner, D. and H.S. Han. 2002. Investigation of the productivity of cut-to-length harvesting in a commercial thinning. *Draft document*, Department of Forest Products, University of Idaho, Moscow, USA. 26 p.

Vissage, J. S. 2003. Fuel reduction treatment: A west-wide assessment of opportunities, from Focus on …Wildfire. *Journal of Forestry* 101(2): 5-6.

Wang, J., J. McNeel & J. Baumgrass. 2003: A Computer Based Time Study System for Timber Harvesting Operations. *Forest Products Journal,* 53(3): 47-53.

Wykoff, W.R., N.L. Crookston and A.R. Stage. 1982: Users guide to the Stand Prognosis Model. General Technical Report INT-133, Intermountain Forest and Range Experiment Station, Ogden, Utah, 84401, USDA Forest Service. 114 p.

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MODELING AND SIMULATING TWO CUT-TO-LENGTH HARVESTING SYSTEMS IN CENTRAL APPALACHIAN HARDWOODS

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ABSTRACT - The production rates and costs of two cut-to-length harvesting systems was simulated using a modular ground-based simulation model and stand yield data from fully stocked, second growth even aged central Appalachian hardwood forests. The two harvesters simulated were a modified John Deere 988 tracked excavator with a model RP 1600 single grip sawhead and an excavator based Timbco 425 with an ultimate 5600 single grip sawhead. The forwarder used in the simulations was a Valmet 524 with 8-foot log bunks. Production rates and costs were simulated for a range of stand conditions. The results should be valuable to managers, planners, and loggers considering the use of CTL and forwarding systems in the region.

INTRODUCTION

A fully mechanized cut-to-length (CTL) harvesting system consists of a harvester that performs cutting, delimbing, bucking, and piling and a forwarder that transports the logs to the landing. Compared to conventional harvesting systems, cut-to-length systems are more environmentally sound and less labor intensive. The CTL also significantly reduces the soil disturbance, compaction, and erosion by leaving the residues on the travel path. In addition, the number of trips of the forwarder also decreases because of the higher payload (Wang and Greene 1999, Wang and LeDoux 2003). The CTL system results in less stand damage by transporting the logs instead of the whole tree and is less sensitive to inclement weather (Lanford and Stokes 1995, LeDoux and Huyler 2001). Huyler and LeDoux (1996,1999) performed time studies on the performance of cut-to-length systems in eastern hardwoods. The objectives of this study were to (1) model two CTL systems with large and small harvesters, (2) generate two central hardwood stands with densities of 462 trees/acre and 194 trees/acre, respectively, (3) perform harvesting and forwarding simulations on these two stands.

SYSTEM MODELING

Six functions were modeled for the harvesters: move, boom extend/retreat, cut, swing boom, processing and dumping. More than one tree within the boom reach could be cut and processed at one machine stop. Felled trees were processed and piled on either side of the harvester trail for later forwarding. The harvester usually runs in straight trail and the trail width is set to 13 feet. All trees on the trail must be removed for the machine movement and trees on either side of the trail could be cut based on the harvesting processing option.

Each standing tree is also presumed as a potential obstacle to the tree to be cut and its position is checked (Figure 1 (a)). If the maximum boom reach is L_{boom}, and the boom reach ratio (the rate of the effective boom reach over the maximum boom reach) is r_{boom}, then the effective boom reach (L_e) could be expressed as $L_e = L_{boom} * r_{boom}$.

Let A (X_1, Y_1) be the current position of the machine, B (X_2, Y_2) be the coordinate of the nearest tree selected to be cut, and M (X_3, Y_3) be the coordinate of the tree being checked as an obstacle. The effective cutting area could be expressed as a circle centered at point A with radius equal to the effective boom reach L_e. If any portion of the tree being checked crosses line $\overline{AB}$ (line $\overline{AB}$ is tangent to or intersects the circle) or the distance from the tree to the boom-moving route is less than 0.8 feet (minimum allowance), then this tree will be considered as an obstacle tree.

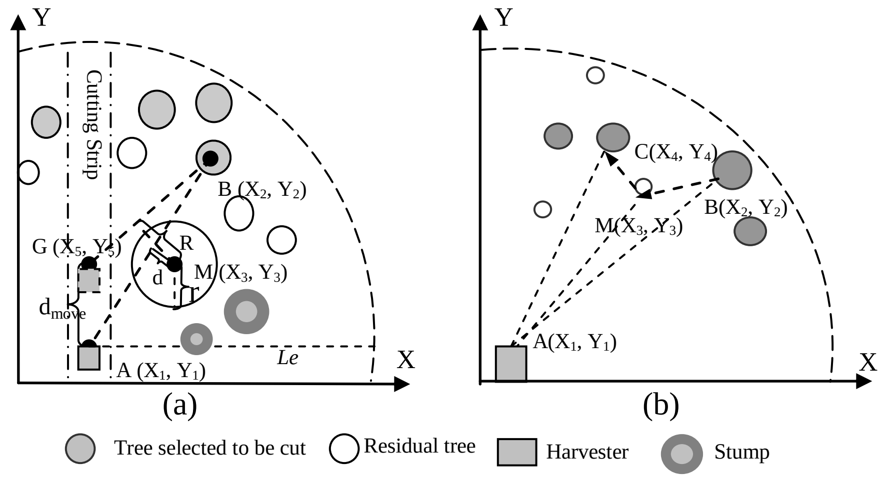

Figure 1. Algorithm for checking obstacle trees.

Where, d = the perpendicular distance from point M to line $\overline{AB}$ **;**
r = half the DBH of the tree examined;
R = the perpendicular distance from the center of the tree to boom;

The line segment $\overline{AB}$ can be expressed as:

$$y = \frac{Y_1 - Y_2}{X_1 - X_2} + \left(Y_1 - X_1 \frac{Y_1 - Y_2}{X_1 - X_2} \right) x \qquad (1)$$

The distance (d) from the center of the tree in between (X_3, Y_3) to line $\overline{AB}$ can be expressed as

$$d = \frac{\left| (Y_1 - Y_3)(X_2 - X_1) + (Y_2 - Y_1)(X_1 - X_3) \right|}{\sqrt{(Y_2 - Y_1)^2 + (X_2 - X_1)^2}} \qquad (2)$$

If d< = r + 0.8, then there is some portion of a tree across line $\overline{AB}$ or the tree is within the protection distance, this tree is an obstacle. Therefore, the machine has to move to point G (X_5,Y_5) to cut the tree checked as an obstacle. To avoid tree damage, the following condition has to be met: $R \geq 0.8 + r$. Because the machine always move on the straight line, this equation will be true: $X_5 = X_1$. The next machine position G (X_5, Y_5) can be derived. Line $\overline{BG}$ can be express as

$$y = \frac{Y_5 - Y_2}{X_5 - X_2} + \left(Y_2 - X_2 \frac{Y_5 - Y_2}{X_5 - X_2} \right) x \tag{3}$$

Let

$$a = \frac{Y_5 - Y_2}{X_1 - X_2}$$
$$b = Y_2 - X_2 \frac{Y_5 - Y_2}{X_1 - X_2} \tag{4}$$

Then $R = \dfrac{|a * X_3 - Y_3 + b|}{\sqrt{a^2 + 1}}$ (5)

From equation (4), we can have $b = Y_2 - a * X_2$ (6)

Substitute b in equation (5) with equation (6), the following equation could be derived.

$R^2(a^2 + 1) = [a(X_3 - X_2) + (Y_2 - Y_3)]^2$ and Let $k_1 = \dfrac{X_3 - X_2}{R}, k_2 = \dfrac{Y_2 - Y_3}{R}$, then (7)

Equation (7) could be rewritten as

$$a^2 + 1 = (ak_1 + k_2)^2 \quad and \quad (k_1{}^2 - 1)a^2 + 2k_1k_2a + k_2{}^2 - 1 = 0 \tag{8}$$

Then solving this quadratic equation for a, equation (10) could be obtained.

$$a = \frac{-k_1k_2 \pm \sqrt{k_1{}^2 + k_2{}^2 - 1}}{k_1{}^2 - 1} \tag{9}$$

When a>0 the machine cuts the right side of the trail and when a<0 the machine cuts the left side of the trail. Based on the above calculation, the next machine position could be expressed as

$$\begin{cases} X_5 = X_1 \\ Y_5 = aX_1 + (Y_2 - aX_2) = a(X_1 - X_2) + Y_2 \end{cases} \tag{10}$$

Then to avoid residual tree damage, the machine move distance should be $d_i = |AG| = |Y_5 - Y_1|$. If there are no trees having obstacles to cut at the current machine location, then the machine should move to next stop - $d_{move} = \min\{d_i\}$.

If the boom is already extended (Figure 1 (b)), the machine is at point A (X_1, Y_1), boom is at point B (X_2, Y_2), and the next tree selected to be cut is at point C (X_3,Y_3). Before swinging the boom directly from B to A, we have to check if there is a tree (X_3,Y_3) between line $\overline{AB}$ and line

$\overline{AC}$ (Eliasson 1998). Mathematically, the following conditions have to be met to avoid residual tree damage.

(1) $Min\left\{\left|S_{\overline{AB}}\right|, \left|S_{\overline{AC}}\right|\right\} \le \left|S_{\overline{AM}}\right| \le Max\left\{\left|S_{\overline{AB}}\right|, \left|S_{\overline{AC}}\right|\right\}$

(2) $d_{\overline{Am}} \le d_{\overline{AB}}$

Where, $S_{\overline{AB}}$, $S_{\overline{AC}}$, $S_{\overline{AM}}$ is the slope for line $\overline{AB}$, $\overline{AC}$, and $\overline{AM}$, respectively.

And $d_{\overline{Am}}, d_{\overline{AB}}$ is the distance from point A to point M and point B, respectively.

$$S_{\overline{AB}} = \frac{Y_2 - Y_1}{X_2 - X_1}\ ;\ S_{\overline{AC}} = \frac{Y_4 - Y_1}{X_4 - X_1}\ ;\ S_{\overline{AM}} = \frac{Y_3 - Y_1}{X_3 - X_1}$$

$$d_{\overline{AM}} = \sqrt{(Y_1 - Y_3)^2 + (X_1 - X_3)^2}; d_{\overline{AB}} = \sqrt{(Y_1 - Y_2)^2 + (X_1 - X_2)^2}$$

If the above two conditions are met, the tree being checked is an obstacle. To cut the tree at C from B, the boom has to retrieve from B to M first, and then extend from M to C if no other trees between line $\overline{AM}$ and line $\overline{AC}$. Otherwise, the boom will swing from B to C directly.

The forwarder moves along the harvester trail, grips the logs from each pile and places them in the bunk at the back of the machine. When the payload is reached, the forwarder will go back to the landing and unload the logs. Four functions are simulated for the forwarder: travel loaded, travel empty, choking, and unchoking.

SIMULATION RESULTS

Felling and forwarding was simulated on two central Appalachian hardwood stands that were computer generated. The plot size was 1.0 acre, which was replicated 36 times for performing felling and forwarding simulations. The hourly machine rates used for this simulation were $146.72 for harvester in CTL system 1 and $115.00 for harvester in CTL system 2 (LeDoux and Huyler 2001) and the hourly machine rate for forwarder is set at $110.00.

The combined simulated hourly productivity for the harvester and forwarder ranged from 747.26 ft^3 (shelterwood, stand 1) to 1339.50 ft^3 (clearcut, stand 2) for CTL system 1 and from 736.17 ft^3 (shelterwood, stand 1) to 1315.04 ft^3 (clearcut, stand 2) for CTL system 2 (Table 1). The CTL system 2 in a clearcut (stand 2) had the lowest cost $0.35/$ft^3$ while the CTL system 2 conducting shelterwood cut in stand 1 had the highest cost $0.73/$ft^3$ (Table 1). Although the combined system productivity is higher for the CTL system 1, the cost per unit for the small CTL system 2 is less for similar conditions. Operators can realize some savings efficiency by matching the size of machines to the size of wood harvested. Stands that have trees with DBH's larger than 14 inches should be harvested with the large CTL harvester.

We have successfully modeled and simulated the cost and productivity of two CTL systems operating in two central Appalachian hardwood stands. It is beyond the scope of this paper to deal with all of the modeling and production/cost results. Future research will investigate and document additional CTL systems, stand conditions, tract layout, traffic intensity, and production/cost results.

Table 1. CTL system production and cost comparisons.

System	Stand	Treatment	BA Removed (%)	Avg. DBH Removed (inch)	Harvester			Forwarder	
					Trees/min	FT^3/PMH	$/$FT^3$	FT^3/PMH	$/$FT^3$
CTL System 1	Stand 1	Clearcut	100	5.32	1.51	328.46	0.44	538.87	0.20
		Shelterwood	72.24	4.82	1.27	304.85	0.48	442.41	0.25
		Diameter Limit	35.56	13.79	1.08	313.32	0.47	678.08	0.16
	Stand 2	Clearcut	100	14.43	1.31	567.87	0.26	771.63	0.14
		Shelterwood	59.40	13.00	0.88	518.23	0.28	580.49	0.19
CTL System 2	Stand 1	Clearcut	100	5.32	1.46	317.43	0.36	513.36	0.21
		Shelterwood	72.24	4.82	1.20	295.19	0.39	440.98	0.25
		Diameter Limit	35.56	13.79	1.06	300.95	0.38	602.52	0.18
	Stand 2	Clearcut	100	14.43	1.29	564.37	0.20	750.67	0.15
		Shelterwood	59.40	13.00	0.79	510.13	0.23	552.92	0.20

REFERENCES

Eliasson, L. 1998. Simulation of thinning with a single-grip harvester. For. Sci. 45(1): 26-34.

Huyler, N.K. and C.B. LeDoux.1996. Cut-to-length harvesting on a small woodlot in New England: a case study. In: Proceedings, planning and implementing forest operations to achieve sustainable forests. General Technical Report NC-186. U.S. Department of Agriculture. Forest Service, North Central Forest Experiment Station. St. Paul, MN: 102-108.

Huyler, N.K. and C.B. LeDoux.1999. Performance of a cut-to-length harvester in a single tree and group selection cut. Research Paper NE-711. U.S. Department of Agriculture, Forest Service, Northeastern Research Station. Radnor, PA.

Lanford, B. and B.J. Stokes. 1995. Comparison of two thinning systems. Part 1. Stand and site impacts. For. Prod. J. 45 (5): 74-79.

LeDoux, C.B. and N.K. Huyler. 2001. Comparison of two cut-to-length harvesting systems operating in eastern hardwoods. J. For. Eng. 12(1): 53-59.

Wang, J. and C.B. LeDoux. 2003. Estimating and validating ground-based timber harvesting production through computer simulation. For. Sci. 49(1): 64-76.

Wang, J. and W.D. Greene. 1999. An interactive simulation system for modeling stands, harvests, and machines. J. For. Eng. 10(1): 81-89.

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SOIL COMPACTION CAUSED BY TIMBER HARVESTING IN CENTRAL APPALACHIAN HARDWOOD FORESTS

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ABSTRACT - A manual system of chainsaw and cable skidder, along with a mechanized system consisting of feller-buncher and grapple skidder were examined to determine the amount of soil compaction in two central Appalachian hardwood forest sites. Examinations of soil bulk density (lbs/ft^3) were made pre-harvest and post-harvest for each harvest unit. Observations were conducted along the skid roads in conjunction to distance from the landing. Sample points were also taken systematically through each harvest site. The physical condition was recorded using a nuclear density probe. Data were analyzed statistically to determine the effect of operational variables on soil impacts. Results indicate that timber harvesting does affect the soil compaction levels in the woods, as well as along skid roads. Soil compaction also varies by different soil moisture level and soil series.

INTRODUCTION

The use of forest roads and equipment has been increased due to selective harvesting of timber. Harvesting machines used for thinning sometimes cause residual stand and root damage with additional soil compaction, rutting, and nutrient relocation on the site (McNeel and Ballard 1992). Recent advances in harvesting techniques and product utilization have resulted in increasing occurrence of removing the entire aboveground biomass of trees. These methods are efficient, but require the use of heavy equipment, which may reduce site productivity by compacting the soil and/or disturbing the litter layer (Steinbrenner and Gassel 1955, Froehlich 1979, Donnelly and Shane 1986). As extraction equipment has evolved from crawler-type tractors to wheel skidders and as felling machines have progressed from chain saws to mechanized harvesters, the percentage of disturbance has increased (Martin 1988).

During the past decade, forest harvesting methods available for the central Appalachian hardwood forests have evolved. Increased rates in worker's compensation, along with the demand for more production, have led to more mechanized harvesting operations throughout the region. Soil changes caused from a mechanized system are unknown at this time due to the variability of soil types, site conditions, harvest types, harvest systems, and season of the year. While mechanized trafficking is believed to cause soil compaction or other effects to the soil the variability throughout the central Appalachian hardwood forest also makes the degree of change uncertain. Evaluations of the soil impacts among harvesting systems, silvicultural treatments, soil types, and soil conditions seem necessary in the region. The objectives of this study are especially to: (1) examine if the occurrence of soil compaction is significantly different between two commonly-used ground-based harvest systems in central Appalachian hardwood forests, (2) physically examine the amount of soil compaction on the skid roads and across the site by soil type, soil moisture, site condition, and harvest system, and (3) statistically analyze the amount of soil compaction associated with the harvest system, soil type/moisture, and site conditions.

METHODS

Two study sites were located on Mead-Westvaco's forest in Randolph County, West Virginia and were similar in size. The manual harvesting system consisted of two timber fellers using chainsaws, one rubber-tired cable skidder, and one bulldozer. The manual harvesting tract was 31 acres in size and tree volume removed was 3600 BF (Doyle scale) per acre. The study area with north-facing slope was moderately steep (approximately 30 to 40%). Soils for the manual harvest site are primarily Gilpin series (GkE), though it is Buchanan (BtE) near the valley bottom. Feller-buncher and grapple skidder were the two major machines used in the mechanized system. The mechanized harvesting site was 34 acres and volume removed per acre was 5765 BF. The mechanized site was north facing with approximately 10-20% of slope. Soils for the mechanized harvest site consists of Buchanan (BtE), Gilpin (GdE), and Lily (LyC) series.

Two harvesting sites were assumed similar in terms of stand and terrain conditions. The two treatments applied were manual harvesting system and mechanized harvesting system. Soil sample plots were pre-determined prior to harvest. Soil samples were taken on skid roads and throughout two harvested sites. Points were systematically located in the harvest sites, while the points on the skid roads were randomly placed. A GPS unit was used to map, record, and relocate the sample locations.

Thirty sampling locations were installed in each of two harvesting sites, which were systematically laid out using a grid of 3 by 3 chains. Four samples were taken at each location at random direction and distance. The direction was determined much like using your second hand on a wristwatch and the distance will be a random length up to 15 feet. Six samples were taken at a cross section on the road. A total of 60 points were measured at 10 cross sections on the skid road in manual harvesting site while 84 points were recorded at 14 cross sections on the road in mechanized site. The soil compaction associated with the first ten-loaded skidder passes were recorded at the first four cross section samples on the skid road in each site. The locations of the samples in relation to the log landing also were measured.

A Troxler density and moisture gauge was used to measure the soil density and soil moisture, which allows taking more samples and provide more accurate measurement. The Troxler can measure bulk density and soil moisture from 2 inches deep to 12 inches deep in increments of 2 in. Samples were measured six inches from the top of the surface to obtain soil bulk density in this study.

The independent variables measured were harvest type, harvest status (pre-harvest and post-harvest), soil types, and soil moisture. The quantitative measurement for the variable was dry density (DD) (lb/ft^3) that is the weight of the soil per unit volume. The soil compaction was computed by differentiating dry soil bulk densities after and before harvests. The general linear model (GLM) was used to test if the significant differences of soil density or compaction exist among harvest system, harvest status, and soil moisture levels. Tests were performed using Duncan's multiple-range test at 0.05 level.

RESULTS

For the points in the woods on the manual harvest site, the mean pre-harvest soil bulk density was 65.75 lb/ft^3, while mean post-harvest soil bulk density was 67.00 lb/ft^3. An increased compaction level of 6.08 lb/ft^3 was present on the manual harvest site. On the mechanized harvesting site mean pre-harvest soil bulk density was 59.31 lb/ft^3 and mean post-harvest soil bulk density was 59.48 lb/ft^3. The mechanized harvesting site showed an increased compaction level of 1.82 lb/ft^3 DD after harvest. Dry bulk density (F = 40.20; df = 1, 479; P = 0.0001) was significantly different between harvesting systems. However, there was no significant difference for DD (F = 0.43; df = 1, 479; P = 0.5147) between harvest statuses. Soil moisture did significantly affect the soil bulk density or compaction. DD decreased as soil moisture level increased from 15% to 70%.

Mean pre-harvest soil bulk density on the roads in the manual site was 85.88 lb/ft^3. Mean post-harvest soil bulk density was 93.16 lb/ft^3, showing an increased compaction level of 9.35 lb/ft^3 on the manual harvesting site. On the mechanized harvesting site mean pre-harvest soil bulk density was 81.88 lb/ft^3. Mean post-harvest soil bulk density was 86.16 lb/ft^3, showing an increased compaction level of 7.88 lb/ft^3. For the points on the road, DD (F = 15.39; df = 1, 287; P = 0.0001) was significantly different between harvesting systems. Similarly, there was no significant difference of DD (F = 16.01; df = 1, 287; P = 0.0001) between harvest statuses. The interaction between harvesting system and harvest status showed a significant effect on DD (F = 1.14; df = 1, 287; P = 0.2874). Soil moisture groups showed a trend that the lower the soil moisture the higher the soil bulk density. However, the higher the soil moisture the higher the soil compaction level. Soil moisture did significantly affect the compaction levels.

The mean pre-harvest soil bulk density was 88.32 lb/ft^3 on the manual harvesting site, which increased as the number of loaded machine passes increased (Figure 1). A decrease in soil compaction was shown after three or four passes. This might be attributed to the rutting observed after three or four-loaded machine passes. As the soil was displaced, the bulk density decreased some. Then, as the soil displacement minimized, the bulk density increased as the number of loaded machine passes increased. The soil bulk density increased to 97.20 lb/ft^3 after 10-loaded machine passes. The soil bulk density on the mechanized harvesting site indicated a similar increasing trend as the number of loaded machine passes increased. However, as in the manual system a decrease in soil compaction was noticed as soil displacement occurred. A smaller decrease in soil density was recorded as rutting occurred. In addition, as the displacement minimized the bulk density increased as the number of loaded machine passes increased. An average bulk density of 78.22 lb/ft^3 before harvest on the mechanized harvest site was observed and it increased to 88.75 lb/ft^3 after five machine passes and 95.60 lb/ft^3 after ten passes.

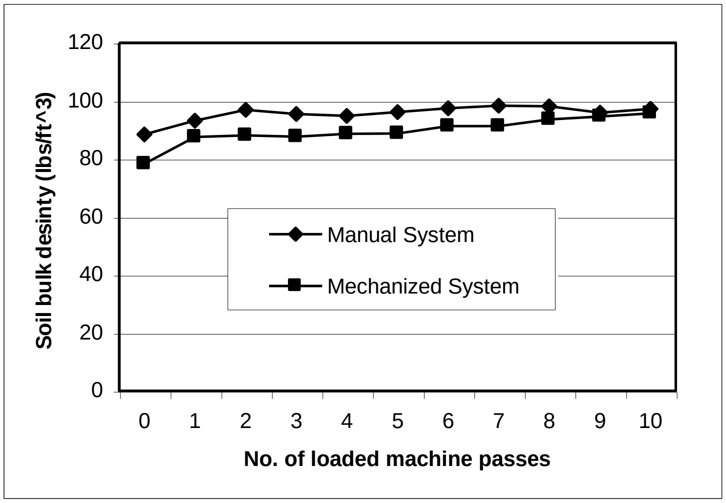

Figure 1. Soil bulk densities vs. loaded machine passes.

DISCUSSION

There are three reasons why the mean dry bulk density is lower on the mechanized harvest site than that on the manual harvest site. The manual harvesting operation started in the late spring and experienced approximately 6.5 inches of rainfall, while the mechanized system began in late July and finished in two weeks and had no rainfall. Secondly, the mechanized harvest site was preplanned and skid roads were put in two to three weeks prior to harvesting operations. There were no points in the woods that fell on the skid road system on the mechanized site. On the manual harvesting site, however, the skid roads were built as the operation progressed. Therefore, five locations for points in the woods were ultimately located on a skid road. Harvesting conditions such as the slope can also contribute to this as well as preplanning or lack of planning. Finally, operator experience contributes to the amount of ground disturbance. The crew for the mechanized harvest system had no wasted motion. The feller-buncher bunched trees and the skidder got all the bunched trees in one turn. However, the cable skidder operator on the manual harvesting site sometimes skidded logs from the same point along the skid road three or four times before moving to another location.

Higher soil bulk density was also observed on the skid roads in the manual harvesting site as compared with the densities on the skid roads in the mechanized site. The reasons are as follows: (1) the ground pressure for the TimberJack 460 cable skidder used in the manual site was 7.2 (psi), while the ground pressure for the John Deere 648GII grapple skidder in the mechanized site was 6.4 (psi); (2) the manual harvesting site had more precipitation during the harvest; and (3) the operator of the John Deere 648GII cut tracks while skidding, on the mechanized site. This means the machine never ran in the same place twice. The skidder operator used the whole width of the road instead of traveling in the same wheel tracks.

The higher the soil moisture the more likely the soil is to be compacted. The soil moisture tends to be low after road construction. The moisture dried out after the road was established. The loggers running the manual harvest system built roads as the harvest progressed. Therefore, the soil moisture was higher than in the pre-planned roads on the mechanized system. This might have contributed to a higher compaction level on the skid roads.

Both harvesting systems showed an increase in soil compaction with the number of loaded machine passes. A small decrease in soil compaction was recorded as rutting began to occur for both harvest systems. For both systems, the soil compaction increased as the rutting stopped. However, more samples might help to improve the accuracy of this observation.

The finding in this study can give a new base line for future studies. Further study is needed to evaluate silvicultural treatments such as clearcut vs. partial cut using the same harvesting system. Future monitoring should also include evaluating the fate of compacted soil on the skid roads. Soil bulk density should be evaluated each year or even every six months to determine how long it takes the soil to return to its original bulk density. Compaction did occur on skid roads, however, trees have grown on old skid roads. It would be beneficial to continue to evaluate the soil density for productivity purposes. The differences in the soil types for each site made it impossible to compare. Similar harvest sites with the same soil types would be beneficial for determining soil compaction by soil types.

REFERENCES

Donnelly, J.R. and J.B. Shane. 1991. Harvesting causes only minor changes in physical properties of upland Vermont soils. North. J. Appl. For. 8: 33-36.

Froehlich, H. A. 1979. Soil compaction from logging equipment: effects on the growth of young ponderosa pine. J. Soil Water Conserv. 34: 276-278.

Martin, C. W. 1988. Soil disturbance by logging in New England-Review and management recommendations. North. J. Appl. For. 5: 30-34.

McNeel, J. F., and T.M. Ballard. 1992. Analysis of site stand impacts from thinning with a harvester-forwarder system. J. of Forest Engineering. 4(1): 23-29.

Steinbrenner, E. C., and S.P. Gassel. 1955. The effect of tractor logging on physical properties of some forest soils in southwestern Washington. Soil Sci. Soc. Amer. Proc. 19: 372-376.

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