

**PROCEEDINGS OF THE
INTERNATIONAL MOUNTAIN LOGGING
AND
13TH PACIFIC NORTHWEST SKYLINE SYMPOSIUM**



Sponsored by

**Department of Forest Engineering
Oregon State University**

**International Union of Forest
Research Organizations**

Edited by John Sessions and Yvonne Havill

**Corvallis, OR
April 1-6, 2007**

INTRODUCTION

Mountain forests are valuable resources providing wood, water, wildlife habitat and scenic quality. Meeting society's demands for wood and wood products while maintaining and enhancing those scenic, protective and productive values requires skillful application of forest engineering operations and management knowledge.

Beginning in 1969 and approximately every three years, the accumulated knowledge and technology gained by experience and research of private industry, contractors, and public organizations in the Pacific Northwest and around the world, is disseminated at the International Mountain Logging and Pacific Northwest Skyline Symposium.

Traditionally the event has been hosted by rotation with Oregon State University, the University of Washington and the University of British Columbia. The symposium series is also supported by the International Union of Forest Research Organizations Division Three, the University of California, Davis; the Forest Engineering Research Institute of Canada; the Washington State Department of Natural Resources; the USDA Forest Service Pacific Northwest Research Station and the USDA Forest Service, Region 6.

This time, in 2007, the symposium is hosted by Oregon State University, Department of Forest Engineering. The International Union of Forest Research Organizations (IUFRO) Division Three is a cosponsor, with the objective of coordinating mountain forest harvesting research activities throughout the world. The Oregon Forest Resources Institute (OFRI) and the Associated Oregon Loggers (AOL) are also hosting the 2007 symposium.

These proceedings are reproductions of papers submitted to the organizing committee with minor editing to conform to common North American logging terminology. No attempt has been made to review or verify results. Specific questions regarding papers should be directed to the authors.



John Sessions
Editor



Yvonne Havill
Editor

Dates and Locations of Previous Symposiums

- 1969 1st Symposium, Oregon State University, Corvallis
- 1974 2nd Symposium, University of Washington, Seattle
- 1976 3th Symposium, University of British Columbia, USDA Forest Service, FERIC, Vancouver
- 1979 4th Symposium, Oregon State University, Portland
- 1983 5th Symposium, University of Washington, Seattle
- 1985 6th Symposium, University of British Columbia, FERIC, Vancouver
- 1988 7th Symposium, Oregon State University, Portland
- 1992 8th Symposium, University of Washington, USDA PNW Station, Seattle
- 1996 9th Symposium, University of British Columbia/FERIC, Campbell River
- 1999 10th Symposium, Oregon State University, Corvallis
- 2001 11th Symposium, University of Washington, Seattle
- 2004 12th Symposium, University of British Columbia, FERIC, Vancouver
- 2007 13th Symposium, Oregon State University, Corvallis

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KEY NOTE PRESENTATIONS

EMERGING TECHNIQUES AND TECHNOLOGIES TO KEEP FORESTRY PROFITABLE CONSIDERING GLOBAL ENVIRONMENTAL IMPACT

Isabelle Bergkvist, Björn Löfgren, Claes Löfroth

Abstract: Today all logging operations in Sweden are mechanized. Cut-to-length systems are used for logging operations and most of the systems comprise a single-grip harvester and a forwarder. What will be needed tomorrow? It is not a wild guess that high productivity and low costs will continue to be an important research area, but more and more focus will probably be on high profitability and global environmental impact. Automation seems to be one way of increasing productivity. This will involve automation of entire operations, knuckle boom manipulation and other parts of the process. The Harwarder and the Beast are two examples of systems that increase productivity through reduction of working elements. Fewer working elements also seem to reduce fuel consumption. A hybrid forwarder, "El-Forest" is being tested in the north of Sweden and the results indicate 30% reduction in fuel consumption. In round wood truck hauling an increase in productivity and decrease in fuel consumption are anticipated when using heavier loads, CTI and hybrid technology. The forest can be also used to produce renewable energy. With improved techniques and methods both forest energy and total biomass production can increase in Sweden and thereby decrease the dependency on crude oil and oil products. The aim is a 50% total decrease of diesel consumption for logging operations and forest transport. The challenge is to use emerging techniques to achieve that and additionally to increase productivity.

Key words: Emerging techniques, productivity, fuel consumption, renewable energy

Introduction

Swedish forestry today

Sweden is covered with 23 million hectares of forest land, which is approximately 50 % of the total land area. The ownership is roughly divided into 50 % smaller private land owners, 30 % forest companies and 20% state-owned land. The harvested volume is approximately 80 million m³ each year of which 60% is saw timber, 36% pulp wood and 4% energy wood. All logging operations are mechanized. However, planting and pre-commercial thinning is still carried out manually in most cases. Cut-to-length systems are used for logging operations and most of the systems comprise a single-grip harvester and a forwarder. Exported forest products account for 15 % of the total Swedish export value.

Swedish forestry tomorrow

Obviously, it is impossible to see into the future and be certain of the needs and demands in forestry of tomorrow. But we can make an educated guess based on the conditions we have today. There are some

critical issues. We have to maintain the profitability of the forest industry in spite of decreasing prices due to competition from alternative materials, fast-growing tree species from the southern hemisphere and cheaper labor abroad. It is not a wild guess that high productivity and low costs will continue to be an important research area but more and more focus will probably be on high profitability concerning global environment impact.

We have to meet the challenge of increasing productivity while at the same time not increasing global environmental impact. As a matter of fact, forestry has a great opportunity to contribute to a decrease of green house gases through manufacture of "green electricity" at the industries and alternative fuel produced from forest biomass. Furthermore it is possible to decrease fuel consumption by using new efficient technologies. Besides protection of the environment, forestry has to be carried on in cooperation with a lot of other interests such as recreation, cultural heritage, hunting and fishing interests. Further on I will present some emerging techniques that correspond to the above expectations.

Examples of Interesting Research Areas

Semi Automation

In a time when forest operations are fully mechanized, we are entering a new era in which automation will probably come to the fore front. This will involve automation of entire operations, knuckle boom manipulation and other parts of the process. A lot of work to reduce the physical stress to which operators are subjected has already been done successfully over the years. However, the higher tempo of work today, combined with the many decisions that operators must make under pressure, is imposing a greater mental load on them. Skogforsk has conducted comparative studies in a forest machine simulator. Through a series of time studies, combined with an analysis of the joystick and pushbutton functions used by the operator, we were able to identify a number of work elements or sub functions that could be worth automating. Forestry-school students took part in a test that involved both conventional control and semi-automated functions on a harvester in the simulator. The following working elements were studied

- Automatic alignment of harvester head on boom out
- Automatic delimiting of a felled tree
- Automatic boom repositioning after felling

The usage of joystick and pushbutton controls was much lower when functions were semi-automated than in conventional operator control which gives the operator time to take micro breaks. In addition, the following results were noted.

- 30 % less use of rotation of harvester head.
- 60 % less use of joystick functions.
- 30 % increased productivity

A professional operator made the same test as the students and there was a significant difference between the students and the operator when the boom was semi-automated. The students used 75% more time when the conventional control was used and just 21% more time when the boom was semi-automated. Our tests carried out in the simulator, clearly demonstrate that automation of forestry machines is a feasible way to increase productivity and to improve the working conditions of operators. Automation should be directed both at knuckle boom work and processing.

Reduction of Working Elements

Another way to increase productivity is to reduce working elements. The Harwarder and the Beast are two examples. Both systems use direct loading which means no (or minimal) loading of logs from the ground. Furthermore, both systems have integrated harvesting and forwarding implying that all timber is at roadside when the cutting operation is done.

The Harwarder consists of one machine with a loading-space and a combined grip and felling head. The loading-space is turnable which makes it possible to process logs directly onto the loading-space. When the loading-space is full the harwarder forwards the logs to roadside. Since it is just one machine the system is cheap and easy to move between sites. However, it is very sensitive to long forwarding distances because there is no production going on when the system is forwarding.



Fig. 1. Harwarder Valmet 801C.

The Beast system, on the other hand, consists of three machines. One remote controlled harvester-unit (the Beast) and two couriers (forwarders with turnable loading-space and radio-equipment for controlling the Beast). The Beast processes trees directly on to the loading-space of courier no.1 which is standing just next to it. The operator in this courier operates the Beast and when the loading-space is full the couriers change places and courier no.2 takes over the control of the Beast while courier no.1 transports the logs to roadside. The benefit of two couriers is that production can continue while one of the couriers is forwarding the logs.



Fig. 2. The Beast with two couriers

Very small studies indicate that both systems have 20-30% less fuel consumption than a Harvester/ Forwarder-system. Theoretical calculations support that result since loading of logs from the ground accounts for approximately 25% of the total fuel consumption and that one working element is avoided with the direct loading in the Beast and Harwarder systems, respectively.

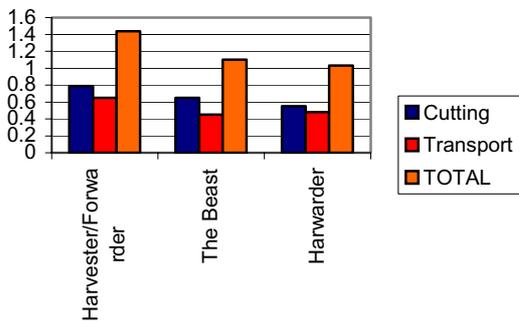


Fig. 3. Fuel consumption for Harvester/Forwarder, the Beast- and the Harwarder- system

The Beast and the Harwarder systems have additional benefits. These include no contamination of the logs, short lead time and reduction of static work for the operator. However those systems can never compete with the Harvester/Forwarder system at long transport distances and high tree volume. The Harwarder system needs conditions where most of the time used will be harvesting i.e. short transport distance and low average tree volume. The Beast system is less sensitive, but at long transport distances and high average tree volume there will be waiting time on the harvester-unit and the system will lose production compared to the Harvester/Forwarder system.

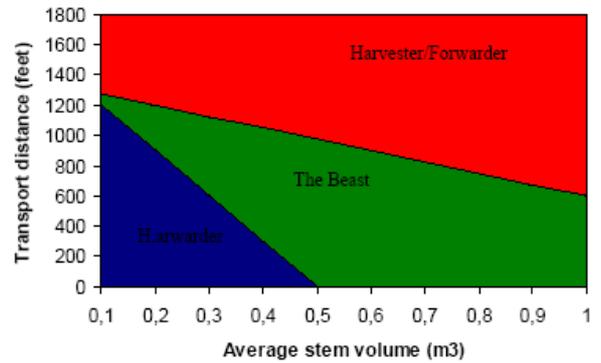


Fig. 4. Competitive working range for different systems

Hybrid Technology

A hybrid forwarder, “El-Forest” was tested in the north of Sweden and the results indicated a 30% reduction in fuel consumption. The El-Forest is equipped with one 40 kW diesel engine plus six electric engines. The diesel engine is working with constant power and each of the electric engines is attached to a wheel. The electric engines generate energy while driving downhill. The reason for the expected lower fuel consumption is the small engine compared to ordinary forwarders which have 100-180 kW diesel engines. Studies of fuel consumption on forwarders have shown a linear connection between engine power and fuel consumption. The interest in the El-Forest forwarder is continuing and studies of production and costs are planned for the spring and summer of 2007.



Fig. 5. The El-Forest forwarder

The hybrid technology could, of course, be used in highway transport operations too. Volvo anticipates a 5-8% decrease in fuel consumption for long distance

trucks (round wood haulage). Some tests made at both Volvo and Scania use fuel cells as an alternative power source to the diesel engine while the truck is not moving. The big potential according to Volvo is to use hybrid technology in city traffic. Trucks, buses and working machines are estimated to have a 20-40% possible decrease of fuel consumption.

Trucks and transport operations

Swedish forestry, the Swedish organization for haulage contractors and The National Road Administration aim to decrease emission of CO₂ by 30% by 2010. Since 1985, fuel consumption for round-wood haulage has decreased from 5.4 l/m³ to 3.7 l/m³.

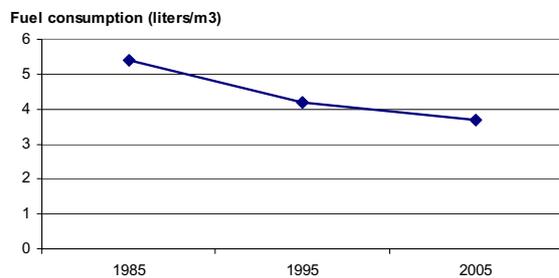


Fig. 6. Fuel consumption for round-wood haulage 1985-2005

One important reason for the decrease is that heavier loads were permitted. In 1995 the total weight of the truck increased from 43 metric tons to 60 metric tons which is the limit today. Additional decreases of fuel consumption are due to improved techniques and more effective engines.

Theoretical calculations in Sweden and other European countries indicates that fuel consumption could decrease another 20% by increasing truck weight to 80 metric tons and the National Road Administration supports the use of a 80 metric ton truck in a test study. In practice a truck will be equipped with an additional trailer allowing more load on the truck. Eighty metric ton trucks would result in fewer trucks on the roads. In addition to decrease in fuel consumption other advantages could be expected such as:

- 20% reduction in green house gases
- Fewer accidents on the roads
- Less damage to the roads because heavier loads on one additional trailer actually means lower axle weight. There is a risk that some bridges are not adequate for 80-ton trucks. In practice this would require a comparison of costs of upgrades compared to the benefits of heavier loads.

The best effect would be achieved if the 80-ton trucks are equipped with CTI (central tire inflation). CTI is a technology that makes it possible to modify air pressure in the tires according to road conditions. This means that more roads could be open to traffic with heavier loads if CTI is used. In addition to the possibility to haul higher weights and decrease fuel consumption with less damage to the roads, CTI gives further advantages, for example low repair costs, improved driver environment and reduced tire wear.

Another example where small efforts make a difference is if round-wood haulers can remove unnecessary items on the truck, such as signboards, extra air horns, extra lamps and other accessories that increase drag. These measures plus fitting a wind deflector on the cab roof could reduce fuel consumption for round-wood haulage rigs by 5–10%.

The aim of Swedish forestry is to reduce fuel consumption to 50% of the level of today both in round-wood haulage and in logging operations

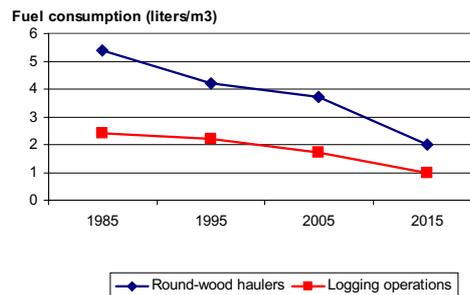


Fig. 7. Fuel consumption in Swedish forest operations 1985-2005, and the goal until 2015

Forest Energy

Production of renewable energy is of increasing importance to Swedish forestry. In 2004, bio-energy contributed 17% to the total energy supply of 650 TWh. About 17 % of the bio-energy had its origin from non-refined forest products. With improved techniques and methods both forest energy and total biomass production can increase and thereby decrease the dependency on crude oil and oil products. Non-refined forest products are preferably used in heating plants, for small-scale heating, in combined power and heating plants, and for production of bio-fuels such as RME, EcoPar and ethanol. Production of bio-fuel will have difficulties in competing with Brazilian “sugar cane ethanol”, but Swedish heating plants should be able to use forest raw material for

most of the production. There is also a significant increase of production of “green electricity” at forest industries using waste products from pulp production, sawdust and bark.

Conclusions

In summary, Swedish forestry of tomorrow will need more-productive, fuel-efficient and flexible machines. Swedish forestry needs to be an international leader in new techniques that maximize productivity and minimize costs with the aim to compete with other materials and fast-growing forests. The aim is a total decrease of diesel consumption of 50% for logging operations and forest transport. To achieve that goal every effort to reduce fuel consumption has to be taken without losing productivity. Production of alternative fuels is probably going to reach a modest level whereas production of heat and green electricity will increase significantly. One goal could be to reach a production of energy from forest products at least as large as the consumption of energy within forestry.

Literature Cited

- Löfroth, C. & Rådström, L. 2006. Fuel consumption in forestry continues to fall. Result No 3 2006, Skogforsk. Sweden.
- Granlund, P. 2006. Five million km covered in CTI project. Result No 4 2006, Skogforsk. Sweden.
- Brander, M. Eriksson, D. Löfgren, B. 2004. Automation of knuckleboom work can increase productivity. Result No 4 2004, Skogforsk. Sweden.
- Bergkvist, I. Nordén, B. Lundström, H. 2006. Innovative unmanned harvester system. Result No 2 2006, Skogforsk. Sweden

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WOOD SUPPLY CHAIN EFFICIENCY AND FIBER COST: HOW COMPETITIVE IS THE U. S. SOUTH?

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Abstract: Fiber is the largest component of cash manufacturing costs. As such, fiber availability and cost have large impacts on industrial profitability. We begin with the examination of wood supply chains across the world's major wood producing regions, including the U.S. South, Western Canada, Brazil, Sweden, and Australia. We evaluate the effectiveness of particular systems based on information about their structure, stumpage costs, and delivered wood costs. Using the linerboard sector as an example, we also examine the impact of using virgin fiber vs. recycled fiber on manufacturing costs. These regional comparisons are used to identify strategies that should be considered by the industry in the U.S. South for improving wood supply chain efficiency. A special emphasis is placed on what wood processing mills can do to improve the wood supply chain efficiency, both in terms of reducing costs and improving fiber availability, including policies associated with truck weight limits, scheduling, equipment, and contracting. This paper is an expanded version of one published in the 2006 **Proceedings of the 29th Council on Forest Engineering Conference (p. 455-461)**.

Key words: forest industry competitiveness, international forest operations

Objectives and Methods

The forest products industry in the U.S. faces increased competition from every corner of the globe. In addition, population pressures and changes in land use in the U.S. South where the industry has traditionally been most competitive are also impacting the industry. For years the industry was a low-cost producer, benefiting from excellent infrastructure, productive forests on low-cost land, innovative logging contractors, and strong product markets. The U.S. South is no longer the lowest cost producer, however, even after discounting the impact of the recent weak dollar (RISI 2004). Recent research supported by the Wood Supply Research Institute identified that unused logging capacity alone cost the wood supply chain nearly \$400 million per year or about \$2 per ton (Greene et al. 2004).

Fiber is the largest component of cash manufacturing costs in forest industries. As such, fiber availability and cost can have a substantial impact on industrial profitability. To successfully compete in a global marketplace, our industry must continually evaluate how it supplies its mills and implements changes to keep it competitive. To address these questions, we assess: (1) the cost of doing business in the U.S. wood supply chain compared to foreign competitors, and (2) how the wood supply chain can be modified to improve its competitiveness in world markets. The major wood producing regions examined include the U.S. South, Western Canada, Brazil, Sweden and

Australia. We evaluate the effectiveness of particular systems based on information about their structure, stumpage costs, and delivered wood costs. The delivery process includes procuring, harvesting, and transporting fiber to the production facility's woodyard and processing there. These regional comparisons are used to identify strategies that should be considered by the industry in the U.S. South for improving wood supply chain efficiency.

Results

In terms of delivered pulpwood prices, the U.S. South is generally competitive with the rest of the world (Figure 1). Delivered softwood prices tend to be higher in Sweden, Western Canada, and Australia. The prices are lower in Brazil, but this gap has been narrowing recently. After accounting for operational conditions, the U.S. South also seems to be competitive on a global scale.

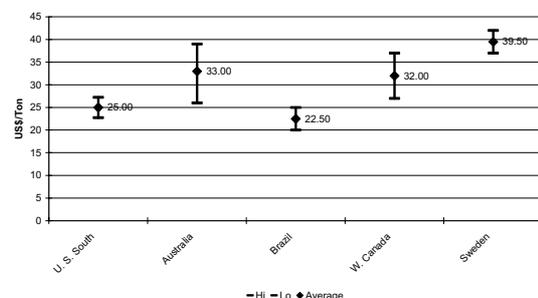


Figure 1. Delivered softwood pulpwood prices, 2005.

Brazil has the lowest wood delivery costs, largely because the wood comes from uniform plantations located close to the mill (Table 1). Furthermore, we find that comparative advantage and the competitive positions of the regions studied have become more changeable and temporal, indicating that global

competition is increasingly intense. Exchange rate changes are responsible for a large part of the short-term change. Next come labor costs including benefits that frequently are the deciding factor in a region's ranking.

Table 1. Logging cost estimates, 4th quarter 2005.

	US South	Australia	Brazil	W Canada	Sweden
	\$US/green short ton				
Harvesting/Extraction/Loading	11 - 13	6 - 18	5 - 7	9 - 12	10 - 17
Hauling Rate	4 - 11	4 - 9	2 - 4	9 - 13	4 - 8
Total Cut-n-Haul	15 - 24	10 - 27	7 - 11	18 - 25	14 - 25

Major operational differences between the U.S. South and other major wood supply regions include truck payloads, scheduling and dispatching, contract hauling, cooperative maintenance, and logging contracts. Our competitors operate primarily in the "cut-to-length" system. Trucking in the major competing regions employs larger payloads than that allowed by gross vehicle limits in the U.S. South. Truck payloads reach 55 tons in Brazil on public roads, and as much as 66 tons on private roads. This is more than twice as much as currently allowed in the U.S. South (25-29 tons). On-board scales are uniformly used in Australia to ensure maximum payloads. Our competitors have also better scheduling and dispatching systems that allow eliminating much of truck wait time while loading and unloading. This, in part, is a result of a different approach to wood hauling, which is based on trucking contractors independent from wood harvesting operators. Further, multi-shifting of all logging operations in Brazil and beyond is also common. The enterprises operate the best machinery available, maintain it well, and operate the machinery up to 20,000 h before retiring. Finally, our competitors benefit from longer work contracts that can be used for financing their operations. Last but not least, our competitors devote substantial resources to research, training, safety, and environmental compliance. At least some of these factors should be considered by the southern industry in evaluating approaches to improve their competitive standing.

Further, our competitors benefit from the fact that forest management, logging, and wood manufacturing operations are closely integrated either through ownership or contracts. Integration and the resulting larger scale of operations allows for a number of efficiency gains in planning and scheduling, in addition to other advantages associated with scale economies. In contrast, the U.S. South appears to be heading in the opposite direction.

To assess the prospective efficiency gains of fully loading our trucks more consistently, we analyzed 24 southern mills. The study found that ensuring maximum payloads and reducing load variability positively affects the wood supply system. In essence, more wood is transported in fewer trips. The resulting savings range from 4 to 13 percent, meaning that the southern wood supply system could save as much as \$100 million annually (Hamsley, et al. 2006).

We further evaluated the impact on trucking costs associated with higher payloads in the U.S. South by increasing the gross vehicle weight from 40 to 48 tons, as most highways are constructed to accommodate the increased weights. The potential cost savings reach 18 percent. The combined savings of fully loading trucks more consistently and implementing higher payloads could range from 20 to 30 percent.

Discussion

The results indicate that the southern industry should consider at least some of the approaches implemented by our competitors to improve its own competitive standing. Clearly, the use of on-board scales to ensure full truck loading and higher payloads has the potential to reduce logging costs in the U.S. South. Some of these changes can be made by individual loggers, encouraged by the mill, while others need state level changes (e.g., a weight law). The mill can play an important role in this process, that of an integrator. Unlike our competitors, our industry is very much disaggregated which makes planning and change implementation a much more challenging task. The mill can and should encourage changes by developing wood delivery policies that encourage full, consistent loading and truck scheduling to minimize down time. This would reduce the number

of trucks on the road, yielding numerous benefits to all wood supply chain participants as well as the general public using the same roadways.

Further, we need to recognize that wood supply chain efficiency needs to be studied through to the final product. The U.S. pulp and paper industry is being challenged by competitors, who despite having higher delivered wood costs, are fiercely competitive on the final product basis. This occurs in linerboard production, which is particularly important in the U.S. South. Competitors achieve these results by operating modern machinery, using innovative fiber strategies which include the increased use of recycled fiber, and developing new or modifying existing products (e.g., lighter linerboard grades).

The problem is that U.S. paper mills as a group are no longer world-class (Siry et al. 2005). Paper machines in the U.S. South are by far the largest in the world, reaching capacities of 450 thousand tons on average. They are also old—their technical age is about 21 years. Overall, southern machines are average in terms of asset quality, which in turn suggests that these machines are expensive to operate.

Machines in the U.S. South have fairly high production costs approaching \$270 per ton. It should be noted here that the new machines put into operation across the world are likely the lowest cost producers. As modern capacity grows elsewhere, cost pressures on the southern industry will continue to mount. Wood and personnel costs were the major cost drivers in the U.S. South, while Latin America has the cheapest fiber and personnel. While wood prices in the U.S. South have already receded from 2003 levels, personnel costs are likely to remain high. As the machines continue to age, they will continue to lose competitive position.

The U.S. industry's position is further eroded by changing markets for packaging materials, primarily by the development and widespread use of cheaper alternatives to kraft linerboard by foreign competitors. About two thirds of European capacity is based on recycled fiber, and Asia produces large volumes of kraft-top testliner. Southern kraft linerboard, while a superior quality product based on virgin fiber, is not cost competitive in some applications. Cheaper alternatives appear to do an acceptable job elsewhere, shrinking our market share.

While the consumption of the recycled fiber has grown over time, the U.S. industry should reconsider the strategic use of recycled fiber, primarily of old

corrugated containers (OCC), in the production of linerboard. Recycled linerboard mills represent only 11 percent of the southern linerboard capacity. Our kraft mills also use limited volumes of recycled fiber (normally up to 20 percent). In total, recycled fiber accounts for about a quarter of the linerboard output. While the United States does use recycled fiber, it may have misjudged the competition and does not sufficiently employ a combined product strategy. Our competitors produce and utilize large volumes of cheaper testliner, oftentimes manufactured in smaller and cleaner mills that can be located closer to recycled fiber supplies. In places where kraft linerboard is called for, our competitors commonly use lighter linerboard grades, which are cheaper to produce.

Therefore, while our logging industry certainly can do and should do several things to bring wood costs down, it needs to be recognized that the industry is already fairly competitive and doing a relatively good job, given the operating conditions. This implies that the true competitive position needs to be studied at the final product level as well as the wood cost level (Siry et al. 2007).

Over the past 15 years, the industrial forest management paradigm in the United States has changed from one assuming vertically integrated companies that owned forestland, converting facilities (pulp mills, lumber mills, panel plants, etc), and in some cases wholesale or retail outlets. Today, very few vertically integrated companies remain and Wall Street is pressing them hard to join the other companies who have spun off timberlands, mills, and other operations into separate companies. Millions of acres of industrially owned timberland have been sold into the hands of private investors or recreational owners. What do these ownership changes portend for the wood buyers and logging contractors? Will timber sale sizes accelerate their decline in acreage or tonnage size? How much will these owners focus on non-market values such as aesthetics and recreation instead of economic value? Large owners such as timberland investment management organizations (TIMOs) that manage land for institutional investors or former vertically integrated companies reorganized as real estate investment trusts (REITs) are already showing their interest in focusing harvest objectives on maximizing the value recovered from timber harvests on their lands. Many of the same people in these TIMOs and REITs used to run procurement organizations for vertically integrated companies with the objective of minimizing the cost to their converting facilities. In fact, some REITs now have logging contractors under contract to them to harvest and deliver their standing timber to mill markets –

these “seller contractors” have a value recovery objective as opposed to the cost minimization objective of the traditional “buyer contractors”.

There is a logical tension in the wood procurement system especially since we now operate with “every diameter a market.” If you are the pulpwood component of a six-product sort, can consuming mills without a land base dictate logger truck scheduling? Multiple sorts to multiple players are very common with four-product sorts, but the number of sorts can go to 8-10.

Conclusions & Recommendations

Comparative advantages of wood producing regions are not static – they change over both the short and long-term. This suggests that the competitive positions of the regions should be monitored on an on-going basis. Global competition is increasingly intense. Exchange rate changes are responsible for a large part of the short-term change.

Wood Sources and Cost

- Wood cost rankings by region can change frequently and cost ranges often overlap.
- Currency exchange rates are often the key factor affecting the cost ranking of regions.
- Our true competitive position needs to be studied at the final product level as well as the wood cost level. Other recent studies indicate that US paper mills as a group are no longer world-class, thus other regions are more competitive on a final product basis even though the US South is competitive at the raw material level.
- Stumpage costs are established by mechanisms other than a free market in some of the studied regions. The US South and Sweden rely heavily on open-market purchases from private landowners. Brazil relies nearly exclusively on wood from plantations of exotic species, often owned by the same company that owns the mills. Western Canada mills rely on Crown timber but pay for silviculture, regeneration, and extensive road building costs.
- Logging contractors in many other regions work under longer-term contracts (1-3 years) than typically seen in the US South. This facilitates greater autonomy on the part of the contractors and allows them greater leverage in negotiating capital financing and other business arrangements to strengthen their business.
- Labor costs (including benefits) frequently are the deciding factor in a region’s ranking. The

gap between labor costs in Brazil and the other four countries is not as large as is often cited when all labor costs are considered. However, Brazil clearly enjoys a labor cost advantage.

- Cost of environmental compliance (from forest to mill) appears to be fairly comparable in the five regions we examined due to a combination of government regulation and widespread third-party certification of industrial forests. It should be noted that other countries not in this study have significant issues with illegal logging and with environmental non-compliance. (Russia, almost all of Asia, etc.)
- The South is increasingly operating as a non-integrated free market wood economy. Other regions are more integrated and concentrated. Does this put the free-market US South at a disadvantage?

Trucking & Logistics

- Trucking in our competing countries employs larger payloads (up to 100% larger) than that allowed by gross vehicle weight limits in the US. This permits cost-effective trucking over longer distances or provides a significantly lower trucking cost at comparable distances to those seen in the US.
- Truck weights are much more tightly controlled and monitored in other countries with stiff fines beginning when weights exceed limits by as little as 2-5%. Many US states permit 5-10% weight tolerances.
- Loaded truck weights in the US are highly variable causing both significant underloading and overloading of trucks. A minority of US log trucks are weighed before leaving the woods while in many other countries the majority of trucks are weighed, thus permitting greater control of payload.
- Our research indicates that greater control of truck loading (less variable weights) leads to greater payloads. This is an opportunity that can be exploited without regulatory changes and regardless of what happens in competing countries. The research identifying these opportunities has been published for nearly 20 years.
- One approach to capturing some trucking gains would be to make trucking contractors aware of the performance of the best operators at each mill to encourage other contractors to emulate their performance. Many trucking contractors are not aware of the tare weights or average payloads of other producers.

- In most other wood producing regions, some type of effort is made to schedule truck arrivals at mills to attempt to reduce truck waiting times and increase trucking efficiency. Such efforts are rare in the US South, yet we continue to discuss this as an issue. Given our extensive communication systems (cellular phone, Southern Linc, GPS, etc.) we have an opportunity to take action to improve this area.
- Trucking costs are directly and immediately impacted by changes in fuel costs. We found mills and logging contractors buying fuel in bulk through cooperative arrangements in other countries. These efforts not only reduced fuel costs but also often resulted in a fueling station on or immediately adjacent to the mill site thus reducing truck miles driven to find a fuel station.
- Many of our competitors field logging operations for multiple shifts per day and obtain more hours from their equipment prior to replacement.

Other Issues

- The US South does not have access to the well-funded, consistent research efforts that our competitors in Sweden, Western Canada, and Australia enjoy from Skogforsk, FERIC, and CSIRO. WSRI is a noble effort that should be strengthened and continued, but we have a long way to go to become a peer of these research programs. Until then, we will continue to watch other countries innovate in this area and adopt their technology after they have obtained the early and more profitable returns.
- While the Master Logger programs and other CLE activities have improved training levels in the logger work force, the US South lags other regions in worker training. Most of our productivity gains over the past 30 years have been the result of mechanizing labor-intensive operations (eliminating labor). We may need to rethink our labor training approach if we are to use more advanced equipment in our harvesting force.
- No single study of this duration can do more than take a snapshot of the competitive position of the wood supply system in competing regions. Such comparisons must be performed on a regular basis if their findings are to have the maximum potential value to the industry.

Literature Cited

Greene, W.D., Mayo, J.H, deHoop, C.F., and Egan, A.F. 2004. Causes and costs of unused logging capacity in the southern USA and Maine. *Forest Products Journal* 54(5):29-37.

Hamsley, A.K., W.D. Greene, J.P. Siry, and B. Mendell. 2006. Improving Timber Trucking Performance by Reducing Variability of Log Truck Weights. *Proceedings, Annual Meeting, Council on Forest Engineering.*

RISI. 2004. World timber price historical data. Resource Information Systems, Inc. Lexington, MA. 36 p.

Siry, J.P, Harris, G.T., Jr., Baldwin, S., Null, D., and Gonzalez, J. Southern U.S. Forest Products: How Competitive? *TAPPI Solutions!* May 2005:34-37.

Siry, Jacek P., Harris, Jr., Thomas G., Baldwin, Sara, Null, David and Gonzalez, Jose. 2007. U. S. South linerboard industry: Restoring the competitive edge. *Forest Products Journal* 57(1/2):78-83.

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SESSION A.1:

**LOGGING OPERATION
EXPERIENCES AND
INNOVATIONS**

HELICOPTER LOGGING - A RECIPE FOR SUCCESS

Max Merlich

Abstract: Many factors affect the success of a helicopter logging operation including species, silvicultural prescription, yarding distance, and load factors. The principal determinants of load factors are density altitude, vertical yarding distance, wood availability, residual stand conditions, landing size, and the skill levels of the hookers and pilots. The relationship of log weight to scaling rules is an important to understand logging costs.

Key words: helicopter yarding costs, harvest layout, logging productivity

All helicopter logging projects should face an early examination to determine if the value of the logs will carry the cost of the operation. While this should be obvious to forest managers, we see many applications of the system, especially on low markets and excessively deteriorated timber where it does not. While there are applications where the value of the product cannot bear the cost of the work, this paper will concentrate on the types of projects where they do.

The most common helilogging projects today that must be subsidized with hard dollars are pure forest health jobs where the timber is deteriorated below merchantability standards for a net sawlog. The forest health projects going on in the San Bernardino National Forest in the Lake Arrowhead and Big Bear areas today are examples of this. Hard dollars must now be spent due to the inaction of government agencies to act in time to use the value of the dying timber to pay for the projects.

Helicopter logging need not be a pure high grade operation of high value species as you often hear. Markets often rapidly change in the timber industry and over time, major shifts can occur. Douglas-fir will certainly carry helicopter logging costs today, for example, with the value of second growth being near \$600 mbf on a low market. Hemlock and other second-growth white woods, at \$475-500 mbf will still be positive in most cases but will not bring a premium stumpage return to the landowner once trucking and other costs are incurred. Western red cedar will bring near \$1000 mbf in a fencing log today and alder has hit over \$900 mbf for sawlogs. Incense cedar also has climbed to new highs, driven by the fencing market. The value of small cedar logs, as well as the alder, have been a pleasant

surprise for many timber owners and have opened up new opportunities for helicopter logging. Selected eastern hardwoods have paid their way for many years with some species rising in value and some falling off.

I won't go into every silvicultural treatment that might be applied in a helicopter logging layout because we have done them all. Instead I will concentrate on some of the layout criteria that effect cost of a job.

Yarding distance obviously is a major factor. Closer is usually better, although there is a diminishing return at very close distances and a buffering of the cost at longer distances when the helicopter can obtain full speed with a load. We consider, in the business, a quarter mile to be short yarding, a half mile to average yarding and beyond three quarters of a mile to be long yarding. We have yarded very valuable species before at 4 miles distance.

Load factors are affected by density altitude, vertical yarding distance, wood availability, residual stand conditions, landing size and skill levels of hookers and pilots. We will discuss each one.

Density altitude plays a big part in what any helicopter can lift. At sea level to 3000 feet elevations nearly all helicopters can lift their maximum gross weights on a "standard day", 15 degrees Centigrade. Above this helicopters begin to lose performance due to thin air via less lift in the blades and less power available through the engines. There is a large difference in what one might expect between individual models of helicopters affected by different density altitudes. For instance the K-Max can hold its maximum lift ability of 6000 lbs on the

hook to a much higher altitude than the BV107 or the S61 is able to. However, this gap narrows considerably when favorable winds are present as the BV107 is an excellent lifter in a favorable wind, as well as the S61 with the “new” blades. This is where a local knowledge of winds that one might expect at certain times of the year and times of the day can be a huge advantage (or disadvantage) in helicopter logging. Temperature is the other factor in density altitude and that can more easily be tracked in past chronological records and projected to the time of year for the operation. It is quite common for helicopter logging companies to give one price for a summer operation (high and hot) and a price much less for a fall operation, (high elevations still but much cooler). Flexibility in the timing of the sale will be discussed later but sales that are “locked” into a high and hot window of time will usually be priced much higher due to, not only performance issues of the machine during this period, but also to inflexible time constraints creating limited operating periods on some jobs.

Most helicopters do better yarding downhill. Gravity is usually your friend in helicopter logging. The S64 is an exception to that; they do better going level or uphill and require special techniques to yard downhill. This is due to a vibration that the S64 experiences, (transitional rotor roughness), peculiar to this machine, in certain torque ranges that one encounters yarding downhill. This can be minimized but it is preferable to avoid it due to the violent shaking. In sale design one can figure that unless you have very large timber that would require lifting capabilities of over 10,000 lbs on individual logs, downhill is always preferable. If lift is needed over 10,000 lbs up to 27,500 lbs, the BV234 and the S64 are both available with the BV234 preferring to go downhill anyway, so, two choices of machines are available. Steep approaches to landings, both up and down are less desirable than more gradual ones and often yarding distance can be increased a bit to flatten out a flight path and actually increase production.

Wood availability is best described as “what logs can I gather up with a 35 foot choker and have them come up without hanging up?” In any partial cut or thinning operation one must protect and thus “rig around” the residual standing timber. More volume per acre is better than less. We are frequently asked to thin second growth 35-50 year old Douglas-fir now, cutting less than 10 mbf per acre out of stands that contain 30-40 mbf per acre. This greatly increases cost due to poor wood availability causing light loads and hang up problems stringing chokers long distances. Often crown closures are still well

over 75% which further slows production and increases hazards. Thinning sales such as this would do well for both economics and future timber growth the remove 40-50% of the stand and open up the crown. Availability is also sometimes impacted in highly selective cuts such as cutting for export in SE Alaska or cutting hardwoods on the east coast. They are nice trees but not that many per acre and you have a lot of logs that will only make part of a maximum load and will reach nothing else. This might be mitigated by cutting a species that does not necessarily bring more profit but adds to wood availability and thus lowers total cost by increasing the chances to load the helicopter to the maximum. Other mitigation for light thinnings with high crown closures have included the use of feller-bunchers and cut to length processing heads, both used to bunch small trees and logs into bundles that can fly as if they were single logs. Often the cutting is more expensive but the savings in speed, load factor and less equipment and men needed more than make up for it. Another situation worth mentioning is clearcutting. While you often have great volumes per acre, you might have a huge slash loading that buries logs and if there are many cull logs present, large hang up and breakout problems exist. If the timber is clean and sound this is not a problem and great turns can be made. In recent years extensive use of grapple and single pick operations have been used with all types of helicopters. The S64 and BV234 are now used nearly 100% in grapple logging applications.

Residual stand conditions we have already covered in thinnings. Basically you want to, at a minimum, be able for the pilot and the hooker to see each other. If you constantly do understory thinnings, you are not accomplishing anything for the stand, you are greatly reducing the economic potential of the project and you are making safety compromises that need not be made. You are also doing little good to the remaining stand. The US Forest Service has gone overboard in this type of cutting and it is one of the major reasons their sales are bringing low dollars and sometimes not selling at all, regardless of logging system.

One might ask “How can landing size be a criteria in load factor on the helicopter?” This is very simple and could easily be demonstrated if you were to ride in a logging helicopter. A helicopter loaded with a maximum load is a much more difficult machine to maneuver than one loaded with a lighter load. Helicopters are limited by a legal maximum load on the hook that changes with the fuel on board. They are limited in this way as well as by engine

temperature limits (power) and by maximum torque on the transmissions (also power). While at low density altitudes the engine power is available to over-torque the transmissions (torque limited) or at higher density altitudes the engines hit their maximum power limits measured by temperature before maximum torque can be achieved in the transmissions, you reach a point where the machine is fully loaded. There is no more power available to stop a descent or increase a climb, untangle a hangup or deal with a wind shift. For this reason, big landings are ALWAYS better than small ones because they give a pilot a bigger target that he can more comfortably land maximum turns into without increasing the safety hazards to men and equipment on the landings. The trend has been for years to make smaller and smaller landings due to environmental aversions to moving dirt and it has cost millions of dollars in lost production as well as increase safety risks. No allowance is made these days for operating on no-haul days, which in California for instance, is any day that it might rain on a road, rocked or not!

In the end, as in any business, people are what make the difference. Hookers must be able to estimate the weight of logs and combine them into turns that are ideal for the helicopter at that point in time. They must know cull, grade and rig for ease of lifting. The pilots must be extensively trained in long line operations (fly the helicopter by direct reference to the load, DVOC) and they must know logging. They must be aggressive in their job but always put safety first. Helicopter logging companies have a huge investment in their people, are all very competitive, and have, at times, delighted in stealing employees from each other.

All of the factors above considered, it is the NET weight flown per hour that governs production. It is a constant tradeoff between speed (turn times) and weight (turn size). One can say and be reasonably accurate that the "most efficient" weight for any logging helicopter is 75% of the maximum load allowable at any time. Conditions such as a favorable wind, excellent flight path, nice clean logs and a big landing might make this figure go to 90% as well as the negative factors moving the target the other way. One of the fine "arts" of helicopter logging is the balancing of this equation hour by hour.

Helicopter loggers are paid many different ways, not unlike other loggers. However, with weight being such a critical factor in helilogging, one must pay special attention to two things. First of all, regardless

of how you are getting paid, unless you are being paid by the flight hour, you only get paid for what net material leaves the job on a log truck. You do not get paid for limbs, tops, culls, snow, bark, off species, rootwads and chunks bucked off. Special attention must be paid in the cutting operations to remove everything you can safely remove that will not be paid for. To not do so you are just robbing each turn of payday dollars. Second of all, you must understand the relationship of weight to the many board foot and cubic foot rules that exist in our world. Scribner long log, Scribner Dec C, Doyle, International quarter inch, CCF, JAS and M3 are just a few. What a board foot or a cubic meter might be expected to weigh in a specific area of the world is probably the most closely guarded secret among helicopter logging companies, I know it is in ours. You might have mature but dead Douglas-fir timber one year old that weighs 8 lbs per board foot Scribner Dec C scale on the hook and have the same species in the same area, but 35 year old green Douglas-fir that weighs 14 lbs per board foot. You fly 150,000 lbs per hour on the hook on both jobs and you have 18.75 mbf per hour on the first job and you have 10.71 mbf per hour on the second one. If your helicopter cost is \$2000 per hour the difference in mbf cost would be \$80/mbf. You need to know what you are doing in this business or you will be broke quickly!

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Figure 1. Two Vertols at Peak Sale 2

ABSTRACT ONLY

**INNOVATIONS AND NEW DIRECTIONS IN HELICOPTER LOGGING
IN BRITISH COLUMBIA**

Michelle Dunham

Abstract: During the last 15 years, helicopter logging has become the preferred method of harvesting high-value timber from steep, difficult and environmentally sensitive terrain in Coastal British Columbia. In that time heli-loggers have implemented many innovative practices in ongoing efforts to improve worker safety and value recovery and reduce costs, such as replacing hill crews with grapples, introducing standing-stem harvesting, and developing strategies and equipment for pre-bunching stems to optimize turn weights. This paper reviews some of the key innovations that are now common practice, describes some new initiatives that are currently under development, and discusses issues and challenges that will shape the direction of heli-logging in BC in the years to come. Drawing on examples from FERIC's heli-logging research program, the paper identifies new opportunities for the heli-logging sector and describes how new technologies may help to drive new innovations.

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LONG SPAN SKYLINE LOGGING: PAST APPLICATIONS AND CURRENT NICHE

Robert King

Abstract: Through time the ability to harvest logs has changed dramatically due to the types of equipment that have been developed to handle the logs. Technology has taken log yarders/towers from wooden trees to round telescoping machines and now to the very important skycars. Log loaders have gone from cable to hydraulic machines to log processors. The layout of logging sales has also changed dramatically due to the environmental regulations and the lack of federal timber sales, which has changed the size of available timber. Due to the extreme advancements in equipment and the challenges of the new logging sites, the successful loggers of today have had to be innovative in the way they harvest particular ground, while challenged with the task of making a profit, while facing a variety of individual logging site challenges and business issues. So...why do we do it?

Key words: yarders, loaders, skycars, environmental regulations, employee challenges, harvesting nightmares, eco terrorism, our niche—logger's way of life

Introduction

At Oregon State I was accepted into the Honors English Program, switched to Forestry and Graduated in Business. I guess you could say when I go to buy a Christmas tree, I know how to ask for it with correct English, knowing that I get the species I ask for and that I'm not getting screwed - the price is right.

After graduation, my dad and I bought the logging division of Erskine Lumber Company in Mapleton that would give us three logging sides. I graduated from Oregon State University on a Saturday leaving an atmosphere of parties, girls and good times and the following Monday I was setting chokers in the bottom of a steep hell hole covered in Poison Oak in Mapleton, Oregon where there were no sidewalks and no women that I could see.

What We Bought-How We Started

What we bought were two broke down logging sides with a guarantee of work. The guarantee came with little money and it was tough but we did end up with a side that had a homemade skycar. It was a good idea but not dependable. We only ran it in a shotgun or gravity system since all the yarders were 3 drums, counting the haywire. We struggled to keep junk equipment patched. We finally put a new Madill hoist on the Berger Telescoping tower and got some speed. Then we came up with the idea of gravity logging with a shotgun carriage by using the

haulback for a skidding line. We had to hang a block in a front guyline to hold the skidding line down below the skyline (1 3/8" mainline) What a great improvement over highlead logging. From then on we only did highlead logging when we absolutely had to.

The next thing that happened was the other tower we bought from the mill, with manual friction and brakes on a BU 135 Skagit hoist broke a tooth off a gear and went in between the gears and split the frame in two. It was time—we got our first Slackline yarder, a BU 98 Skagit that allowed us to log across creeks and up the back hillside, using a gravity carriage.

After buying the Skagit from Ross Corp we became pretty close business entities with them. Ross branched out to form a company called Danebo, which began making skycars. We were their guinea pigs, even burning up skylines when their brake clamps would go on or not release. They finally developed a descent car, under our guidance, but you had to have two on the landing to get a day's work in, since one was always broke down. Then a company in Salem, Bowman Industries, came up with a Bowman skycar which really worked well and we just kept buying them. We have 6 skycars today at a cost of \$85,000 each.

The Skagit slackline yarders were great in the kind of wood we logged up to the early '80's, which was Federal Forest Service type wood. The average DBH was 36", 120 year old stands. But with the enactment

of the Clinton Forest Plan, times have changed. The federal forests are basically closed to logging at this time, except for some small thinning sales. We harvest on private lands and we now average 20" and 40-50 year old stands, so we run smaller, faster yarders. We have a TMY 50' tower, 4 TMY 70' towers and a Washington 137 90' tower.

We are versatile, fast and operate with quality control. When we say longspan skyline logging, I'm talking an average of reaching 2400 feet and we have tailholds up to 6000 feet. Why? 1) To get deflection—or lift 2) to get tailholds 3) guyline anchors. 4) to get access to the back end.

The longest we have actually yarded logs was 3700'. We went to smaller swedged skidding line to be able to spool it on the drum. One of the main problems with the long span of 3,000 to 6000 feet—is the time it takes to make road changes—to be able to change the skyline for the next road.)

If possible, we use our tree puller-road changer which is a little Skagit drum set mounted on a 6 wheel drive truck that we get to the backend. In order to set up and use our line changer it sometimes requires going farther to find an access road. Of course the faster the road changes, the better the production. Therefore using the line changer is worth the effort. We have been in situations where there was no access to the get to the backend. The distance is too long, too time consuming and difficult to get the rigging to the backend so sometimes we call a helicopter to make a drop of blocks, straps and haywire to the back end. Then, we make the layout from the back to the bottom, and then string wire from the yarder, (frontside) down to the bottom. Without access to the backend, road changes can take up to 4 hours. With access to the backend it only takes 30 to 40 minutes for a road change, especially if we can get our line puller there.

Bidding Jobs

Figuring out how to bid these jobs gets tougher and tougher. Very seldom to we get to negotiate with the mills, except on very tough jobs where they need our expertise. On an average job, we will bid against 6-8 other companies and if you get the job, you think, "what did I do wrong?"

The prospectus sent to us includes acres, volume, timber type and a map. A good topography map is very helpful. There is but one teacher in this game, and it's experience. To figure \$/day takes a lot into account 1) volume per acre 2) yarding distance 3)

topography 4) whether we are paid per ton or per M (thousand board feet) 5) landing size 6) type of wood 7) chip wood volume 8) tail holds and 9) guy line anchors (10) access to the back end. Some mills send good information, directions to the job and maps and others are not so good. We always figure 1) fall & buck 2) yard and load 3) haul but of course we have to figure all that out ahead of time, before the unit is cut. I'm a lot smarter when the wood is on the ground, but that's after the bid.

Challenges Facing the Contractor On Site

1. Lines

When reaching out so far, everything is crucial. Taking care of the expensive lines is imperative when it comes to handling the rigging—from wrapping the skyline with a rigging chain to send the line to the back end, to checking the eyes of the haywire and the inside eyes of the skyline, to hanging the skyline, to the right amount of bite for the tail, to rendering the line around the stump, to hanging the knock out shackle so it can be knocked out, to standing in the right place for safety when knocking out the pin, all these are crucial to profit or loss and safety or death. It's so important not to run bad lines and to keep line spooling on the drum with no slide off-or pinched wires. If we are on long roads for more than a day, changing position in the top of the tower in the skyline sheave is crucial to prevent it from cutting in two.

2. Equipment Challenges

No Guyline Anchors or Skyline Anchors Tower can Fall at Any Time - Skycar can crash (can't insure)

Due to smaller timber we have become very innovative. Here are two different types of anchors. You can anchor with a cat as the anchor or you can use trees or stumps as anchors.

(Twisters keep tree from being pulled over)

3. Accidents

One major accident can take away a year's profit and devastate the company emotionally and fiscally. Make it hard to get insurance next year. Employees must be in shape. I always tell the men the wives always thank me because their husbands are always in good shape—makes better lovers.

4. Fire Danger

Insurance and Liability

As long as we follow the state guidelines we can be held for up to \$300,000 per incident, going up to \$600,000. But even if the operator is in compliance, it would be difficult to get liability insurance again. However, if the operator is found to not be in compliance, the operator can be responsible for the entire cost, which could easily be in the millions. Even if you have good Inland Marine Insurance, which covers equipment replacement, you could never get them to insure your company again.

Down Time during fire season-

\$4500 per day per side loss

Additional Business Challenges

- Help Hard to Find
Because the mills keep us beat down, we can't offer any higher wages than we do. Safeway makes as much---no risk. The Hispanic workforce is imperative to logging companies.
- Insurance
 - Health Insurance
 - Liability Insurance
 - Worker's Comp Insurance
 - Inland Marine Insurance
- Mills-No guarantee of work - no future financial guarantee for business planning
- Contract Administrators
- Government Regulations
 - OSHA, worst enemy
 - Red Tape-Tailholds on US lands, buffers,
- Private Landowner Challenges
- Environmental Restrictions
- Taxes
- Eco-terrorism

Our Niche

- Our reputation
- Experienced

- Versatile
- Long Span
- Ability to figure out the way to tackle a difficult job
- Ability to work with the public (private landowners, homes)
- Ability to Communicate with the mills, media,
- Understanding the importance of community involvement
- Ability to be involved in the legislative process, promote forestry education
- Ability to lobby against ridiculous environmental issues and promote multiple use of our forests.

Why Do We Do It

- 1) Logging is a way of life—It's in the blood. It's not for everyone.
- 2) Need for the product is always going to be there. We use of 7000 products that come from trees in our daily lives.
- 3) Finally weeding out the hobby loggers/ Non-businessmen
- 4) Clearcut to grow more trees
 - Reforestation: 5-7 trees replanted for every tree harvested
 - Sun to Grow
 - Foraging Animals
 - Economics
 - Sustained Yield

Day in the Life of a Logger

3:30am Call from Police –Two of our Hispanics were picked up by the new California import City Cop while waiting for the crummy to pick them up. No ID—No Speak English except to say they work for Bobby King.

4:30am Call from Hooktender on one side - forgot his talkie tooters. Go to house - Go to garage to get them like he told me. "Freeze or I'll Shoot" - turn around to see wife with her shotgun.

6:00am Get to the woods with Talkie Tooters. The shovel wouldn't start

7:45am Get the shovel going

8:00am Get call from other side. Pulled tailhold (pulled big old growth stump). Dropped the skycar. Have to make whole new layout 3000' out.

Fortunately had 6 extra sections of haywire in the back end.

10:30am New layout made - run the car into the landing - major damage - hit stump. Estimated damage \$40,000. Happen to have another one off another side to switch over to.

2:30pm Back to working with the spare skycar

3:30pm Back at the office. Get a call from mechanic. He is going to work for the mill we log for. Giving 2 week notice as if we can come up with a a key mechanic in that amount of time.

4:30pm Crew comes in to the shop - office. Had safety inspection from OSHA. His opening statement was "I used to be a hooktender for XL Logging - used to be one of you. Now I'm your worst enemy." He then proceeds to write a citation for too much wear on the inside of a shackle. A guard on the yarder was loose with only 2 bolts missing.

5:00pm Fax comes in from the mill. I was second again on a job I bid the day before. That makes 8 jobs I bid in 2 months which took days to prepare each bid - didn't get any of them. My competition which is on COD all over and has no insurance for his men - he got the job.

6:00pm Heading home - feeling down. Get a call on my cell phone - "Grandpa - We won our game. I got 8 points." I'll make it another day.

Conclusion

If people knew that we ride 1- 2 hours to work one way every day, that we fight the rain, wind, cold, snow and heat all year long, that we run up and down steep mountains all day - that logs are round and the ground is steep - logs roll - Cables are above our heads along with sky cars every single minute and that our lives are in danger every minute of every day - they should be thanking us - not saying "you are raping the ground" and certainly giving us the respect we deserve while risking our lives - all this to provide over 7000 products that they use in their daily lives and can't live without.

Remember these two things: Clear Cut and Sustained Yield

I'm proud to be a logger
"Log Em or Loose Em"

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FROM OFF-ROAD TO ON-ROAD HARVESTING IN STEEP TERRAIN IN NORWAY (CAN CREW EXPENSES BE REDUCED WITH NEW SYSTEM?)

Morten Nitteberg

Abstract: In Norway, considerable areas of mature forest are located in steep and difficult terrain. In 1990 almost 10 % of the annual cut in Norway was harvested in steep terrain, and a large share of this was harvested with cable logging systems. Today, only 1% of the annual cut is harvested with cable logging, and there are only a few contractors left. The annual increment is 25 million m³, but we only harvest about 10 million m³. The Norwegian government has developed a national strategy to increase the annual cut. This implies an increase in steep terrain harvesting.

Today, Norwegian cable logging systems use an off-road vehicle (forwarder) as the base machine for the cable crane, and commonly a second-hand harvester and forwarder. This system requires 5 workers' and the delay times are large owing to frequent maintenance and repair of the old machines.

Recently, a contractor purchased a Mounity cable crane system from Austria. The system is mounted on a 6WD truck and has a harvester on a boom mounted on the tower. The system uses a fixed skyline and yards uphill and downhill. A self-driving carriage is used when downhill yarding.

The total costs of wages are low for this system because only 3 workers are required. Costs for moving the equipment are also low as the truck moves along established forest and public roads, compared to previous systems where three forest machines had to be moved by truck with trailer. A drawback of the on-road system is that many harvesting sites have no road access or only access on roads with low standard. In these cases road construction and upgrade costs are a challenge.

This paper reports the results of long-term productivity studies. Detailed time studies have been conducted and the result of these are also presented. When compared to off-road cable logging systems the following results were obtained with the new system:

- Increased profitability of cable logging operations
- Reduced operating cost.
- Reduced need for workers
- Higher flexibility

Key words: Cable logging, steep terrain, operating cost, Mounity 4000, time studies, harvesting, productivity

Introduction

In Norway the annual cut is almost 10 million m³ and has been relatively stable since the beginning of last century. At the same time the annual increment has increased from 10 to 25 million m³. The Norwegian government has implemented a national strategy for increased cutting. Since a large part of the mature forest in Norway is located in steep and difficult terrain, this implies increased harvesting in these areas. In the coastal areas of the western part of

Norway there is a especially high share of mature forest located in mountainous areas. More than 30 % off the mature forest grow in terrain that is steeper than 40%.

In the beginning of the 1990's about 700 000 m³ per year was cut in steep and difficult terrain. A large part of this was forwarded by cableway. In recent years the activity in steep-terrain harvesting has decreased, and the main reason being poor profitability in cableway harvesting owing to low timber prices, and high wages and high operating

costs. Generally in Norway the cost increase has been high, and wages are higher than in rest of the Europe.

The objectives of this paper are to compare the productivity and profitability of on-road cable logging systems to off-road systems.

Off-Road Harvesting in Steep Terrain

Traditional cable logging systems in Norway is off-road. The most common system is a cable crane with running skyline, built on a second-hand forwarder. In addition to the cable crane a harvester to process the stem is needed. All harvesting in Norway use Cut-To-Length (CTL) systems and timber trucks for long logs are not used. Since the cable crane is working off-road a forwarder is necessary to forward the logs to an accessible landing for the timber trucks. Figure 1 shows an Owren 400 cable crane, a harvester and a forwarder in an off-road operation.



Figure 1: Traditional off-road cable logging system in Norway

To keep the investments low, it is most common to buy a second-hand harvester and forwarder. The disadvantage with this system is the need of many workers. This system needs 4 to 5 workers:

- one feller,
- one choker setter,
- one cable crane operator
- one harvester operator
- one forwarder operator.

Some times one worker will operate both the harvester and forwarder, for example when forwarding is short range. The productivity of this system has been measured as 43 m³/day using statistics from 4651 m³ on a forwarder-mounted cable crane (Nitteberg and Lileng 2004). Since the wages are generally high in Norway, it is important

to minimize the number of workers. The operating cost is relatively high because the use of second-hand machines. A lot of time is used for repairing old machines, which negatively affects productivity.

On-Road Harvesting in Steep Terrain

In 2004 a contractor operating on the west coast of Norway purchased a truck-mounted cable crane system, the MOUNTY 4000 from KONRAD Forsttechnik in Austria. This system is built on a 6WD Man truck and powered by a 400 bhp diesel engine. The cable crane is a standing skyline system primarily built for uphill yarding, and use a Liftliner carriage. The carriage is powered with an Iweco diesel engine, which operate a hydraulic pump and motor. The hydraulic system operates the skidding line drum. For downhill yarding a WOODLINER 3000 self-driving carriage is used. This carriage is in principle the same carriage as the Liftliner, but has in addition pulleys for propulsion. The skidding line can be driven at the same time as winching. The whole system is automated and radio controlled, which means that all functions are operating from a portable panel either by the machine operator or by the choker setter in the field. The machine has a working platform with tooth on the edge. The load is placed on this edge. Therefore the operator does not need to leave the machine to unhook the load. Figure 2 shows the MOUNTY 4000 with processor.



Figure 2: On-road system with MOUNTY 4000 cable crane.

Only three workers are needed too operate the cable crane system:

- one machine operator who unhooks the load and operates the harvesting head
- one choker setter
- one manual feller

After unhooking the load, the operator uses the harvesting head to process the stem and to place the logs in short-term storage in close proximity to the machine. Since the system is mounted on a truck and is operating on-road there is no need for a forwarder. The timber truck can load the logs directly from the short-term storage. Normally it is possible to store about 100 m³ in the area surrounding the machine. Figure 2 shows the Mounty 4000 and the timber truck loading logs.



Figure 3. On-road system Mounty 4000, and timber truck.

Results After Two Years Operation

Norwegian Forest and Landscape Institute (NFLI) has during one year recorded operating statistics from the system and conducted time studies.

The machine operator recorded working time, meals, terrain conditions, weather, slope, yarding up or down, strip length and number of loads, number of trees and m³/shift. All delay times as repair and maintenance were recorded. Time for rigging and moving between logging areas was also recorded. During this period the cable crane produced 13,690 m³ distributed over 331 shifts. The average shift length was 10 hours. The average productivity was 41 m³/shift. These results reflect the first year of operation and the crew was not experienced. Normally the system operates one shift each day, but in a short period during the summer two shifts per day were used. The average stem size was 0.42m³ and average load size when winching was 1.03m³. Average volume harvested on each logging site was 622 m³, and the cable crane moved between logging sites 22 times. There was a distinct difference between uphill and downhill yarding. The productivity was 20% higher when uphill yarding. This was due mainly to the shorter rigging time for uphill yarding because fewer corridors required

intermediate supports. In the downhill yarding, 60% of the corridors required rigging intermediate supports, while only 22% of uphill corridors required intermediate supports. Most of the harvesting areas were located in coastal areas. In these areas the snow is scarce so reduced productivity owing to snow was not an issue. There were only 42 shifts with snow on the ground, and only 4 of these had more than 20 cm snow depth.

Time studies were carried out at three harvesting sites, where yarding and processing was studied. The studies were performance studies which is a form of work study aimed at quantifying the output per time unit. The studies were carried out by two men. One studied the winching operation and the other studied the processing. All sub-operation times were collected by field computers. Numbers of trees in load, DBH, yarding distance and number of logs processed were entered. The main types of wood were Norway spruce. Standing volume was 580, 840 and 1100 m³/ha. The steepness varied from 60 to 80%. A total of 331 loads were studied and the results from the three time studies show that productivity varied from 7.5 to 10.7 m³/hour. Average load size was 1.45 m³. Figure 4 shows the productivity for different winching distances.

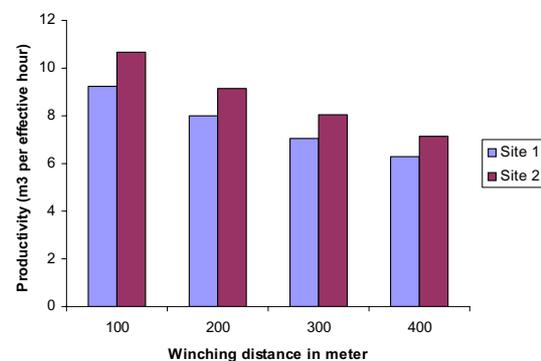


Figure 4. The productivity for different winching distances for the two sites.

Practical Challenges and Economic Advantages

There are some challenges to overcome with the on-road system. One important challenge is finding logging sites which have satisfactory road access. This challenge is especially important in coastal areas on the west coast of Norway, where the roads mainly have been built in the lower part of the mountain slope. The system has been operating almost two years now, and for the time being, the access to

logging sites has been good. This is because of high interest from the local forest owner association and county governor representatives which organized the operation. Since the knuckle boom loader normally is mounted in back of the truck (between truck and hanger) the truck had to leave the hanger on a suitable place like a crossroad or turnaround, and then drive the timber truck to the logging site and turn the truck and back into the landing. If this system is to become the leading system for the future, the forest industry and public authorities must prepare for increased road construction in these areas. When building new and upgrading old forest truck roads it is important to plan for turnarounds and landings for future systems and methods. Road construction is, in general, controversial from an environmental point of view, but with skillful planning it is possible to access a large quantity of timber for cable logging. Cable logging is the most environment friendly and economically defensible logging method in steep terrain owing to almost no tracks after operation and no erosion problem. High wages and operating cost has been the main reason for poor profitability in cable logging operations. Existing off-road cable logging systems use an off-road base machine in addition to a harvester and a forwarder. This system has high wages and operating costs. The old age of the machines leads to high delay times, due to leakage in the hydraulic systems and component breakage.

The Mounty system has only one machine with one engine, fewer hydraulic components and hoses, which reduce the costs of maintenance and repairs. The moving cost is another important advantage for the on-road system. When the equipment is rigged down, and loaded on the base machine, the truck is driving on private and public roads to next logging site. This system is not dependent on transport with low-bed trailer and is therefore very flexible and can move over large areas in a short time, with low expenses.

When comparing the productivity of the two systems only minor differences are found. Practice shows that the off-road system with forwarder mounted cable crane has somewhat higher productivity. This can be explained by the differences in yarding system. The running skyline system has higher productivity when downhill yarding, mainly because the rigging time is shorter than the standing skyline system. The difference is the operating expenses. The on-road system, using only one machine and 3 workers, has productivity similar to the off-road system using three machines and five workers. Since the off-road system has higher operational costs, it needs to have a higher production to obtain identical profitability. Assuming the price of each operation is identical, the off-road system had to produce 2 m³ per hour more than the on-road system to achieve the same economic result. The reason for this is higher operational costs per hour for the off-road system. It would be interesting to build the same machine system with a running skyline, but this requires development of an automatic remote system for running skylines. Such a system can give even better profitability because of somewhat higher productivity owing to reduced rigging time.

Literature Cited

Nitteberg, M. and J. Lileng. 2004. Mechanized harvesting in steep terrain. Report 8.04 Norwegian Forest Research Institute. 24p. (In Norwegian: Mekanisert hogst i bratt terreng)

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ABSTRACT ONLY

A CONTRACTOR'S PERSPECTIVE ON SKYLINE THINNING EQUIPMENT AND LOGGING INNOVATIONS

Pete Bailey

Abstract: A shift in the forest resource and timber management philosophy, both on private and public land in Oregon, has resulted in a need for skyline thinning operations. Thinning with skyline systems requires more planning, in terms of safety considerations, harvest unit layout, and operation scheduling due to site specific environmental harvest restrictions. Equipment versatility, where equipment has several different functions within the operation, is a critical facet for successful thinning. Small yarders and carriages with multi-span capabilities are necessary for most thinning units. The most critical factor for corridor layout in thinning is the straightness required, increasing the time spent laying out corridors. Straight corridors will reduce rigging complications and associated down-time for the operation. Layout is even more critical for multi-span corridors, requiring that the rigging for tailtrees and intermediate supports line up perfectly with the yarder. Obtaining guy stumps in the proper safety zones can be a limiting factor for any lift-obtaining aspect. Corridor layout should begin at this critical point and progress in the necessary direction(s). Multi-span skyline thinning is a beneficial tool for any forest manager or forest contractor. Although this application requires additional knowledge and experience, multi-span systems can be successful if planned correctly.

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NEW SKYLINE LOGGING TECHNOLOGY FOR YARDING AND TREE PROCESSING WITH A TWO PERSON CREW

Martin Fischbacher, Martin Mairhofer

Abstract: An economic way of timber harvesting is one of the most important factors to remain competitive. The technology offered by Koller GmbH contributes to a more efficient work. New techniques provide a safer environment for a two person crew. These techniques are described in the following paper.

Introduction

In recent years an increase in timber production has been obtained that has affected the entire branch of the timber industry. The topic discussed in this paper is the technology of a mobile tower yarder combined with a processor head. This combination is operated by a two person crew. Important economical and geographical aspects are described and discussed.

Basic Information

The existing majority of European manufactured mobile tower yarders belong to the category of standing skyline with motorized slack-pulling carriage. For over 10 years, motorized slack pulling carriages have been manufactured at Koller. The combined version of a tower yarder and a processor head have been produced since 1995. These techniques have been tested and optimized by Koller GmbH.

The result of this development is demonstrated in the product the “Mountainharvester K507”. The system uses a standing skyline system with a motorized slack-pulling carriage (Fig 1).

An advantage of this method results from the good efficiency for harvesting small wood quantities, as used in thinning and overstory removal in protection forests and small clear cuts.

These result to a large extent from the silvicultural measures which are practiced in Europe; moreover cable logging has a major advantage of more sensitive care of forest soil.



Figure 1: General picture for the Koller K507 in downhill operation



Figure 2: General picture for the Koller K507



Figure 3: General picture for the Koller K507 in downhill operation



Figure 4: General picture for the Koller K507

Geographical, Economical and Environmental General Set-up

The reason for the development of this machine results primarily from basic geographical conditions.

Forest roads in Austria are very expensive to construction. Moreover the problem of small storage possibilities is by-passed by a good infrastructure of wood processing companies.

In Austria there are about 1774 wood processing companies and about 20 million cubic meters are processed per year. In Alpine regions avalanches and mudflows are a present danger. Thus protection forests are mandatory and the care of protection forests is of great importance.

The small wood quantities which are harvested from the overstory and the necessity to leave the sensitive soil intact are two more reasons for developing this machine.

Due to geographical reasons in Austria uphill logging cannot always be realized.

From the view of economy further advantages result from this machine. Therefore the following parameters are important: Labor cost, fuel costs, and productivity and wood prices.

Closer interpretations result from the explanation of the technology which is illustrated further down the paper.

The environmental criteria results particularly from the protection forest problem which has already been discussed.

The main focus is that only a small quantity of timber may be harvested. The highest maxim for such a mode of operation must thus be economy!

A further point is the sustainable forest base for forest harvesting. Forests occupy about 47% of the surface area of Austria. Approximately 30 million cubic meters are grown annually. The harvested quantity however amounts to only 20 million cubic meters. Sustainable management in Austria has been practiced for more than 200 years. The first law for sustainable silviculture was legislated in the 16th century. Mining had caused exhaustive cultivation.

K507 Mountainharvester

The K507 Mountainharvester is a combination of tower yarder and a crane with processor head. This combination is mounted on an all-wheel driven truck with four axles. All components are powered by the truck engine.

Through this combination and its innovative control it is possible to accomplish harvesting, followed by processing and sorting with a 2 person crew only.

With this extremely compact and flexible machinery it is possible to meet the requirements of the forest transport network, which contains narrow, small turning radii and poorly maintained roads.

The tower yarder is powered by the truck engine with approximately 480 HP. The winches are powered hydrostatically and are controlled by Koller Multi-MatiK which also accesses through CAN-Bus, the diesel engine control. A colored display serves as operating surface and represents all relevant machine data (See Fig. 5).



Figure 5: The KollerMultiMatiK control with a colored display

Moreover error messages are displayed on the display. The operating surface is graphically programmed, whereby for the operator a simple and ergonomic operation is made possible. The assembly of the tower yarder at the operating location is setting new benchmarks. New assembling tools have been developed such as radio control for all winch operations as well as a separate radio for secondary functions at the ground equipment. Simplified and rationalized, it is also possible for a small team of two persons to accomplish the rigging of the total machine and corridor.

Radio control:

The tower yarder has a very efficient radio system with frequency of 433 MHz and 1000 meters range which also controls the winches and motorized slack-pulling carriage. The radio control contains two hand radio transmitters and a transmitter which is located at the top of the tower. The hand transmitters are operated through a multifunction joystick (See Fig. 8). One transmitter is carried by the choker setter and the other one is left in the cab at the tower yarder. It is only used for rigging operations, or if there is an additional excavator with a processor head, the operator can also carry it with him to control the tower yarder from the cab of the excavator (See Fig. 6).



Figure 6: The Koller K507 with separate excavator processor

On these transmitters are keys to control the MSP carriage, automatic distance operation and an analog joystick for a stepless control of the winches (See Fig. 7).



Figure 7: The choker setter with transmitter



Figure 8: Multifunctional joysticks for processor and yarder

For safety reason only one transmitter at the same time is able to operate. Through a button on the transmitter the control is transferred to the second operator. The joystick is able to operate uphill as well as downhill. The haul back line and the main line are synchronized by pressure and speed measuring devices. While the haul in operation the system operates with the main line only given that the motorized slack- pulling carriage with motorized slack pulling takes action. The hoists are equipped with a cable slack locking feature whereby loose ropes can be avoided.

Range programming:

The range programming is a fully automotive system whereby the motorized slack- pulling carriage moves along the skyline automatically. This makes it easy for the crew to concentrate on the main duties.

When starting the range programming, the motorized slack-pulling carriage is positioned at a point about 20 meters before the landing ramp. On the display, the starting point is then set and the other parts along the corridor can be programmed by running down the skyline corridor manually. If there are intermediate supports or other critical objects located along the skyline changes in speed can be programmed.

These programmed areas can be user defined in length and speed which are fitted to the kind of object. At the end of the skyline a target location is programmed where the first turn is located. This is also the target point and declares the end of the programmed automatic outhaul. This finishing point automatically moves along with the new carriage positions that are created as the work goes on. If the range programming is completed, the automatic run can be started. The speed for empty and loaded run can be adjusted any time from each operator by radio.

Description of an Operating Cycle:

An operating cycle is described as follows:

1. Start of the automotive outhaul by a keystroke of the operator. The motorized slack-pulling carriage runs down the programmed passage and slows down between the programmed areas where a slow approach is necessary. The motorized slack-pulling carriage then stops at the programmed target point. After the operator in the cabin has transferred the control to the choker setter he is able to concentrate fully on his work with the processor.
2. As soon as the motorized slack-pulling carriage arrives at the target point the choker setter positions the motorized slack-pulling carriage above the log pickup point. The mainline clamp is closed and the spool out operation is started. The motorized slack-pulling carriage spools out the mainline which is synchronously spooled out by the tower yarder. By another key press the slack-pulling is stopped again.
3. After hooking the turn, the load is broken out by the choker setter sensitively. After lateral yarding the skyline clamp is released again.
4. The automatic inhaul starts through a key press and the control is transferred to the operator in the cabin. From that point on the choker setter is able to prepare additional loads.
5. The motorized slack-pulling carriage runs along the programmed distance and stops at the starting point again.
6. Meanwhile the operator has processed the previous load and is ready to move on. The motorized slack-pulling carriage is pulled into the end position and the trees lowered onto the landing ramp. The landing ramp has teeth which prevent logs from slipping.
7. The radio controlled chokers are released by the operator in the cabin.

8. After lifting the chokers and opening the skyline clamp the cycle starts over again.

Safety Features of the System and the Machine

- Radio control
 - o Only one person has the control over tower yarder and carriage. Ideally everybody at his working area.
 - o The choker setter decides when and how fast the turn is broken out. He is the man who has it in his view. The choker setter now is an operator. The precision is higher, for example the positioning of the carriage. Actually the machinist (upper operator) wouldn't have time to do the winch operations because he is busy processing the trees until the carriage is back again with the next load.
 - o If the choker setter sees a danger by spinning trees or other reasons then he just has to let the joystick go and all the winches are stopped. The use of communication or signals would be too late in some situations.
 - o The choker setter does not activate the automatic drive not until he feels safe. Then he has to pass the control.
 - o Motorized slack pulling carriages are used for uphill and downhill logging. These carriages allow the choker setter to work alone because does not get exhausted as much as if he has to pull hundreds of meters wire rope during the whole day. Less loss of concentration due to exhaustion can be prevented.
- Adjustable overload shut-down at automatic drive
- Maximum force in the mainline can be adjusted
- The use of Radio Controlled Chokers, minimize the dangers by unloading
- Electronic monitoring system for the whole machine to protect against machine breaks. (Truck, Hydraulic, ...)
- Cable break protection at the carriage with emergency clamping
- Emergency skyline drop down by radio control

Economic Aspects:

- Low personnel costs, only two persons are necessary
- High production at minimum personnel cost
- Short rigging times furthered by the rigging functions
- Less time to drive the K507 from one point to the other, because the tower yarder and harvester head is mounted on one truck.

- Less fuel consumption. Only one diesel engine powers the whole system.
- Less maintenance cost. One engine, one hydraulic-system and one truck have to be maintained.

Technique in Detail:

The K507 Mountainharvester:

Maximum length:	12.7 m (41.5 ft)
Height:	4.0 m (13.1 ft)
Width:	2.5 m (8.2 ft)
Weight:	33500kg(73,855 lbs)

Truck:

4 axle MAN Truck
480 HP
All wheel drive

Tower yarder:

Tower height: 11.5 m (37.7 ft)
2 main winches: each 1400m (4592 ft) cable,
Diameter 11mm (7/16") swaged, 43 kN
(9500lbs) line pull at average drum diameter.

Skyline winch:

1000m(3279 ft) cable,
Diameter 20mm(3/4") swaged, or 24mm
(1") with a length of 530m (1740 ft), 120kN
(26455 lbs) line pull in the tension section.

Rigging winch: 1600m (5250 ft),

Diameter 6mm (1/4")
4 guylines powered by a hydraulic winch
and going up inside the tower

Carriage MSK3 (Fig. 9):

Motorized slack pulling carriage
Powered by a 7.5 HP Diesel engine
Slack pulling force up to 6 kN (1300 lbs)
Weight: 690 kg (1521 lbs)



Fig. 9: Motorized slack- pulling carriage MSK 3

Crane:

Lifting torque: 260kNm (190 klbf ft)
Range 9.2m (30 feet)

Harvester head:

Within upward folding forward-feeding function.
The processed logs can be moved easily on the timber yard.
Maximum log diameter 0.6 m (24 ")

Landing Ramp:

For secure holding of the trees until they are processed with the harvester head (Fig. 10)
The landing ramp is also a cover for the truck chassis. On the front end of the ramp are mounted teeth to keep the trees from slipping away.



Fig. 10: Landing ramp and Processor

Radio controlled Chokers:

Radio chokers from Johnson Industries Ltd. are used. They save 10 – 20% extra time.

Economic Facts:

- Average wood rate per line is between 300 and 400 cubic meters. (127,000 up to 169,510 board feet)
- Generally fir and larch are harvested in the dimension of 1.5 to 4 cubic meter (640 up to 1,700 board feet) per tree
- Average skyline length 450 m (1470 ft)
- Average number of jacks is 2
- The division is:
 - 70% 3- cable downhill operation
 - 30% 2- cable uphill operation
- Fuel consumption: 1 cubic meter wood needs about 1 liter diesel (with 1 gallon, 1630 board feet can be logged)
- Daily production rate is about 100 to 200 cubic meters. This is 3 to 6 truckloads. (Fig. 11)

Utilization:

- o 70% Logging
- o 24% Rig up and take down
- o 6% Trucking

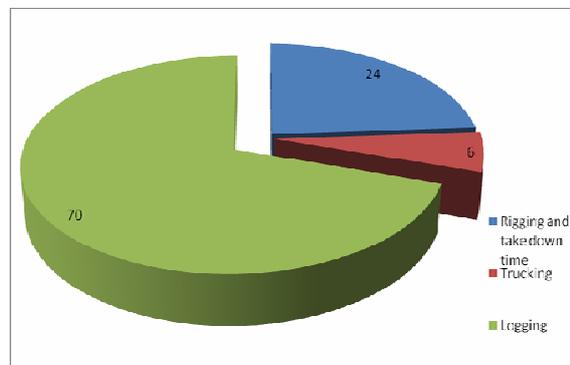


Fig. 11: Time management

Result:

Economy is the basic demand that can be covered optimally with the K507 mountain harvester. The use of radio control and range programming allows running the system by a two-man crew with a high safety standard.

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COMPARISON OF INTEGRATED WITH CONVENTIONAL HARVESTER-FORWARDER-CONCEPTS IN THINNING OPERATIONS

Günter Affenzeller, Karl Stampfer

Abstract: Due to the structure of forest ownership and silvicultural treatment strategies in Austria, those harvesting systems which can work efficiently with small harvesting volumes per operation area are of great significance. Major advantages of integrated harvester-forwarder concepts are transportation costs, which are significantly lower than those of conventional two-machine systems (TWIN concept). At present approximately 160 combined machines are operating in Germany, Austria and Scandinavia. They represent two different concepts of the operation method (COMBI and DUAL). As part of this study, a productivity model for the Ponsse Buffalo Dual was developed on the basis of empirical research. Furthermore, recommendations regarding maximum harvesting volume per operation area depending on relocation distance were derived. For the felling/bucking operation the model, including tree processing and travel, was based on 1,073 trees with an average tree volume of 0.31 m³. The model for the forwarding operation, including loading, travel and unloading, was based on 40 loads with an average volume of 8.26 m³ per load, an average piece volume of 0.093 m³ and an average extraction distance of 170 m. The study provides total productivity for felling, processing and extraction of 5.12 m³/PSH₁₅. The savings of relocation costs result in a cost advantage of the DUAL in comparison with the TWIN concept up to a harvesting volume of 120 m³ per operation area.

Key words: Dual, Combi, harvesting small volumes, harwarder, relocation

Introduction

According to the Austrian forest inventory 2000/02 there is a considerable backlog of thinning operations. The small scale owner structure leads to small harvesting volumes per operation area. Natural disasters such as wind-throw, snow-break or bark beetle might also create situations where a small volume of timber needs to be harvested. A large part of that stock is located on slopes which can be managed full mechanized.

Harvester and forwarder (concept TWIN) incur high costs due to equipment location and relocation of the two machines, especially when harvesting small volumes. In order to operate cost efficiently the harvesting volume per area has to increase or relocation costs have to be reduced. Considering the small scale structure of the Austrian forests, cooperation might increase the harvesting volume per operation area. The technical approach is to use a harwarder (COMBI) or a combined harvester-forwarder (DUAL) with the ability to do the felling/bucking operation as well as the forwarding operation. By using just one machine relocation, costs can be reduced significantly. While several studies into the COMBI system have already been

conducted (e.g. Bodelschwingh 2003), the DUAL concept has not as yet been investigated.

The aim of this study is to explain the difference in work procedure and to compare productivity and costs between the COMBI, DUAL and TWIN concepts. Hence an empirical time study of the Ponsse Buffalo Dual has been conducted to answer questions as to productivity and costs in felling/bucking and forwarding operations. Another goal is to determine the impact of relocation distance on relocation costs in order to derive application recommendations for the integrated harvester-forwarder-systems in relation to the TWIN concept.

(Integrated) Harvester Forwarder Concepts

COMBI concept

The explanation of the construction characteristics of the COMBI concept is based on the harwarder model Valmet Combi 801. The majority of the harwarder components are already standard equipment and can be found in serial models of harvesters and forwarders. The rotate-able (540 °) crane-cabin combination as well as the rotate- and tilt-able load

carrier can be considered as special constructions (Bodelschwingh, 2003). A further characteristic is the aggregate, which is similar to a common harvester aggregate, where just two grapple arms are added. In order to facilitate the un- and uploading process the delimiting knives can be stowed away hydraulically.

Because of the rotate- and tilt-able load carrier it is possible to process trees directly onto it. Felling,

processing and extraction take place in one continuous process. In thinning the strip road can be entered load carrier first. If there is as yet no strip road, the operation starts with felling the trees within the strip road first. In the opposite direction the trees on the left and the right hand side of the strip road will be felled, processed and loaded (Figure 1: Graphic representation COMBI concept).

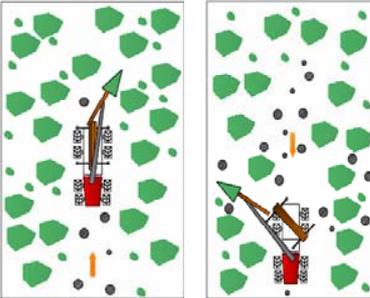
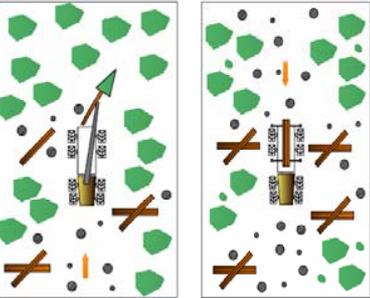
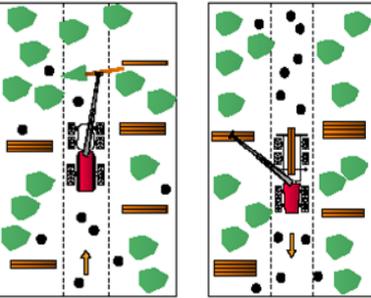
Concept COMBI	Concept DUAL	Concept TWIN
 <p style="text-align: center; font-size: small;">photo: Komatsu Forest</p>	 <p style="text-align: center; font-size: small;">photo: Steinmüller</p>	 <p style="text-align: center; font-size: small;">photo: Odenwaldholz</p>
<p>technique tilt and rotatable load carrier, combined aggregat</p> <p>working pattern felling, processing and extraction takes place in one continous process</p>	<p>technique load carrier can be uncoupled by the grapple; the grapple can be exchanged by a special clutch with the harvester head or vice versa</p> <p>working pattern first like a harvester - after exchange process like a forwarder</p>	<p>technique Two-machine-system each with special components (grapple, harvesterhead)</p> <p>working pattern harvester fells, bucks and deposits the logs in a pre-concentrated way. The forwarder loads the logs in a second separate operation, starting at the top of the slope</p>
 <p style="text-align: center; font-size: x-small;">Graphic representation concept COMBI</p>	 <p style="text-align: center; font-size: x-small;">Graphic representation concept DUAL</p>	 <p style="text-align: center; font-size: x-small;">Graphic representation concept TWIN</p>

Figure 1. Harvester-Forwarder-Concepts (Affenzeller and Holzleitner)

DUAL Concept

The following explanation of the construction characteristics of the DUAL concept is based on the harvester-forwarder model Ponsse Buffalo Dual. The standard configuration of the Dual is based on the forwarder Ponsse Buffalo. It is equipped with a robust crane and a powerful hydraulic pump (Ponsse, 2002). Unlike the COMBI concept, the Dual can be converted by uncoupling the load carrier and by replacing the grapple with the harvester head (Figure 1: photo concept DUAL). Due to a quick release coupling this works also vice versa and takes about 15 minutes.

Processing and extraction take place as in usual harvester and forwarder operations in two separate specialized phases (Figure 1: Graphic representation concept DUAL).

TWIN Concept

The TWIN concept involves two different operating machines, thus they are not considered as integrated machines. Felling and bucking are done by a harvester. After the harvester operation the logging operation is carried out by a forwarder (Figure 1: Graphic representation TWIN concept). Each of the machines is equipped with special components. The components are not meant to be exchanged with each other.

Operating Machines

In 2005 approximately 160 combined machines were operating in Germany, Austria and Scandinavia. A rough overview of the distribution of the different harvester-models and the combined machines is given in Table 1. With about 85 units, the company Ponsse contributes the majority of the machines (Wagner 2005).

Table 1. Numbers of integrated harvester-forwarder-systems in AUT, GER, SWE and FIN (2005)

Producer	Austria	Germany	Finland	Sweden	Total
Ponsse	1	4	30	50	85
Valmet	--	2	15	8	25
Pika	n.s.	n.s.		20	20
Hemek	n.s.	n.s.		5	5
Moipu	0	0	10	n.s.	10
Sonstige	n.s.	n.s.	15		15
					Σ160

Material and Methods

Before the time study was conducted, the stand and tree characteristics were measured (dbh, height, slope angle). In addition, the heights of all removed trees were estimated by adding up the length of the logs and the length of the treetops. The harvested trees were sorted into saw logs and pulpwood. The time studies were conducted for felling/bucking operation and for the forwarding operation. The time was recorded using the electronic time consumption tool, LATSCHBACHER EG 20. The felling/bucking operation was split into 5 work phases (Figure 2). The forwarding operation was split into 7 work phases (Figure 3). For the forwarding operation of the Ponsse Buffalo Dual a forwarder model was developed. Therefore approximately 20% of all pieces were measured and an average volume for each assortment was calculated. Furthermore, the number of all pieces per load was counted and multiplied with the respective average assortment volume. In this manner each load volume was determined.

Possible influencing parameters were estimated for the harvester model and for the forwarder model and were determined by variance analysis. The regression analysis supplied the estimated coefficients for the respective parameters. The harvester model consists of a model for travel and for processing. The forwarder model is divided into a model for loading, a model for unloading and a model for travel. This statistical analysis was carried out using the software package SPSS 12.0. Delays less than 15 minutes were taken into account using the correction factor

($K=1.3$) taken from the literature (Stampfer 2002). By adding up the efficiency for the harvesting and the forwarding operations, a total system efficiency and, subsequently, a total system productivity could be generated. Cost calculation was carried out according to the FAO standard scheme. The utilisation per year was assumed at 1500 PMH15 and 2000 PMH15 per year respectively. However, in this case study, disproportionate results for productivity of the DUAL resulted so for subsequent calculations the data of the latest productivity studies conducted by Eberhardinger and Pausch (2006) were used. The data for comparisons of costs and productivity of the COMBI originate from the studies of Bodelschwingh (2003). The productivity data for the TWIN were chosen according to the results of the studies of Bodelschwingh (2003) and Eberhardinger and Pausch (2006). The relocation cost model by Friedl et al. (2004) is used for the relocation cost simulation. Friedl calculates 70 € per hour for a flat bed truck and an average driving speed of 55 km/h. Loading and unloading take 0.3 hours each. Journey time between sites is assumed to take 0.75 hours.

Results

The study of the Ponsse Buffalo Dual was conducted in Styria (a province in the south-east of Austria) in a 100 year old spruce dominated stand. The terrain had a 10 % slope and thirty percent of the stock was removed. The time distribution, by percent, for each phase, is shown in Figure 2 and in Figure 3. For the harvester model, 1073 harvested trees were recorded, for the forwarder model 40 loads were taken into account. A total volume of 330 m³ (all volumes under bark) was harvested. An average of 2.1 trees was removed per stop with an average tree volume of 0.31 m³. The average extraction distance was 170 m, and the average piece volume was 0.093 m³. The mean load volume constituted 8.26 m³. The observed productivity for the felling and bucking operation was 9.1 m³ per Productive System Hour including delays less than 15 minutes (PSH15) (Figure 4) and for the forwarding operation 11.7 m³ per PSH15 (Figure 5). Overall the Ponsse Buffalo Dual achieved a total system productivity of 5.12 m³ per PSH15 in the thinning operation. One reason for this below average performance might be the lack of experience of the young machine operator.

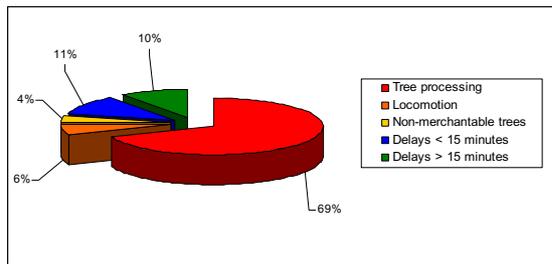


Figure 2. Time distribution for the work phases of the felling/bucking operation

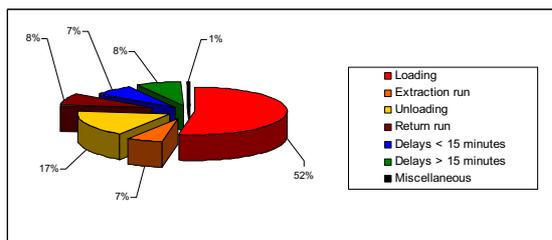


Figure 3. Time distribution for the work phases of the forwarding operation

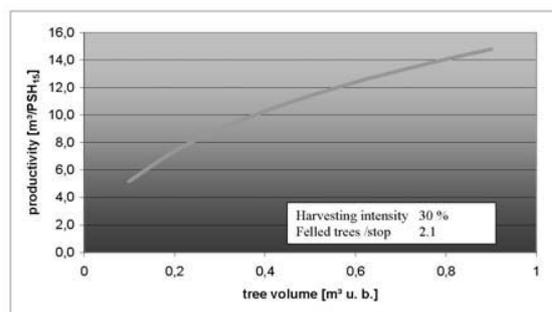


Figure 4. Productivity for the felling/bucking operation, Ponsse Buffalo Dual (k-factor 1.3)

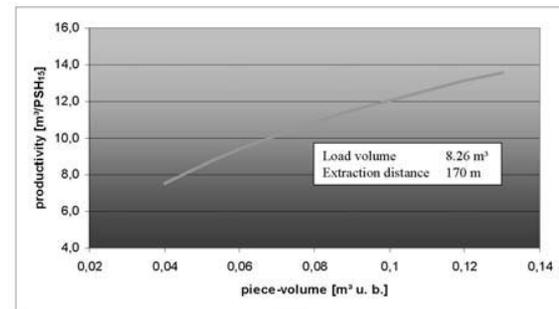


Figure 5. Productivity for the forwarder operation, Ponsse Buffalo Dual (k-factor 1.3)

Productivity of the COMBI, DUAL, and TWIN Concepts

The results of Bodelschwingh's study (2003) of the Valmet Combi 801 (COMBI concept) shows that at an average tree volume of 0.30 m³ and under favourable conditions a productivity of 9.8 m³/PSH₁₅ can be achieved (Table 2). For further calculations a reduced output of 9.0 m³/PSH₁₅ is used. In the same study the TWIN concept (Valmet 901 and Valmet 820) achieved a productivity of 8.2 m³/PSH₁₅ at the same average tree volume. The higher productivity of the Valmet Combi 801 is a result of direct loading and less motion time (Bodelschwingh 2003). In this study the DUAL concept (Ponsse Buffalo Dual) achieved a productivity of 5.12 m³/PSH₁₅ at an average tree volume of 0.31 m³ and a mean piece volume of 0.093 m³.

Table 2. Results of different productivity studies

Machine	Productivity [m ³ /PSH ₁₅]	Ø Tree-volume [m ³]	Extraction distance [m]	References
Valmet 801 Combi	9.8	0.3	250	Bodelschwingh (2003)
TWIN	8.2	0.3	n.s.	Bodelschwingh (2003)
Hemek ²	7.5*	0.2	n.s.	Denkinger (1998)
Pika 728 ²	6.8	0.2	n.s.	Lilleberg (1997)
Ponsse Buffalo Dual ³	5.1	0.31	170	Affenzeller and Steinmüller (2005)
Hemek ¹	6.0*	0.09	n.s.	Wester and Eliasson (2003)
Hemek ²	5.0*	0.09	n.s.	Wester and Eliasson (2003)
Hemek ²	4.8	0.13	160	Strömgren and Eliasson (2000)
Pika 828	4.1	0.14	250	Siren and Aaltio (2003)
Pika 828	3.8	0.09	250	Siren and Aaltio (2003)

¹[load carrier turn- and tiltable]

²[fixed load carrier]

³[removable load carrier]

*[m³/PSH₀]

Eberhardinger and Pausch (2006) could not detect any disadvantages in productivity in the felling/bucking operations when comparing the Dual with a harvester (Ponsse Beaver) of the TWIN-System. In the study of Eberhardinger and Pausch (2006) the Dual for felling and bucking accomplished at an average tree volume of 0.3 m³ a productivity of 16.5 m³/PSH15. Due to the similarity of the Ponsse Dual as a forwarder to the appropriate special forwarder, studies concerning the forwarder operation could be neglected (Eberhardinger and Pausch 2006). For further comparisons a total productivity for both felling/bucking and forwarding is needed. Due to the results of Eberhardinger and Pausch (2006) and Bodelschwingh (2003) a total productivity for processing and forwarding of 8.0 m³/PSH15 for both the concept TWIN and DUAL is used for further calculations.

Costs of the COMBI, DUAL and TWIN concepts

Table 3 provides the comparison of the costs for the Ponsse Buffalo Dual, the Valmet Combi 801 and the TWIN-System which is made up of the Ponsse Beaver and the Ponsse Buffalo. The Ponsse Beaver and the Ponsse Buffalo are very similar in technique and size to the Ponsse Buffalo Dual. The purchase price for the TWIN-System will always be much higher than that for the DUAL- or COMBI-System. However the per unit costs are always cheaper for the TWIN-System if the costs for planning and relocation are not considered.

Relocation costs, relocation distance and harvesting volume per operation area

Due to one more relocation run, the relocation costs for the TWIN are higher than the relocation costs for both the DUAL and the COMBI. At a relocation distance of 120 km the relocation costs for the TWIN amount to 647 € and for the DUAL and COMBI the relocation cost is 300 €. Changeover for the DUAL machine from harvester to forwarder and vice versa costs an extra 40 € (Figure 6).

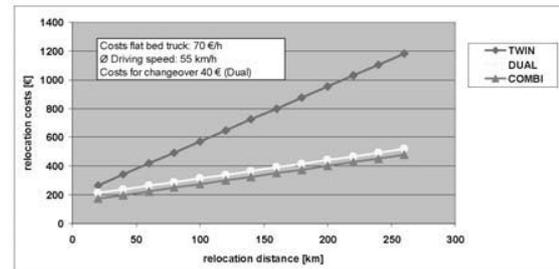


Figure 6. Relocation costs depending on relocation distance for the TWIN, DUAL and COMBI concepts

One goal of this study was to derive harvesting volume per operation area from situations where the COMBI and DUAL are able to operate at least as cost efficiently as the TWIN. Relocation distance means relocation costs and they are much cheaper for the COMBI and DUAL than for the TWIN (Figure 6). On the other hand, taking into consideration the productivities for the DUAL, COMBI and TWIN, the costs are 2.5 €/m³ and 1.8 €/m³ higher for the DUAL and the COMBI respectively (Table 3). Consequently the maximum harvesting volume per operation area is a result of lower relocation costs divided by the difference of the harvesting costs per m³. Figure 7 shows a maximum harvesting volume for the COMBI and the DUAL concepts depending on relocation distance in comparison with the TWIN concept. At a relocation distance of 120 km the DUAL and the COMBI are more economically efficient than the TWIN up to an harvesting volume per operation area of 123 m³ and 188 m³ respectively (Figure 7). If the productivity increases (maybe due to higher tree volumes harvested), the difference of the costs per m³ compared to the TWIN decreases. Consequently the recommended maximum volume harvested per operation area for DUAL and COMBI increases and vice versa.

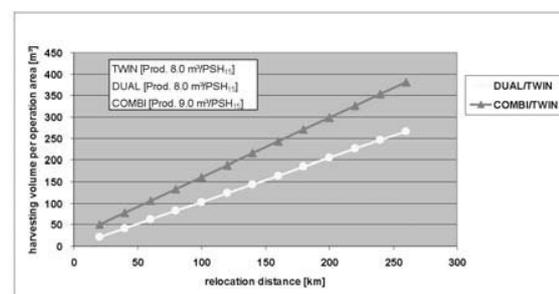


Figure 7. Maximum harvesting volume per operation area in dependence of relocation distance for the DUAL and COMBI concepts in comparison to the TWIN concept.

Table 3. Relation of cost unit and system costs

Machine	Purchase price [€]	Utilization PMH/year*	System costs €/PSH ₁₅	Productivity m ³ /PSH ₁₅	Cost unit €/m ³
Buffalo Dual	354,000	1,500	123.3	8.0	15.4
Valmet 801 C	378,000	1,500	132.2	9.0	14.7
TWIN	528,000	1,500/1,500	102.5	8.0	12.8
Buffalo Dual	354,000	2,000	119.9	8.0	15.0
Valmet 801 C	378,000	2,000	129.1	9.0	14.3
TWIN	528,000	2,000/2,000	100.0	8.0	12.5

* Calculated utilization threshold:1667 PMH/year

Discussion

Combined harvester-forwarder machines and harwarders can be an alternative to the conventional harvester-forwarder system (TWIN) on small scale logging sites with a low harvesting volume and short extraction distances (Wester and Eliasson 2003). Low harvesting volumes are usually due to first thinnings, small forests, single tree selection, salvage harvests, etc. During thinning operations in Scandinavia, Siren and Aaltio (2003) observed an advantage of the combined machines to the special machines (harvester) because of the better utilisation of their capacities compared to the special machines. Eberhardinger and Pausch (2006) identify a higher flexibility of the DUAL compared to the TWIN-System. The possibility for a changeover leads to a higher capacity of reaction e.g. necessary repairs of the harvester aggregate (harvester stop) and restrictions concerning the traffic ability as a result of poor weather conditions (forwarder stop). Nevertheless the application of integrated harvester forwarder systems is restricted to low harvesting volumes per operation area. Different harvesting volumes for economic efficiency are documented in the literature. All of them are located between < 87 m³ (Wester and Eliasson 2003) and < 250 m³ (Talbot et al. 2003) harvesting volume.

Literature Cited

Affenzeller, G. and Steinmüller, T. (2005): Ponsse Buffalo Dual – Eine technische Metamorphose. Österreichische Forstzeitung 2/05, Arbeit im Wald: p.1-3.

Bodenschwing, E. (2003): The new Valmet 801 Combi – First operational test results under Central European conditions. Austro 2003 High Tech Forest Operations for Mountainous Terrain.

Denkinger, B. (1998): Multifunktionsmaschine „Harwarder“. Allgemeine Forstzeitschrift/Der Wald 19/1998: p.986-988.

Eberhardinger, A. and Pausch, B. (2006): Das Kombikzept „Dual“ von Ponsse. Wald und Holz 11/06: p.49-51.

Friedl, K.; Kanzian, C. and Stampfer, K. (2004): Netzwerk Holz. Universität für Bodenkultur Wien, Department für Wald und Bodenwissenschaften p.82-83.

Lilleberg, R. (1997): Evaluation of a harvester-forwarder. Forestry & Forest Products International: p.27-28.

Siren, M. and Aaltio, H. (2003): Productivity and Costs of Thinning Harvesters and Harvester-Forwarders. International Journal of Forest Engineering, Vol. 14/No. 1: p.39-48.

Stampfer, K. (2002): Optimierung von Holzerntesystemen im Gebirge. Habilitationsschrift an der Universität für Bodenkultur Wien, 96p.

Strömgren, A. and Eliasson, L. (2000): Harwarder im Testeinsatz. Forst & Technik 6/00: p.16-17.

Talbot, B.; Nordfjell, T. and Suadicani, K. (2003): Assessing the Utility of Two Integrated Harvester-Forwarder Machine Concepts through Stand-Level Simulation. Studies in Forest Operations Management, Ph. D. thesis: p.44-60.

Wester, F. and Eliasson, L. (2003): Productivity in Final Felling and Thinning for Combined Harvester-Forwarder (Harwarder). International Journal of Forest Engineering, Vol. 14/No. 2: p.45-50.

Wagner, W. (2005): Firma Wahlers Forsttechnik GmbH, D-97215 Uffenheim, oral message: 4. April 2005. Table 1. Numbers of integrated harvester-forwarder-systems in AUT, GER, SWE and FIN (2005) Günter Affenzeller

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ABSTRACT ONLY

GOING WIRELESS – UNDERSTANDING SYNTHETIC ROPE AND UNLOCKING THE POTENTIAL FOR AERIAL LOGGING

Howard Wright

Abstract: The logging industry makes extensive use of wire rope in harvesting operations. The wires are used either above ground for lifting and transporting logs from the field to trucking operations or used on the ground to hold and drag the logs. High strength synthetic ropes are an excellent wire replacement in various logging applications. These synthetic ropes have the equivalent strength of the same diameter wire rope but only one-seventh of the weight of wire

A high strength, light weight synthetic ropes can dramatically reduce set up times and increase efficiency. High strength synthetic ropes can increase winch drum capacity by reducing the diameter with out compromising strength. With synthetic ropes you get can get all these benefits in a design that's easy to service and field repairable. This paper discusses the overall benefits of synthetic ropes to the logging industry in operation time reduction, safety and productivity improvement.

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SESSION B.1:

**FOREST ROADS AND
TRANSPORTATION
MANAGEMENT**

ABSTRACT ONLY

EVALUATING FOREST ROAD CONSTRUCTION TECHNIQUES: A CASE STUDY OF THE RIGHT-OF-WAY LOGGING AND CONSTRUCTION ACTIVITIES

Chris Matthewson

Abstract: In British Columbia's Interior region, the conventional road building process is comprised of several phases including pilot trail construction, right-of-way felling, right-of-way skidding, log processing, log loading and hauling, and road and landing construction. There are many variations of the road building process but typically the roads are built in stages, with the equipment used for each phase continually switching positions along the right-of-way. Conflicts between road construction and right-of-way logging activities cause inefficiencies and poor equipment utilization. As a result, many forest companies in the Interior would like to investigate alternative construction strategies. Currently, there is minimal information available on the productivity and costs of alternatives, so FERIC initiated a series of case studies to

- Document selected road building techniques.
- Evaluate equipment utilization levels, productivities and costs by phase.
- Determine how the road building phases interact, identify inefficiencies between the right-of-way logging and sub grade construction activities, and recommend improvements.

The studies will provide needed data on road building operations to help managers make decisions about where and when to apply alternative techniques, and to improve their assessments of operating costs.

Field work for the first study was completed in southeastern British Columbia in January 2006 data analysis and draft report preparation is in progress. A second study's, also in southeastern British Columbia, data collection will be completed in the fall of 2006. The presentation and paper will outline these case studies and provide a brief description of the results.

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ABSTRACT ONLY

ENGINEERING THE FOREST ROAD STRUCTURE

Kevin Boston, Marvin Pyles, Andrea Bord

Abstract: There is a very large body of knowledge about the design and performance of the structural section of asphalt or Portland cement concrete surfaces roadways. Some but not all of this knowledge applies to the design and performance of the aggregate surfaces roadways that make up the bulk of the forest road system. The key to economic road design is knowing which design elements produce better performance, and which do not. With this paper, we reintroduce a basic, fundamental element of road design and construction that has been largely ignored over the past 50 years in the design and construction of forest roads.

Soil compaction from design through construction has long been the gold standard of road subgrade and base preparation. Soil compaction can improve soil properties to the point that typically more expensive paving material can be reduced without a loss in structural performance of the road. Compaction of subgrade soils on the majority of industrial forest roads ranges from non-existent to uncontrolled, and is only rarely conducted in a manner constant with the state of the art in road design and construction.

This paper illustrates with a case study, the opportunities that exist at the design level of a forest road project, and carry the results through to performance in the form of an economic trade-off analysis between compaction and aggregate surfacing thickness. Actual performance under an array of designs has yet to be installed in the field.

Although aspects of actual construction will no doubt dilute the suggested economic benefit to designed and controlled compaction, the economic analysis strongly suggests that renewed attention should be given to this important cost and performance element of road design and construction.

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CONTROLLING TRUCK PRODUCTIVITY AND COSTS

Glen Murphy, Jeff Wimer

Abstract: Transporting logs from the forest to the mill is becoming the largest single component of wood supply costs for many suppliers around the world. Even small increases in transportation efficiency can significantly reduce costs. There is, therefore, considerable interest by forest industries worldwide in new work procedures, decision support systems, and equipment configurations that can lead to reductions in overall transport costs and numbers of trucks on the road.

A spreadsheet model was developed to estimate truck productivity and costs under different equipment configurations and input values. Six types of trucks are modeled; Long Saw Log, Short Saw Log, Chip Log, Chip Van, Self Loading, and Slash Bundle Trucks. Route characteristics are specified by the user.

Using an engineering economics approach, ownership costs associated with the purchase of the vehicle and its accessories if applicable, labor costs, the fuel costs and consumption rates, road user charges, tire costs, maintenance costs, and overhead costs are calculated. The costs are reported on a per annum basis and on a per ton-mile basis.

Reliable estimates, as well as understanding the relationship between cost variables and the cost of transportation, are important considerations in controlling truck productivity and costs.

Key words: truck configurations, economic models, transport routes.

Introduction

Global competition on national and international forest products markets demand that wood supply chains are created in a way that help forest owners and wood processors to reduce the costs of harvesting and transportation, optimally match wood to market needs, and capture more value (Hecker *et al.* 2000). The forest resources industry is highly dependent on heavy truck transport to move logs from the harvesting sites to the mills. Transporting logs from the forest to the mill is becoming the largest single component of wood supply costs for many suppliers around the world. For example, McDonald *et al.* (2001) comment that log transport represents nearly half the delivered cost of wood fiber in the southern United States. In the intensively managed plantation forests of New Zealand, where costs for activities such as pruning and precommercial thinning must also be considered, log transport still accounts for 20 to 30% of the seedling to mill-door discounted costs, depending on lead distance (Carson 1989).

Since transportation costs make up a large proportion of the overall costs, even small increases in efficiency can significantly reduce costs (Ronnqvist *et al.* 1998). There is, therefore, considerable interest by forest industries worldwide in new work procedures (Barrett *et al.* 2001, Murphy 2003), equipment

configurations (Parker and Amlin 1998), and decision support systems (Cossens 1993, Palmgren 2001, Chung and Sessions 2003) that can lead to reductions in overall transport costs.

Controlling truck productivity and costs implies making necessary adjustments to the overall system when productivity and costs deviate from planned performance. Obtaining reliable estimates of these performance characteristics for specific transportation scenarios can be difficult. Quoted costs may relate to a particular point in time and to particular, but often not stated, forest conditions, truck configurations and conditions, route characteristics, labor expenses, overheads expenses and the trucking company's business practices. Many cost studies in the heavy truck transport industry, therefore, use an economic-engineering approach to estimate trucking costs based on a given set of factor prices.

In order to estimate log truck transport productivity and costs for specific conditions a spreadsheet model was developed in Excel. As part of developing the model a literature review was conducted to pinpoint truck costing data from previous studies and to ascertain relevant costs for the forest industry. Some of the more pertinent information was contained in Goldsack (1988), Taylor (1988), Nader and Jalinier (1993), and Groves *et al.* (1987). A model developed

by Berwick and Farooq (2003) for the grain transport industry of the north central plains of the USA was also of interest.

In this paper we describe the model and demonstrate its utility for several truck configurations, route characteristics, and operating conditions.

Model Structure

The spreadsheet allows the user to modify data reflecting a specific cost input or particular route or truck characteristic if necessary. This application provides production estimates and total costs per annum; also, trucking cost rates are provided per ton with possible conversion in per cubic foot, per cunit, per board foot, per cord, per tonne, and per cubic meter. It allows the user to follow how changing input parameters is reflected in costs. The model is currently populated with costs relevant to 2006 Oregon conditions.

In this spreadsheet model, there are six configurations of trucks included and the costs associated with the use of each one are calculated in an analogous way. Only one example will be explained: Long Saw Log Truck. The other five configurations are as follows: Short Saw Log Truck, Chip Log Truck, Chip Van, Self Loading Truck, and Slash Bundle Truck. The user can modify any one of these to model a different truck configuration if needed, e.g. adding an extra axle on trailer. On these six truck configuration worksheets, the calculations consist of the capital costs associated with the purchase of the vehicle and its accessories if applicable; the fuel costs and consumption rates; road user charges; tire costs; and maintenance costs. All these parameters can be specified and modified if needed by the user. As an output from these Worksheets, truck and trailer distances are given, payloads (tons) and payload* distances (ton-miles) are calculated. The associated costs per annum are calculated by type (depreciation, insurance, fuel, etc.) and the total costs per annum for the particular truck type are shown at the bottom of the page. The total cost is transferred to the summary page if the particular truck configuration is selected.

On Labor Cost Estimate Worksheet the number of workdays per year is specified. Holidays, wet days and sick leave days can be designated. The hourly wage as well as the number of workers can be entered along with the tax free allowances. Changes to those parameters can be made. In the final output, an average daily cost per worker is given.

On the Overhead Costs Worksheet, various costs not directly attributable to a unit of output and not

included in the hourly wage can be specified: office, depot, office equipment, postage, telephone and tolls, clerical, legal, financial, insurance, and other user-defined costs.

On the Pickup Worksheet, the costs that are associated with a pickup truck vehicle can be set and calculated. It consists of the price of the vehicle, all fixed costs for registration, insurance, etc., and the running costs and expenses. A final chargeout rate per mile is given as an output and it is added to the total cost of the operation per annum based on the distance the vehicle is used daily.

On the Loader Costing Worksheet, the costs that are associated with purchasing a loader can be set and calculated. The layout of the costs is similar to that for the pickup truck and a final chargeout rate per hour is given as an output. It is then added to the total cost of the operation per annum based on the hours the loader is used daily.

On the Travel Speeds Worksheet, loading and unloading times, payloads, and utilization rates as well as loaded and unloaded travel speeds on various road types are specified for the designated truck configurations. These values can be changed by the user.

On the Normal Day Worksheet, the specific route characteristics for a "normal" day can be set. A "normal" day activity means one that is recurring at uniform intervals and is expected as usual, ordinary, or average. Up to six trips per day can be specified. Distances can be entered for three types of off-forest road ("on-highway", "rural", and "user-specified"), and five types of on-forest road ("primary", "secondary", "spur - good", "spur - poor", and "user-specified"). It is assumed that the "normal" day will be repeated for all working days of the year. The trips of the vehicle from forests to mills are assumed to be loaded and the ones from the garage to the forest or from the mills to the forests – unloaded. Also, the distance from the last mill to the garage can be designated.

The Summary Page Worksheet contains the output of the spreadsheet model. The desired truck configuration, that the user needs to include costs for, is selected by the user. Annual labor costs, overheads, and pickup costs and loader costs (if selected by the user) are added to annual truck costs. An acceptable profit margin may also be entered. Total annual costs, as well as the \$ per ton costs for a user-specified, one-way trip distance are provided.

Model Demonstrations

To demonstrate the utility of the Truck Productivity and Costing Model we have selected two truck configurations that could handle significantly different products; a 6 x 4 truck with a 2 axle pole trailer for transporting long length sawlogs, and a 6 x 4 truck with a 3 axle trailer with fold-down sides for transporting biomass slash bundles for energy. A travel route, which covers a total distance of 212 miles and visits three processing plants (sawmills or energy plants), is used in the demonstration for both truck configurations. The cost per ton and the distribution of costs are reported.

The Base Case for the Long Sawlog Truck configuration included unloading times of 16 minutes per load, fuel costs of \$2.40 per gallon, a catalytic converter fitted to the truck, a 24 ton payload, no lift axle, and three 35 mile one-way trips per day. The model was then re-run an additional eleven times for the Long Sawlog Truck configuration to quantify the effects of varying:

- average unloading times; 16, 30 or 60 minutes per load
- fuel costs; \$2.30 to \$3.00 per US gallon

- the presence or absence of a fuel catalytic converter
- payloads; 23 to 25 tons
- number of axles; a lift axle was added to increase payload by 2 tons
- trip distances (from 18 to 114 one-way miles per trip) and trips per day (2 to 5)

The Base Case for the Slash Bundle Truck configuration included unloading times of 35 minutes per load, fuel costs of \$2.40 per gallon, a catalytic converter fitted to the truck, a 22 ton payload, no lift axle, and three 35 mile one-way trips per day.

Model Results

The results are summarized in Table 1. The estimated total annual costs for the Base Case Long Sawlog Truck configuration were \$134,540 which equated to a unit cost of \$7.78 per ton (\$0.222 per ton-mile). The estimated unit costs for the Slash Bundle Truck configuration were 18% higher (\$9.16 per ton) due to a combination of 8% higher annual costs and 8% lower annual productivity.

Table 1. – Estimated productivity and costs for a range of truck configurations and route characteristics. Percentage changes from the Base Case: Long Sawlog Truck are shown in parentheses.

Scenario	Productivity (ton-miles per year)	Trips per day	\$/ton	\$/ton-mile	Total annual cost
Base Case: Long Sawlog Truck (35 miles one-way per trip)	605,172 (0)	3	7.78 (0)	0.222 (0)	134,540 (0)
Fuel @ \$2.30 per gallon	605,172 (0)	3	7.71 (-1)	0.220 (-1)	133,369 (-1)
Fuel @ \$3.00 per gallon	605,172 (0)	3	8.19 (+5)	0.234 (+5)	141,567 (+5)
Without catalytic converter	605,172 (0)	3	7.52 (-3)	0.215 (-3)	129,998 (-3)
23 ton payload	579,957 (-4)	3	8.12 (+4)	0.232 (+4)	134,540 (0)
25 ton payload	630,388 (+4)	3	7.47 (-4)	0.213 (-4)	134,540 (0)
Add a lift axle to increase payload to 26 tons	655,603 (+8)	3	7.34 (-6)	0.210 (-6)	137,505 (+2)
Long unloading time (60 minutes per load)	605,172 (0)	3	8.47 (+9)	0.242 (+9)	146,498 (+9)
Short unloading time (16 minutes per load)	605,172 (0)	3	7.46 (-4)	0.213 (-4)	128,960 (-4)
Long trips (114 miles one-way per trip)	1,255,976 (+108)	2	20.08 (+158)	0.176 (-21)	221,912 (+65)
Short trips (18 miles one-way per trip) with 30 min unload time	385,776 (-36)	4	5.81 (-25)	0.323 (+45)	124,491 (-7)
Short trips (18 miles one-way per trip) with 16 min unload time	482,220 (-20)	5	5.34 (-31)	0.297 (+34)	143,169 (+6)
Base Case: Slash Bundle Truck (35 miles one-way per trip)	554,741 (-8)	3	9.16 (+18)	0.262 (+18)	145,132 (+8)

Figures 1 and 2 show the distribution of annual costs for the two Base Case scenarios. Labor was the largest cost component for both scenarios, accounting for a bit over a third of the costs. Ownership costs (depreciation, interest, and insurance) were the next largest cost component, accounting for about a fifth of the costs. Fuel and oil also accounted for about a fifth of total annual costs for both scenarios. Repairs and maintenance costs plus tires accounted for about 10% of total costs. Road user charges, overheads and profit margin accounted for the remaining 15 to 17% of costs.

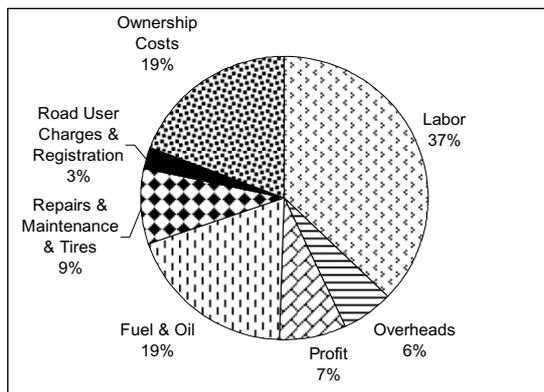


Figure 1. – Distribution of costs for the Long Sawlog Truck Configuration.

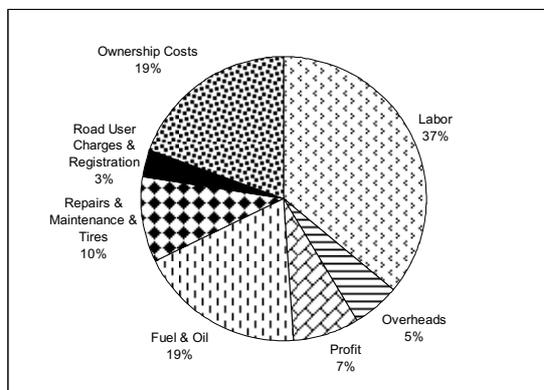


Figure 2. – Distribution of costs for the Slash Bundle Truck Configuration.

The remaining comments relate to changes to the Long Sawlog Truck configuration scenarios.

Reducing the cost of fuel by 10 cents to \$2.30 per gallon, through such actions as bulk purchasing of fuel, would reduce unit costs by about 1%. Increasing fuel costs to \$3.00 per gallon would increase unit costs by 5% to \$8.19 per ton. If a catalytic converter were not fitted to the truck, unit costs would be about 3% lower.

Increasing average payload by one ton leads to a 4% reduction in unit costs for the same truck configuration. Likewise if the average payload was one ton less, unit costs would increase by about 4%. Adding a lift axle so that average payloads could increase by two tons would lead to a 6% reduction in unit costs.

Some trucks have to wait longer than 30 minutes on average for unloading. A 60 minute average unloading time would lead to a 9% increase in costs. Reducing the unloading time from 30 minutes to 16 minutes will lead to a 4% reduction in unit costs for the 3 trip per day scenario. When haul distances are shorter, a reduction in unloading time may mean the difference between hauling an extra load per day or not. The unit costs for the 5 short trips per day scenario are 8% lower than for the 4 short trips per day.

Trip distance obviously has an impact on unit costs. Unit costs were 158% higher (\$20.08 per ton) for a 2 trips per day, 114 mile one-way route than for the Base Case scenario (3 trips per day, 35 mile one-way route). Unit costs were 25% lower for the 4 trips per day, 18 mile one-way route.

Discussion and Concluding Remarks

Blair (1999) reported that, for average log haul conditions (one-way trip distance of 109 miles) in Alberta, the six parameters that indicated the largest potential for cost improvement were payload, truck utilization, cycle time efficiency, labor cost, capital cost, and fuel consumption.

With the Truck Productivity and Costing model we have demonstrated for PNW conditions that, for a given trip distance and product type, costs could be altered by up to 8% by changing a single parameter. Of the six important parameters reported by Blair (1999) we looked at four – payload, cycle time efficiency (through changing unloading times), fuel consumption (through the use of a catalytic converter and through changes in fuel costs), and capital costs (through adding a lift axle or catalytic converter). We could also have easily looked at the other two - impact of changing truck utilization and labor costs. We did, however, also look at the costs of hauling other product types using alternative truck configurations over a range of trip distances.

In addition, by using the Truck Productivity and Costing model, we could have looked at the impacts on costs of many other things such as alternative transport routes, repairs and maintenance costs, interest rates for borrowing, and services provided.

The Truck Productivity and Costing model was developed to enable robust decision making through reliable estimates of trucking productivity and costs over a variety of equipment configurations, labor and overheads expenses, and route characteristics. Use of models such as this one will allow transportation managers to plan, optimize and control a key cost element of the forest industry.

Literature Cited

- Anonymous. 2002. Operating costs of trucks 2001. Transport Canada Policy Group. (www.tc.gc.ca/pol/en/Report/OperatingCost2001/final2001-02.htm Accessed 4/26/2004).
- Barrett, S.M., S.P. Prisley, and R.M. Shaffer. 2001. A computer simulation model for predicting the impacts of log truck turn-time on timber harvesting system productivity and cost. In: Proceedings of the 24th Annual Council on Forest Engineering meeting, Wang, J. et al. (eds). Council on Forest Engineering, Corvallis, Oregon. pp.1-6.
- Berwick, M., and Farooq, M. 2003. Truck costing model for transportation managers. Mountain Plains Consortium, North Dakota State University, Fargo. MPC Report 03-152. 61p.
- Blair, C. 1999. Log transportation cost model. Forest Engineering Research Institute of Canada, Vancouver, B.C. FERIC Field Note No. 67. 2p.
- Carson, M. 1989. Comparison of improved radiata pine breeds using STANDPAK. In: New approaches to thinning in plantation forestry, James, R.N. and L. Tarlton (eds.). Ministry of Forestry, New Zealand. Forest Research Institute Bulletin. No. 151.
- Chung, W. and Sessions, J. 2003. NETWORK 2000: A program for optimizing large fixed and variable cost transportation problems. In: Proceeding of the Eighth Systems Analysis Symposium in Forest Resources, G.J. Arthaud and Barrett, T.M. (eds.), Aspen, Colorado, September 27 – 30, 2000, Kluwer Academic Publishers. pp. 109 – 120.
- Cossens, P. 1993. Evaluation of ASICAM for truck scheduling in New Zealand. Logging Industry Research Organisation, New Zealand. Report. Vol. 18. No. 7.
- Goldsack, R. 1988. Log truck estimates handbook. Logging Industry Research Association, Rotorua, New Zealand.
- Groves, K.W., Pearn, G.J., Cunningham, R.B. 1987. Predicting logging truck travel times and estimating costs of log haulage using models. Aust. For. 50 (1): 54-61.
- Hecker, M., Becker, G., and Ressmann, J. 2000. Estimating benefit potentials in German logistics for wood procurement and timber logging. In: Logistics in the Forest Sector, SJOSTROM, K. (ed.), Timber Logistics Club, Finland. pp.153-164
- McDonald, T., Rummer, B., and Valenzuela, J. 2001. Potential for shared log transport services. In: Proceedings of the 24th Annual Council on Forest Engineering meeting, Wang, J. et al. (eds). Council on Forest Engineering, Corvallis, Oregon. pp. 115 – 120.
- Murphy, G.E. 2003. Reducing trucks on the road through optimal route scheduling and shared log transport services. Southern Journal of Applied Forestry 27(3):198-205.
- Nader, J.A. and C. Jalinier. 1993. Otto. Truck performance simulation program. Forest Engineering Research Institute of Canada. TN-195. 8p.
- Palmgren, M. 2001. Optimization methods for log truck scheduling. Licentiate Thesis No. 880. Linkoping Institute of Technology, Sweden. 116p.
- Parker, S., and Amlin, E. 1998. Western log trucks configuration study. Forest Engineering Research Institute of Canada, Vancouver, B.C. FERIC Contract Report No. CR-98-03-15. 166p.
- Ronnqvist, M., Sahlin, H., and Carlsson, D. 1998. Operative planning and dispatching of forestry transportation. Linkoping Institute of Technology, Sweden. Report LiTH-MAT-R-1998-18. 31p.
- Taylor, P. 1988. Log truck cost estimates. Logging Industry Research Association, Rotorua, New Zealand. LIRA Report Vol. 13. Number 23.

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TEMPORARY ROAD AND LANDING OBLITERATION WITHIN SKYLINE LOGGING UNITS

Jim Archuleta

Abstract: Temporary roads and landings are often needed during skyline logging. Essential to the implementation of some skyline units, these features can sometimes become both political and environmental liabilities to land managers. When assumed to be of little consequence temporary roads and landings are rehabilitated passively. While this is fiscally sound for the present, it may not be environmentally sound in the long-term. Passive rehabilitation has left some not-so temporary roads and landings to become legacy features that can be reused in second entries but these areas can increase the risk of future slope failures. Active rehabilitations of temporary roads and landings are becoming common contract provisions and are in some Forest Plans (Umpqua NF and Sisikyou NF). With these concepts in mind, the Umpqua NF has developed two implements which bridge the gap between soil rehabilitation and harvest related activities.

Key words: compaction, passive rehabilitation, skid trails, soil rehabilitation, temporary landings, temporary roads

Introduction

Soil disturbance from harvest activities can reduce tree performance, contribute to stream sedimentation, or visually suggest poor stewardship (Heninger et al. 2002). A form of soil disturbance is compaction from temporary roads. In the past many compacted areas have been left to rehabilitate passively which has reduced tree seedling growth (Amaranthus et al. 1996) and decreased slope stability (Guthrie. 2002). Direction from the U.S. Forest Service Manual on forest soils, states that activities will create less than 20 percent detrimental soil conditions, (FSM 2521. 1-1 a, R-6 Supplement 2500-96-2). This U.S. Forest Service objective is achievable in the steep landscapes where skyline harvest occurs, but skyline harvest is not without impacts to the soil.

Temporary roads and landings are often needed during skyline logging. Roads are considered temporary, if their purpose was only for a single activity (Garland and Jackson. 1996). Essential to the implementation of some skyline units, these features can sometimes become both political and environmental liabilities to land managers. When assumed to be of little consequence temporary roads and landings are left to be restored with time and elements; i.e. passive rehabilitation. While this is method of rehabilitation is fiscally sound for the present it may not be environmentally sound in the long-term. Passive rehabilitation has left some not-so

temporary roads and landings to become legacy features that can be reused in second entries but these areas can increase the risk of future slope failures. Slope failure is not the result of every attempt at passive restoration; however, there is an elevated risk of volume loss to the residual stand if a slope failure were to occur. Prior to active rehabilitation efforts, compaction can cause localized surface erosion, which may remove the topsoil and hinder the soil's ability to support vegetation (Adrian et al. 2005, Brady, 1990, Bulmer 2000, Jurgensen et al, 1997, Powers et al, 2005 and Spears et al, 2003); either planted or desired native vegetation. Soil damage will appear when surface organic layer is substantially reduced by erosion (Waldrop et al. 2003), or mechanical means (Amaranthus et al 1996 and Froelich et al 1985).

Active rehabilitation of new or legacy temporary roads and landings can be a challenge to implement during a timber sale or costly to do with post-harvest projects. Active rehabilitation of temporary roads and landings are becoming common contract provisions and are based in some Forest Plans (Sisikyou NF and Umpqua NF). With these concepts in mind, the Forest Service, U.S. Department of Agriculture and the Umpqua NF have developed two implements to reduce the implementation time and cost challenges that this type of timber sale mitigation creates. The implements combine the needs of multiple project objectives with subsoiling treatments. The Subsoiling Grapple Rake (Archuleta

and Karr, 2006) and Subsoiling Excavator Bucket (Archuleta and Karr, 2006) are U.S. Forest Service patented designs which bridge the gap between soil rehabilitation and harvest related activities. Subsoiling temporary roads and skid trails after each first entry or re-entry will reduce the opportunity for cumulative detrimental soil conditions to continue to degrade a site.

Active Harvest Mitigation Methods

The common treatment for compaction is to subsoil with either a dozer-mounted ripper implement or a dozer-mounted subsoiling implement. Regardless of the implement used the dozer method is considered the cheapest of the active soil restoration treatments. This method is considered cheap, because the equipment is readily available and can quickly decompact a site. Despite being the lowest cost, a few problems with dozer subsoiling can arise from a site soil productivity stand point. First is the difference between soil ripping and subsoiling. Soil ripping will create furrows and can leave some compaction, since it does not provide much lateral fracture from ripping alone. While dozer-mounted subsoiling does offer lateral fracture of compaction, decompacting to a higher level than ripping alone; it does not provide a means to return organic matter to the treatment site. The inability of the dozer method to provide effective ground cover to the treatment site means the soil treatment may be subject to loss of aggregate stability. Reasons for using an effective ground cover are for soil aggregate stability (Luce 1997) and tree response (Bulmer. 2000). Exposed subsoiled sites poor in organic matter can be influenced by rain slash without effective ground cover, “fines eroded from between fragments” can clog macropores and lead to surface crusting and runoff (Luce 1997). Adequate surface organic material creates a buffer from temperature and moisture fluctuations increasing plant vigor and growth. Additionally, inattention during operations can cause boulders to surface, resulting in an undesired boulder covered surface.

Subsoiling and Slash Reduction

Often associated with ground-based systems, the grapple-piling operation provides a means of treating compaction before leaving the harvest unit. Logging residues slash treatment and treatment of compaction (subsoiling operations), have recently become concurrent activities. Previously these two operations

have been done separately in time, and sometimes by differing equipment which increases the overall cost of treating an acre of land. To respond to both the need of restoring site soil productivity and to reduce the overall cost of this type of work, excavators used for grapple piling are being employed to decommission temporary roads and landings immediately following log haul. The versatility of excavators lends itself to these joint projects of grapple piling and subsoiling. Excavators without a specialized implement can treat compaction by forcing the machine’s grapple rake or tines into compacted soil (see Figure 1), once a work station is completed it can utilize harvest slash for effective ground cover (see Figure 2). Placing organic material on top of a subsoiled surface has been shown to maintain soil aggregate stability, which can allow for increased natural regeneration and maintain the vigor of planted seedlings. Observations on subsoiled temporary roads at Diamond Lake Ranger District (Umpqua NF) indicate 8+ years of soil aggregate stability, when effective ground cover is used. While these concurrent rehabilitative treatments can offer heightened versatility to logging operations, the rate of production can still be cost prohibitive depending upon the amount of acreage being treated. The need for improving this situation prompted a U.S. Forest Service innovation that was recently patented; the Subsoiling Grapple Rake (see figures 1-3). This implement has been able to triple the subsoiling rate of an unimproved grapple rake or bucket. The improvement was achieved by integrating subsoiling shanks into the grapple rake (Archuleta and Karr, 2006).



Figure 1 Subsoiling position of an unimproved grapple rake. Subsoiling Grapple Rake is used to illustrate position and action described for unimproved grapple rake subsoiling.



Figure 2 Grapple piling mode returning effective ground cover to treated soil surface.



Figure 3 Subsoiling treatment with improved Grapple Rake (SGR).

Subsoiling and Recontouring of Temporary Roads

Excavators are commonly used for the removal of culverts, creating waterbars, and recontouring (excavation pullback of the fill slope) of temporary roads in sloped landscapes. Most restoration of temporary roads is done in separate operations. The subsoiling is characteristically done with a dozer pulling an agricultural subsoiling implement or dozer-mounted ripper system followed by an excavator recontouring the slope. While this approach to subsoiling reduces compaction with the dozer and can return organic matter to the soil surface with the excavator during recontouring; some project managers recognize this is a logistical nightmare and abandon the dozer subsoiling. In the name of efficiency and to reduce time and labor costs the project manager may revert to only recontouring, which results in a buried compacted ditch line. This may have the outward appearance of a full restoration; however, the now buried compacted ditch line will remain a water routing feature subsurface (see figure 4). If the project has removed all culverts and water impounding features; the result could be subsurface concentrated flow to

restored stream courses, causing minimal problems. On the other hand, if an unrecognized water impounding feature has been retained through this shortcut, then slope saturation may lead to slope stability problems in the future.

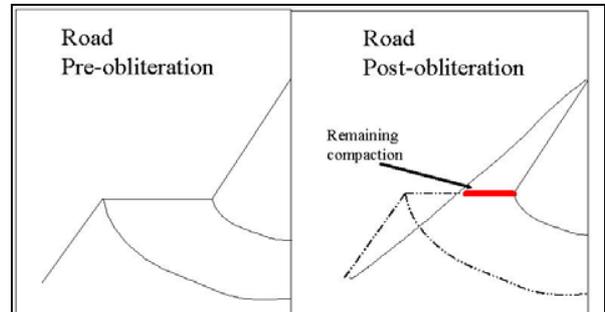


Figure 4 Conceptual drawing of temporary road pre and post obliteration with legacy compacted ditchline.

To reduce the potential of these situations being created within watershed restoration projects; the Subsoiling Excavator Bucket, a U.S. Forest Service innovation was recently patented (see figure 5). This innovation has the ability to be a fully operational excavator bucket in one position then subsoil compacted ditch lines in another. This implement has not only been proven an environmental benefit to watershed restoration projects it has also proven to be an economic benefit. During a road decommissioning on the North Umpqua Ranger District of the Umpqua NF; this implement was credited with a \$40,000 dollar savings. This savings was recognized by the Forest engineering group; when the U.S. Forest Service project cost (completed in house) was compared to the lowest bid price for that project.



Figure 5 Subsoiling Excavator Bucket, used for culvert pulls and recontouring.

Concluding Remarks

The concepts of these new implements have been taken on by contractors near the Umpqua NF. One contractor has gone so far as to retrofit company equipment to meet the timber sale contractual requirements of these types of treatments. The SGR and SEB are not intended to replace traditional dozer subsoiling defined earlier. These implements should be considered as an alternative or additional method to use when developing either a harvest implementation or a land restoration pre-scription. The economic benefit of the SGR and SEB to the USDA Forest Service is expected to be found in the reduction of contract costs. These costs are reduced by eliminating multiple entries with differing equipment and objectives and having an operation which treats the soil without leaving an equipment footprint.

While both implements bridge similar gaps in forest management practices, each creates its own potential benefit. The SGR spans the previously large gap in time between treating harvest related fuels and treating harvest related soil impacts. When subsoiling in a closed regeneration harvest unit, one already burned, there is little organic matter available for effective ground cover. The concurrent activities of grapple piling and subsoiling allowed by the SGR remedies this situation, slash is utilized as effective ground cover while subsoiling and piling operations occur in tandem.

The SEB makes it possible to implement road obliterations just as it was envisioned during the planning stage of the project. By subsoiling the compacted ditch line of a recountoured decommissioned road; there is little opportunity for the restored slope to reach saturation and attain slope failure. Ultimately both implements increase the opportunity to treat legacy compaction while concurrently treating new compaction. Other applications of these implements include wildland fire suppression and rehabilitation including BAER work (Burned Area Emergency Rehabilitation). Through field trials on the Umpqua National Forest, these implements have shown that implementing quality restoration projects and being fiscally responsible are not mutually exclusive entities in good forest management.

Literature Cited

- Amaranthus M. P., D. Page-Dumroese, A. Harvey, E. Cazares and L.F. Bednar. 1996. Soil compaction and organic matter affect conifer seedlings, nonmycorrhizal and ectomycorrhizal root tip abundance and diversity. USDA Forest Service Pacific Northwest Research Station, Research paper NR 494.
- Archuleta, J.G. and M.W. Karr., inventors. 2006 (June 13) Subsoiling Excavator Bucket. U.S. Patent 7,059, 072.
- Archuleta, J.G. and M.W. Karr., inventors. 2006 (August 8) Subsoiling Grapple Rake. U.S. Patent 7,086,184.
- Bulmer, C. 2000. Reclamation of forest soils with excavator tillage and organic amendments. *Forest Ecology and Management* 133:157-163
- Garland, J.J. and Jackson, D.J. 1996. Planning Woodland Roads. Oregon State Extension Service Publication. EC 1118. <http://extension.oregonstate.edu/catalog/pdf/ec/ec1118.pdf>
- Guthrie R.H. 2002. The effects of logging on frequency and distribution of landslides in three watersheds on Vancouver Island, British Columbia. *Geomorphology* 43 (2002) 273-292
- Froehlich, H. A, D.W.R. Miles, and R.W. Robbins. 1985. Soil bulk density recovery on compacted skid trails in central Idaho. *Soil Science Society of America Journal*. 49: 1015-1017.
- Heninger, R., W. Scott, A. Dobkowski, R. Miller, H. Anderson, and S. Duke. 2002. Soil disturbance and 10-year growth response of coast Douglas-fir on nontilled and tilled skid trails in the Oregon Cascades. *Can. J. For. Res.* 32: 233-246.
- Luce, C.H. 1997. Effectiveness of Road Ripping in Restoring Infiltration Capacity of Forest Roads. *Restoration Ecology* Vol. 5 No 3. pp.266-270.

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TRANSPORTATION PLANNING FOR THE WILSON RIVER WATERSHED IN THE "TILLAMOOK BURN"

Keith Mills, Blake Lettenmaier, Rick Thoreson, Bob Teran, Greg Miller

Abstract: The Tillamook State Forest (formerly Tillamook burn) contains roads built for timber salvage after four wildfires that occurred between 1933 and 1951. The terrain is very steep and rocky with many existing roads located next to streams and unsuitable for skyline logging. Some roads have been improved or relocated over time, but a master transportation plan has long been desired, since many areas have either no or inadequate access. Initial transportation planning indicated that timber harvesting would not pay for road construction in some areas for a long time into the future. Additional investigation of roads, harvesting options and costs was required to produce more a comprehensive and achievable transportation plan. This plan will consider road construction costs, environmental risks, and recreation. It will also be used as a transportation planning template for the rest of Oregon's state forestlands.

Introduction

The Oregon Department of Forestry (ODF) manages approximately 780,000 acres of forestland, mostly in the Coast Range Mountains. The Wilson River Watershed is roughly in the center of the ownership (Figure 1). Most of the basin has experienced multiple extreme wildfires, the most recent almost 60 years ago. There was intense salvage activity after these fires, with roads and skid roads constructed with little regard for long term drainage or slope stability, often at very steep grades. The burn area was the subject of one of the earliest and largest replanting efforts in the world. The elevation varies from near sea level to 3706 feet. Slopes are steep to extremely steep in the middle part of the basin, with the gentlest slopes near the Coast Range divide (Figure 2). Forested slopes between 70 and 130 percent steepness with some even steeper non-forest rock slopes are not uncommon. These steep slopes are prone to both shallow and deep seated, rapidly moving landslides.

This watershed covers two Oregon Department of Forestry administrative districts, Tillamook and Forest Grove. To date, transportation planning has been informal, as formal guidance is limited (Oregon Department of Forestry, 2000). The existing guidance defines transportation planning as "any planning activities involving new road construction, road improvement or road maintenance." This neglects road closures and recreational uses (very heavy in the watershed). ODF staff began this process in May of 2006, revising transportation planning objectives to three fundamentals: A) Display and description of current road conditions important for transportation planning; B) Display and description and analysis of

fully managed road and trail locations and conditions; and C) a description of the process for getting from A to B.

On November 6, 2006 the Wilson River Watershed experienced the flood of record (largest flow ever recorded). The storm event caused landslides and washouts, with a peak flow twenty percent more than the great flood of 1996. As a result, a Federal emergency was declared. Road repairs and closures are in progress, and have delayed transportation planning efforts. Therefore, this paper summarizes a work in progress. When complete, it will be used to help guide road and trail construction, repair, maintenance and closures (temporary and permanent). It will be used for future annual operating plans and for evaluating ways to get roads constructed, relocated or removed over the long-term. This plan will be a starting point, recognizing better data and new technologies will be available in the future.

Data Available

Roads and Units from the "Harvest and Habitat" model

ODF developed a "Harvest and Habitat Model" (H &H) (Sessions et al, 2006) to balance timber harvesting and wildlife habitat under four different scenarios for most ODF managed lands. The transportation system was prepared for the model by compiling all existing roads on ODF lands and other roads necessary to connect the forests to mill sites on a GIS layer. Where roads did not access any of the planned harvest units, additional roads were planned with the location based on the shortest reasonable route that met a number of environmental protection

and alignment criteria (Figure 3). The roads were classified into five use categories based on land area accessed by the road or road system. Road construction and reconstruction cost estimates were applied to each road based on road classification, slope steepness, and number of and type of stream crossings.

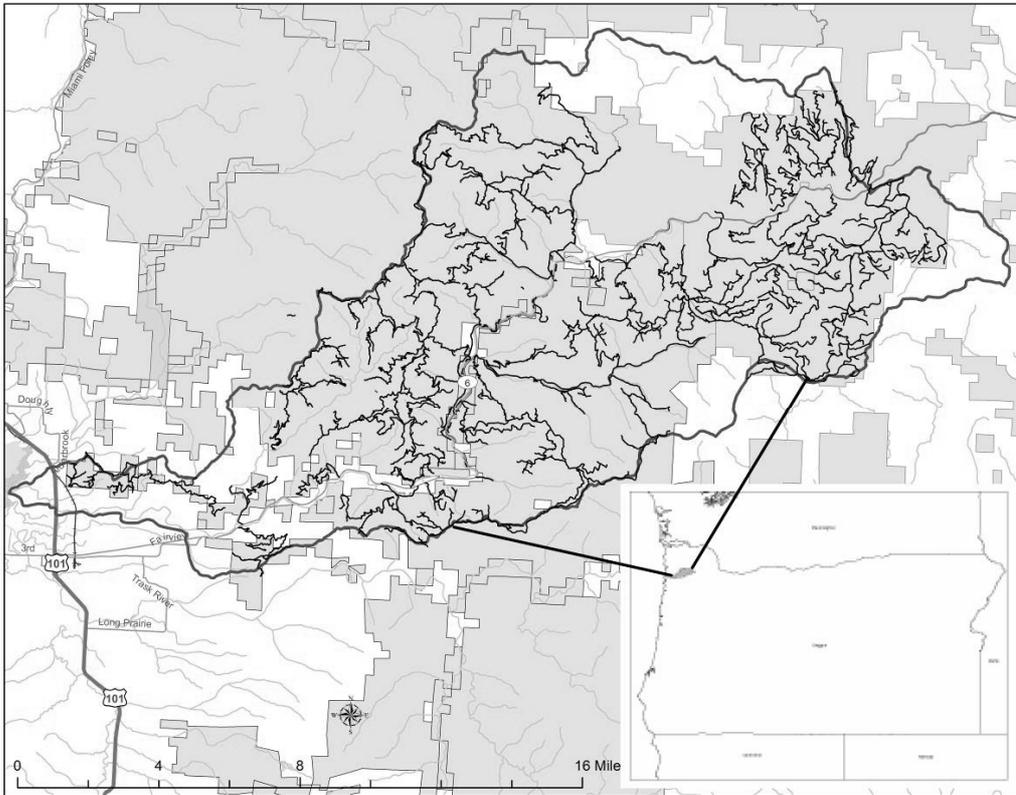


Figure 1. Map of the Wilson River Watershed showing major roads managed by ODF

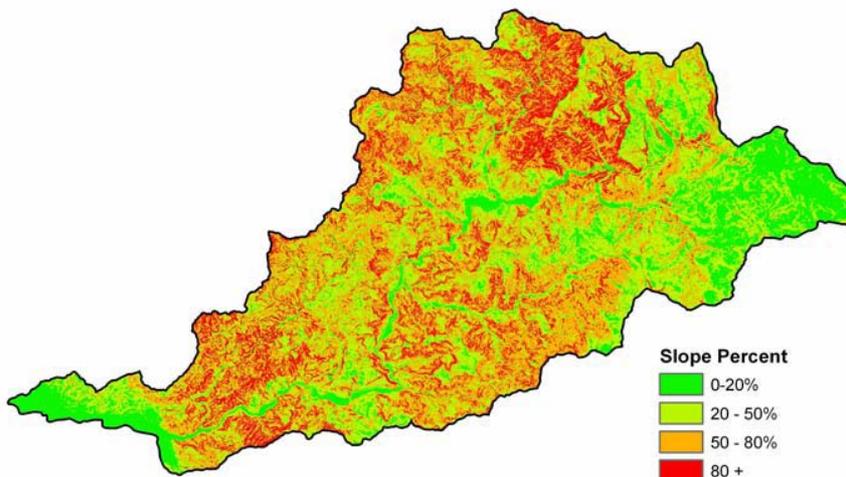


Figure 2. Slopes for road planning in the Wilson River Watershed

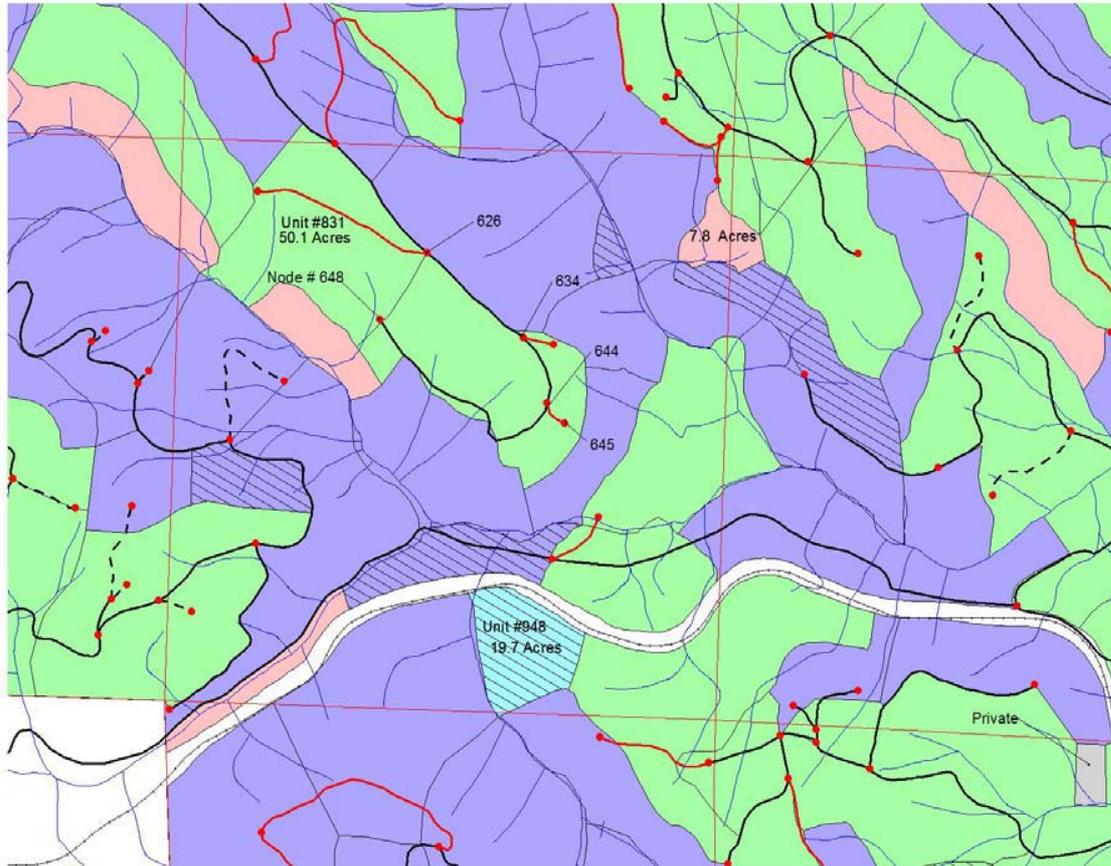


Figure 3. Harvest and Habitat Model planned Harvest unit and roads. Roads in black are existing, roads in red are planned, Solid green is ground based yarding, purple are cable units, pink no harvest areas, blue helicopter, with hash marks indicating units that cannot be thinned.

A network analysis of the road system was conducted to insure that all harvest units were connected to a potential mill site in a reasonable efficient manner (Chung and Sessions, 2003). The network analysis was used to identify a specific haul route for each harvest unit that was used to calculate specific road maintenance and log hauling costs associated with that harvest unit in the model. The roads and their costs were incorporated into the overall model to ensure that any future harvest operations were economically feasible. This model considered construction/reconstruction costs, maintenance costs, log hauling costs and logging costs.

Stand information

Most of the forests in the basin were established by replanting after the fires. This occurred between 1940 and the mid 1960's and was the earliest major reforestation effort using seedlings. Most of the seedlings were off site Douglas-fir stock. Natural Douglas-fir

stands are uncommon within 10 miles of the coast. The areas that were planted with Douglas-fir are often infected with the disease Swiss Needle-cast, which can significantly slow growth but rarely result in mortality.

In the early 1970's stands of alder and conifer were sprayed with herbicide to kill the alder and release the conifers. Unfortunately, instead of killing the alder with the herbicide, it deformed the alder. These stands now have multiple stems and tops and are known locally as "zombie" alder. They are of limited value and growing on otherwise productive lands. In addition, since the alder stands are overstocked and over 40 years of age, the growth is usually stagnated.

Many of the more accessible areas have been commercially thinned. We have classified stand volume (in MBF) per acre into the following categories: non forested; 0-5; 6-10; 11-15; 16-20; 21-30; and 31 mmbf/acre or higher. The hardwood volume per

acre in the H&H model is approximately two to three times higher than what actually exist. An adjustment in the volume must be made to account for this discrepancy.

Road Inventory

The department manages 430 miles (all just surveyed) of open roads and approximately 170 miles (146 miles just surveyed) of closed road in the watershed. Roads that have been used for timber harvesting have generally been improved, with correctly sized drainage structures and surfaced for wet weather road use. Other roads have aging culverts or may be closed by landslides and washouts. Oregon State Highway 6 runs right down the middle of the basin, and serves as a public, high speed mainline access road for all activities in the watersheds. This road is in excellent condition, though as with the rest of the forest subject to occasional closure by landslide.

The following road attributes are available for roads in the Wilson watershed:

- Road Location - on GIS based on orthophoto
- Road Status - open, closed, abandoned and planned new
- Road Surface - Gravel, dirt or unknown
- Road Classification - collector, spur or administrative
- Stream Crossing Information - type, size and many details
- Cross Drainage Information - culverts only, condition code
- Current Condition of open and most closed roads (see below)
- Environmental risk of open and most closed roads (see below)

Consistent terminology for all these attributes has just recently been developed, though metadata standards have not yet completed for all of them.

The current condition of roads as related to the need for repair work to reduce short term risks to the environment and/or road users has been summarized by Attention Priority (AP) Codes (Mills et al, 2007). This was part of the recent road survey. A rating of 1 indicates the highest priority for immediate road work, while a rating of 5 indicates that element is in excellent condition. The AP Codes are used to describe the following elements of the road:

- Prism
- Drainage system
- Running surface
- Brush/weeds
- Stream crossing structures
- Cross drainage culverts

Environmental risks are also part of the just completed road survey and evaluated based on indicators (Mills et al, 2007). There are six principal environmental indicators based on metrics from the survey:

1. Road location in relation to streams or landslide/erosion prone slopes;
2. Stream crossing effects on fish passage;
3. Washout and diversion risk at stream crossings;
4. Percent of road system with hydrologic connection to streams;
5. Land area dedicated to roads and not growing forests; and
6. The general condition rating of the prism, surface, drainage system, drainage structures and brush/weeds (above) is also a short term risk indicator.

Based on these risks, we have also just developed environmental performance measures for roads, focused on fish passage and hydrologic connectivity (Mills, 2006).

Slopes

The slope data currently available is based on USGS quadrangle 1:24,000 contour maps. On these maps, this means there is roughly a ground point on about a 30 feet, and depending on canopy cover and photogrammetric technique, this information may not be very consistent. Slope steepness from the USGS quadrangle maps for the basin is illustrated in Figure 2. Most of the basin is in the geologic province known as the Tillamook highlands. These are rocks of volcanic (lava flows) origin that were deposited on the seafloor or an ancient island, then uplifted over time. This is the geologic unit associated with the steepest slopes. There are also sedimentary rocks on the margins of the watershed, usually associated with less steep slopes.

Recreation

The Wilson River is close to the Portland metropolitan area, with a population of over one million people. There is high recreational use, especially around the main state highway (Highway 6), especially since many private lands are closed most of the year to recreation, and roads on other public forests may not be suitable for recreation. Data on the condition of trails was collected during the road survey. This survey found that most of the trails are old or abandoned roads that we may need to use as roads again. Recreational uses in the forest include four wheel drive vehicles, ATV's, motorcycles, horseback riding, and hiking.

Data Needed

The biggest data gap identified was the lack of reliable slope data (see the Process Section). We are currently in the process of obtaining LiDAR for the watershed. LiDAR (Light Detection and Ranging) is an optical remote sensing technology which measures properties of scattered light to find range and/or other information of a distant target. This technology accurately determines distances to solid objects. Through post processing, pulses that reach the ground can be separated from pulses that hit vegetation. Thus the technique is also being investigated by others for determination of canopy properties (tree height, stand and canopy density). Among other things, this is expected to provide ground elevation data that is at least 100-1000 times more accurate than data from the current USGS topographic maps. Part of this initial transportation plan will be to compare roads planned using the USGS topographic data to those planned using the LiDAR data. A shaded relief map produced from LiDAR is for the nearby East Fork Trask River is shown in Figure 4. Maps produced from this LiDAR clearly show roads, including long abandoned roads, old donkey cable yarding roads toward railroad grades, stream initiation points, and deep seated landslides (including those not visible even when walking the ground).

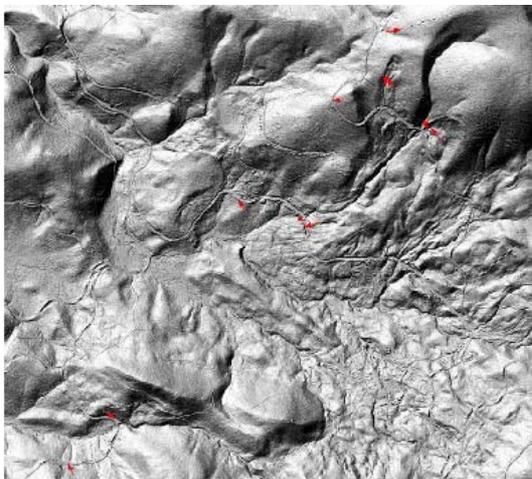


Figure 4. Shaded-relief map produced from LiDAR for a portion of the East Fork Trask River Watershed.

Another data gap is that the state forests road information system is not completely developed, and varies by administrative district. Information on road constraints is just now being collected. Many of the existing road have constraints on use, including: width too narrow, grade too steep, curves too tight, or blocked by vegetation, washouts or landslides. We have asked operators that use these roads for infor-

mation about vehicle use restrictions on these roads by type of vehicle: large yarder, low-boy; log-truck (poles and short logs), four wheel drive road vehicle, and two-wheel drive road vehicle. For planned new roads, we are working to identify critical control points that include saddles, flat ridges, landings, and slopes under 50 percent. Verification of planned road locations is critical, as the current slope information is not accurate. We have many easements, but this is generally lacking in our current information system. Finally, the recent storm will allow us to collect repair costs associated with landslides and washouts, and to compare these costs to risks identified in the recently completed roads survey.

Process

This plan is based on internal (ODF) and external (County, Oregon Department of Fish and Wildlife, and State Forests Advisory subcommittee) input. District engineers and planning and marketing unit foresters, information technology and recreation specialists all collaborated on this project. The State Forests Engineer and a transportation planner also worked on the project. There is a Core team with Assistant District Forester and County Commission representation, plus a review group of the State Forests Advisory Committee. The Core group met twice to establish objectives and form of the plan. Priority data available and needed were determined. Then a smaller working group met, looking at the existing and planned roads and long-term planned harvest units. Road locations were refined based on experience planning roads in the basin, or in similar basins. A goal was to have roads travel to ground based yarding areas (gentler terrain) and use these areas to advantage to reach suitable landing areas (usually ridgetop flats, or spur ridge flats).

An initial Guiding Road Planning Vision was developed as follows. "Roads will access critical control points (landings, saddles and mid-slope benches) based on careful planning. To the maximum extent feasible, roads will avoid streams and wetlands, and especially narrow canyons. Transportation planning will consider current and future stand economics, maximizing logging efficiency, and minimizing disruption to designated and planned trails. Existing roads that do not meet these objectives will be properly vacated or stabilized and converted to trails. Where feasible road locations are unavailable, roads will be designed to facilitate aerial logging methods. The road and trail networks will be integrated to reduce user conflicts and keep risks to users low and consistent with the road or trail classification. Roads will be located, designed, constructed and improved using techniques that protect natural resources. This

includes minimizing the creation of non-forested areas, and not significantly elevating the already high landslide risk. The transportation plan will be flexible, recognizing that when new technologies and better information becomes available over time it will be used to update the plan as appropriate".

Transportation planning has included the following tasks: 1) Review existing road information and information gaps; 2) Prioritization of existing roads to determining use constraints; and 3) Develop a use constraint survey and use on priority roads. We are in the process of identifying: main access routes; critical control points (flatter locations, saddles, and good landing locations); and existing roads needing improvement to collector standard. This includes determining which existing roads to vacate or turn to trails; if planned collectors need additional verification; planned spurs located with reasonable confidence (generally not field verified); and the time period roads are needed (permanent, periodic, single use).

We verified three planned road locations in the basin on-the-ground. The routes were pegged using the USGS 1:24,000 maps and 10-meter Digital Elevation Models (DEM) made from these maps. In all cases,

road grades appeared significantly steeper than as pegged (as much as 4 to 10%). Since pegging grades were already steep (12- 16%), many of the actual grade sections became excessive (>20%). In difficult terrain, planned road sections crossed unfavorable landscape features. During the field reconnaissance, we were able to find better alternative locations that were not identified using the USGS quads. We found that USGS quads are not adequate for detailed transportation planning in difficult terrain. Planning for these slopes must emphasize using favorable land features that exist on the ground but are not apparent on the 10-meter DEM maps.

A slope steepness planning criteria for roads was developed as follows:

- Under 20% (road unlimited except within 100 ft streams)
- 20-50% (excellent for roads, focus for roads in steep terrain)
- 50-80% (not for switchbacks)
- Over 80% (avoid except for very short segments)

Road construction and improvement costs for planning purposes based on these slopes are shown in Table 1 (for aggregate surfaced roads).

Table 1. Road costs for planning purposes - new construction and major improvement

Average New Road Construction Costs				
	slope class			
Road Class	0-20%	21-50%	51-80%	>80%
	rate/sta	rate/sta	rate/sta	rate/sta
Mainline	\$2,135	\$2,224	\$4,761	\$8,310
Collector	\$1,477	\$1,596	\$3,414	\$5,958
Spur	\$952	\$1,120	\$2,397	\$4,183
Average Road Reconstruction (major improvement) Costs				
	slope class			
Road Class	0-20%	21-50%	51-80%	>80%
	rate/sta	rate/sta	rate/sta	rate/sta
Mainline	\$672	\$700	\$917	\$1,435
Collector	\$493	\$500	\$870	\$1,230
Spur	\$372	\$376	\$653	\$923

Costs and Benefits

A general construction and improvement costs by slope was developed. For this process, we used the Harvest & Habitat model (Sessions et al, 2006) average rates and adjusted costs based on information provided from recent appraisals in Tillamook and Forest Grove Districts and from observation and interpolation based on the planning slopes listed above. An estimate of volume hauled per time period was part of the recently completed H & H model. However, due to slope steepness inaccuracy in the topographic data, the original road construction cost estimates ended up at very similar average rates, despite the great variation in terrain. Therefore, the costs have been reviewed and modified (Table 1) and will be applied to the revised new roads. Similar tables are under development for road maintenance, vacating, and upgrading roads to a higher classification (spur to collector). Environmental costs in a small portion of the watershed were evaluated using an Analytic Hierarchy Process (AHP) (Dodson et al, 2007). Another way this will be evaluated is with a network analysis, removing segments of collector roads and determining the increased haul costs associated with those removed road segments.

These roads provide many benefits, including generally all season timber haul, recreational opportunities, stand management and fire control. Roads are an asset unless they are in the wrong place or unneeded. The original model run produced a timber haul volume per segment per time period, and this will be done with the revised transportation planning roads layer. Another benefit of the plan is identification of roads with the greatest environmental risk. The planning process will identify which of these roads to vacate, which to relocate or improve, and those to maintain as they are. Ultimately, this process should allow the transportation system to have maximum asset value and also to minimize road associated liabilities.

Goals

The project Goal is to develop and establish a process and products for transportation planning that that integrates environmental, social and economic values. It provides an access plan (roads and trails) that meets current and future needs for forest management, fire protection, public use, and other special use access needs. The plan will include alternatives with information so that associated costs and benefits can be evaluated. It increases the overall cost effectiveness, efficiency, and safety of the access system

and identifies areas or projects that will require significant investments or alternative funding mechanisms to implement. Another goal is to minimize unanticipated conflicts between forest roads and recreational trails, and provides a more integrated approach for planning the two systems (roads and trails). Following the plan should eliminate, mitigate, or minimize environmental degradation and adverse effects from forest roads and trails on aquatic systems, wildlife habitats, productive forests and sensitive plants. It will result in more effective forest management plan implementation over time, and encourage integrated planning activities to promote sensible, economic choices. Finally, it must be able to integrate the use of innovative technologies and road development systems.

Products

This plan will be used to help guide road construction, repair, maintenance and closures (temporary and permanent vacating). It will be used for future annual operating plans, for evaluating ways to get roads constructed and removed over the long-term. This plan will be a starting point, recognizing better data and new technologies will be available in the future. For example, actual road location now requires detailed field reconnaissance work and terrain assessment during location, and LiDAR data is expected to reduce this need in the future (at least for planning, not so much for design).

The products being developed are: 1) Display and narrative summary of and summary of current road conditions important for transportation planning; 2) Display and narrative summary of and summary of fully managed road conditions and trail conditions; and 3) Road work by timeframe (short, mid and long term). Recreational opportunities associated with roads that can be closed or vacated, or will remain abandoned will also be documented. All of these will be in a report; with data will be in GIS format with event or attribute tables.

There will be a list of roads to build over time, and roads to vacate over time. This list will include road length, estimate construction cost, value accessed, environmental risk and priority. Finally, in some cases timber sales may not support construction to otherwise productive forest lands (currently affected by Swiss needle-cast or deformed alder) or provide important recreational access. Such roads will be identified for special funding considerations and options.

Conclusions

This is a pilot study, and is designed to solicit input and changes. Validation will be based on review by the very experienced personnel working on this project, and in both the Tillamook and Forest Grove Districts. For these planning purposes, road locations can be improved with better ground data. This product is concurrent with the watershed analysis for the basin, and there will be data sharing during the watershed analysis process, especially in prioritization of basins for road repair. The work group recognizes that this product is only as good as the data used to develop it. At the present time, there are major limitations in the slope (landform) data. Accuracy in terms of costs is plus or minus 40 percent, and confidence in the planned roads locations prior to field or LiDAR verification is low to moderate at best.

Transportation Planning is a process and with all that is going on it will take some more time. The fact that many existing roads may or may not be essential makes this a more complex process than transportation planning in a un-roaded landscape. Most of the elements and data needed are available, or will be available soon. How best to assemble, analyze and display them so that managers and stakeholders can understand the alternatives is yet to be resolved. We expect this to be complete on the Wilson Watershed this year and complete for all State Forests by 2011. As a public agency we need to work directly with many stakeholders, and also consider uses in addition to timber harvest. Ultimately, this process is intended to help us understand how to obtain the "greatest permanent value" (a term defined in law) for these lands.

Literature Cited

- Chung, W. and J. Sessions. 2003. NETWORK 2000: a program for optimizing large fixed and variable cost transportation problems. In: G.J. Arthaud and T.M. Barrett (eds.) Systems Analysis in Forest Resources, Kluwer Academic Publishers. pp. 109-120.
- Dodson, Elizabeth, W. Chung, K. Mills, R. Nall, J. Sessions and G. Zartman. 2007 Transportation planning to determine low volume road standards, long term needs, and environmental risks and tradeoffs Paper 9LVR-0059, in Press for Proceedings of 9th International Conference on Low Volume Roads (Transportation Research Board. 2007)
- Mills, K. 2006. Environmental Performance Measures for Forest Roads. Paper presented at the 2006 Annual Meeting of the Council on Forest Engineering
- Mills, K, L. Dent and J. Cornell. 2007. Rapid survey of road conditions to determine environmental effects and maintenance needs. Paper 9LVR-0128, in Press for Proceedings of 9th International Conference on Low Volume Roads (Transportation Research Board. 2007)
- Oregon Department of Forestry. 2000. Forest Roads Manual
- Sessions, J., P. Overhulser, P. Bettenger and D. Johnson. 2006. Linking Multiple Tools: An American Case. In: Computer Applications in Sustainable Forest Management. Chapter 11. Springer. G. Shao and K. Reynolds, eds.

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STEEP GRADIENT FISH PASSAGE CULVERT ALTERNATIVES TO BRIDGES

Brandon Gallagher

Abstract: Forest engineers are sometimes faced with replacing culverts buried under deep fills spanning steep-gradient fish streams. Large culverts have traditionally not been a good solution for these situations because engineers could not maintain a simulated natural streambed due to the steep-gradient (over 8%) stream velocity through the culvert (ODF Tech Note #4). This led to the practice of installing large-diameter culverts with steel retaining structures (Figure 1) to hold the simulated streambed material in place.

Key words: Steep Gradient, culvert, bridge, retaining structure

Introduction

Forest engineers are sometimes faced with replacing culverts buried under deep fills spanning steep-gradient fish streams. Large culverts have traditionally not been a good solution for these situations because engineers could not maintain a simulated natural streambed due to the steep-gradient (over 8%) stream velocity through the culvert (ODF Tech Note #4). This led to the practice of installing large-diameter culverts with steel retaining structures (Figure 1) to hold the simulated streambed material in place. In the appropriate application, this engineering design has proved to be a cost-effective alternative to either re-routing the road to a lower stream crossing (and short bridge) or constructing a fairly long bridge in the crossing to maintain the existing grade.

Typical Stream Characteristics

These headwater streams with an average drainage area of 400 acres and have a gradient between 8% and 14%. These streams have a structure of large cobble to boulders (not bedrock). Fish habitat is limited in both quantity and quality above these crossings, so it is imperative to determine a solution that provides fish passage in a cost-effective way.

Alternatives

The current alternatives for steep gradient fish passage are bridges, open bottom arch pipes, and weir/baffle culverts.

Bridges

Bridges are much higher in cost. Costs for bridges are on average \$1500/ft. An 8 to 10 foot stream would require a span of at least 30 feet. 30ft x \$1500/ft = \$45000 for a short bridge. The other drawback to bridges are the logistics of installing them in headwater stream locations. Poor alignment and steep road grades make it very hard to deliver and install a bridge.

Open Bottom Arch Pipe

Bedrock is required to prevent scour, and the streams that we are dealing with are not bedrock.

Weir/Baffle Culverts

These culverts are very difficult to maintain over time. The pool at the outfall and the baffles inside the culvert are difficult to maintain.

Adaptive Trial

In 1998 a field tour was conducted on Weyerhaeuser land with ODF and ODFW where some existing crossings were examined and options for fish passage were discussed. Stream Gradient limits on streambed simulation culverts were discussed. The state agencies expressed concerns about rock remaining in a streambed simulation culvert. Since there are many fish streams with gradients in excess of 8% and limited or marginal upstream habitat, Weyerhaeuser proposed an adaptive trial to find a more economical solution to this problem. The adaptive trial consisted of a streambed simulation culvert with special design considerations and a follow up monitoring of the

installation to determine success of the adaptive trial, maintenance needs, and possible design change needs for future trials. The more economically that these old crossings could be reconstructed to allow fish passage, the greater the number of crossings could be upgraded in a shorter time span.

Specific design considerations will be as follows:

1. A large ladder shaped metal frame (figure 1) will be installed inside of the culvert to insure that bed load is retained inside of the culvert. This metal frame anchored to the culvert inlet will span the width of the arch pipe and will be installed approximately 12 inches above the culvert invert. The internal rails of the frame will be constructed out of 3" x 3" x 1/4" angle iron. The rail across the inlet of the pipe will be constructed out of 4" x 4" x 1/4" angle iron. The internal cross rails will be placed approx 10' apart except for the two closest to inlet, which will be placed 5' apart.
2. Boulders 24 inches to 36 inches in diameter will be dug into the streambed to a depth of 18 inches to 24 inches at the outfall of the arch culvert. This will prevent down cutting at the outfall and will help hold bedload inside of the culvert.
3. The culvert will be bedded with a mix of rock ranging in size from gravel to boulders 18 inches or larger. A row of boulders 15 inches or larger will be placed against each rung of the metal frame. This will serve to prevent movement of smaller gravel out of the culvert and will prevent wood from snagging on the frame during storm events. This mix of sizes randomly placed will allow the stream to form a channel with enough roughness to slow water velocity and create pools within the culvert.

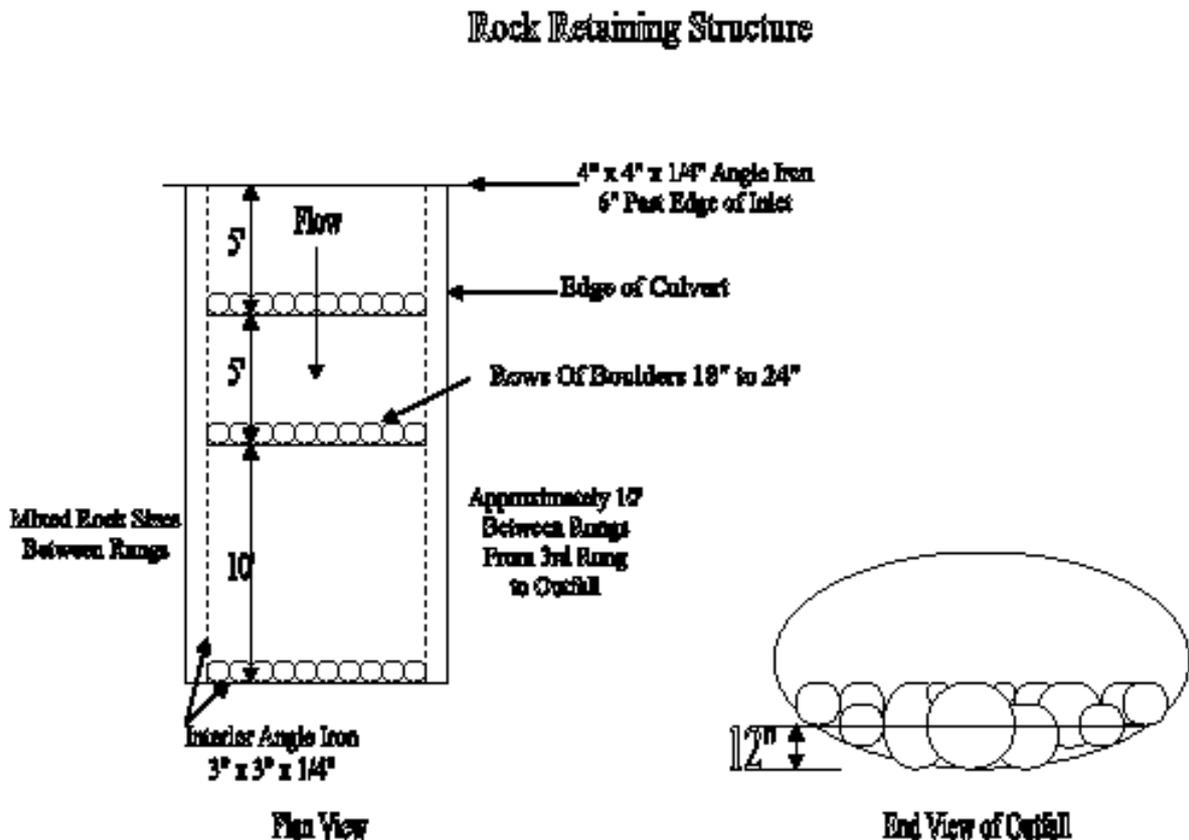


Figure 1. Detailed views of rock retaining structure

Monitoring

This adaptive trial will be field checked annually to evaluate how well it is functioning for fish passage and for possible maintenance needs. As part of the monitoring process photos will be taken of the inlet, outfall, and stream structure inside of the culvert each year for ten years at which time the need for continued monitoring will be reviewed.

Conclusion

There is a great need for more economical options to crossing steep gradient small fish streams than are currently available. This adaptive trial has been developed to address this need.

Table 1. Example stream and culvert data is as follows: (ODF Tech Notes 4 & 5, OAR 629-605-0170(1)(a) and 629-625-0100(1,2), and 629-625-0320(1,2))

	CASH CREEK
Drainage Area	410 Acres
50-year event	110 cfs
Average stream gradient	11.5%
Stream bed material	Gravel & Cobble
Stream width	8 feet
Culvert size	112" x 75" x 56"
Culvert gradient	10.0%
Inlet depression	3 ft
Outlet depression	2 ft.
50-year event head ratio	72%

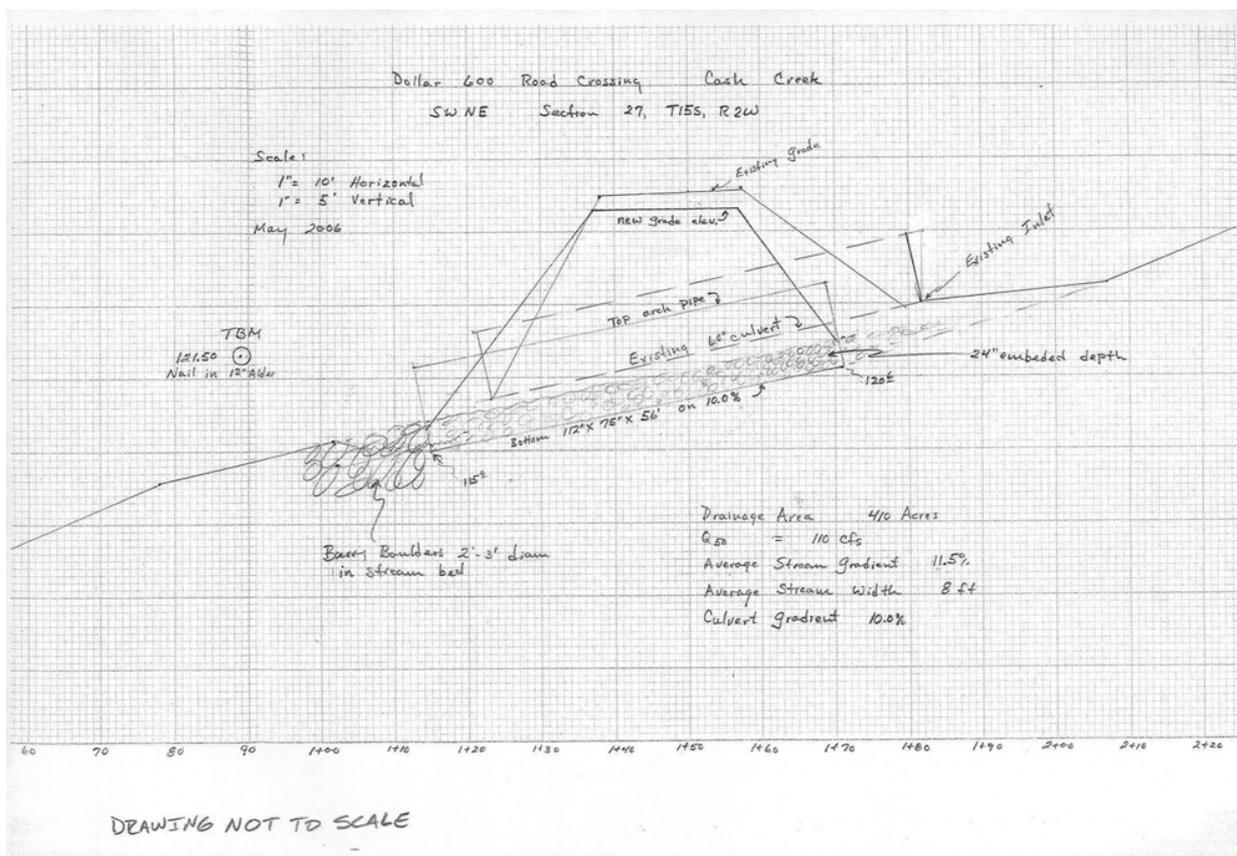


Figure 2. Detailed plan/profile of a stream crossing (ODF Tech Notes 4 & 5, OAR 629-605-0170(1)(a) and 629-625-0100(1,2), and 629-625-0320(1,2))

References Cited

Oregon Forest Practices Administrative Rules
629-605-0170(1)(a) and 629-625-0100(1,2), and 629-
625-0320(1,2)

Oregon Forest Practices Technical Note #4

Oregon Forest Practices Technical Note #5

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A CASE STUDY OF AN EROSION CONTROL PRACTICE: THE BROAD-BASED DIP

Kevin Bold, Pamela Edwards, Karl Williard

Abstract: In 2006, 19 gravel haul roads with broad-based dips within the Monongahela National Forest were examined to determine if those dips adhered to Forest specifications for cut depth and dip outslope. Data on the azimuth, contributing road lengths, slopes of the contributing lengths, landscape position of the dip, and soil texture of the road bed materials also were recorded to identify variables that explained variation in cut depth and dip outslope. Only about 22 percent of the dips met allowable cut depth specifications, and just over half of the dip slopes met the 2-5 percent outslope specifications. Cut depth was explained primarily by road geometry variables, suggesting that proper construction is important to ensure the dip impedes longitudinal drainage down the road while remaining traversable. Dip slope was affected by environmental and use variables, so maintenance during and following use is critical to ensuring proper short- and long-term drainage.

Introduction

The construction and use of forest roads can alter natural forest hydrologic processes primarily through destruction of the forest floor, including soil compaction (Stuart and Edwards, 2006; Greacen and Sands, 1980; Packer, 1967). Forest roads can generate significant overland flow resulting in erosion and sedimentation (Jones and Grant 1996; Elliot, 1999). As a result many best management practices (BMPs) are implemented to control water on roads and road runoff. One such BMP is the construction of cross drainage structures designed to efficiently drain water off the road prism in order to control the erosion potential of water collecting on the road surface (Packer 1967). Culverts and broad-based dips are the primary cross drains constructed on cut-and-fill haul roads (Copstead et al. 1998). Broad-based dips originally were designed for eastern forests because they provide water drainage while providing vehicular traffic a smooth, traversable route (Swift, 1985; Cook and Hewlett, 1979; Hewlett and Douglass, 1968).

Visual observations during and after rain events on a limited number of roads within the Monongahela National Forest, however, indicated that many broad-based dips were not functioning properly. Water was either ponding in the dip or moving longitudinally down the road. Consequently, the objective of this paper was to determine how commonly broad-based dips on roads in the Monongahela National Forest maintained original designed specifications, after use and road closure, and to identify the factors that

significantly explain the variation in broad-based dip geometry.

Methods

Study Site

Broad-based dips examined in this study were from cut-and-fill haul roads on the Monongahela National Forest, West Virginia. A sample of roads across the entire Forest was desired, but there were fewer roads with dips in the southern and southwestern portions of the Forest. Thus, the majority of sampled roads were in the northern and east-central part of the Forest. An average of 8 dips per road were sampled on the 19 roads included in the study.

Field Methods

In each dip, points of interest were surveyed in 2006 by a two-person crew using a total station. The parts of the dip that were surveyed included the base of dip, defined as the transect across the dip where water should concentrate and drainage should occur (Fig. 1), and the upper and lower dip boundaries, which were the longitudinal limits of each dip (Fig. 1). The points measured in the transect across the base of the dip were: the bottom of the cutbank, the outside edges of both wheel tracks, the center of each wheel track, the approximate center of the road, and the outside edge of the road (Fig. 2). The outside edge of the road, which at times was the same point

as the outside tire track (Fig. 2), was identified as the approximate point where the road surface substrate noticeably changed in size or material. A point was

surveyed in each wheel track in both the upper and lower boundaries of each dip (Fig. 1).

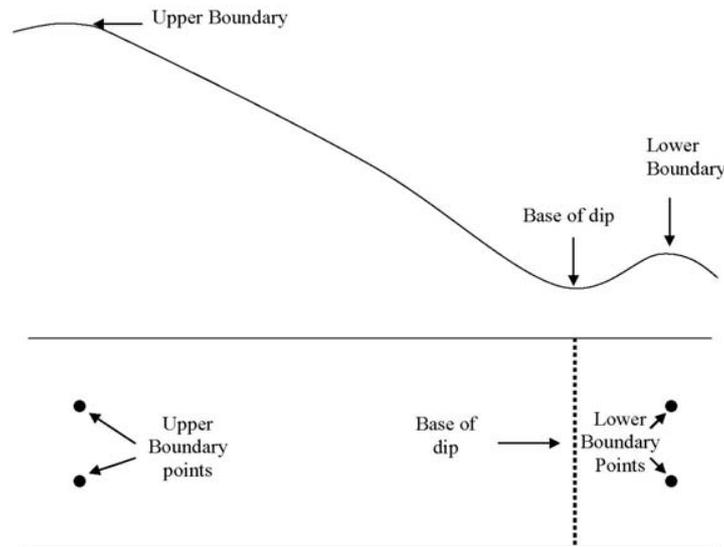


Figure 1. (Top) Exaggerated schematic of a road profile displaying upper and lower boundaries and the base of a broad-based dip. (Bottom) Plan view schematic of a broad-based dip showing the surveyed transect at the base of the dip and the two points in the wheel tracks in the upper and lower boundaries of the dip.

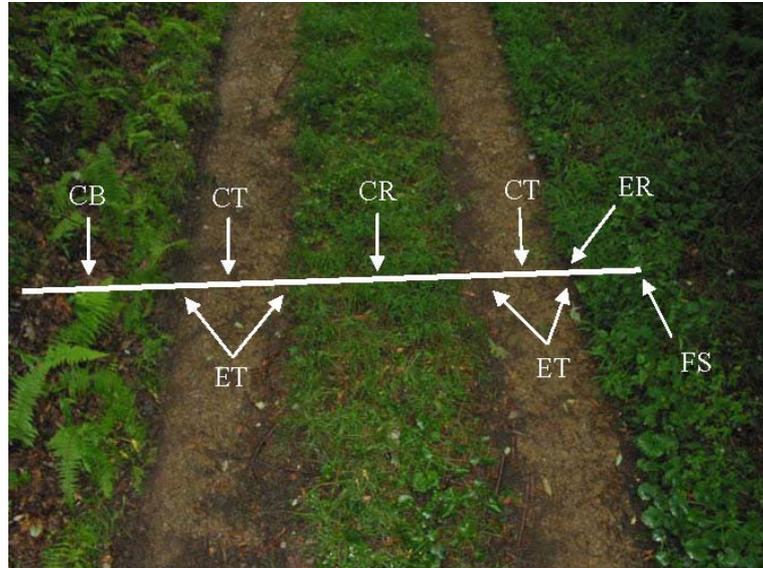


Figure 2. Points were measured in a transect across the base of the dip from the bottom of the cutbank (CB) to the top of the fillslope (FS). Points included CB, edge of track (ET), center of track (CT), center of road (CR), and edge of road (ER), which is the same as edge of track in this example.

Data on other variables also were collected. These variables were position of the dip on the road, azimuth, presence/absence of seeps, and soil texture. Three possible dip positions were identified in the field: nose of ridge (nose), cove, and other, which included all positions that were not classified as nose or cove. Azimuth was measured using a compass at the dip outlet, facing the fillslope in the direction water would flow through the dip. The number of dips in each of the road positions by aspect (determined from azimuths) is presented in Table 1.

Presence/absence of seeps within the boundaries of each dip was recorded; however, seeps were present in only 9 of studied dips so this variable was not used in further analyses.

Table 1. Number of dips in each road position by aspect in the Monongahela National Forest.

Aspect	Azimuth range	Position on road			Total
		Cove	Nose	Other	
North	>337.5° to 22.5°	8	13	11	32
Northeast	>22.5° to 67.5°	2	7	9	18
East	>67.5° to 112.5°	6	1	4	11
Southeast	>112.5° to 157.5°	4	1	4	9
South	>157.5° to 202.5°	3	5	5	13
Southwest	>202.5° to 247.5°	5	8	18	31
West	>247.5° to 292.5°	3	3	7	13
Northwest	>292.5° to 337.5°	1	7	11	19
Total		32	45	69	146

Samples for soil textural analysis (i.e., percents sand, silt, and clay) were collected from the bottom of the cutbank near the base of the dip using a spade. This location represents the soil from which most of the road surface is composed. Approximately 2 kg of soil was collected and placed into a bag containing the Forest Service road number, the dip identification number, and position on the road. Generally one soil sample was collected from each dip, but occasionally, one sample was used to represent the texture for two or three adjacent dips located in the same position on the road. Soil texture then was determined on the <2-mm material using the hydrometer method (Gee and Bauer 1986). Several of the dips did not have textures associated with them because some of the identification numbers became smeared and were not readable. Five dips were missing soil textures because one road could not be accessed at the time of soil sample collection because of a locked gate for which a key was not available.

Forest Broad-Based Dip Specifications

The Monongahela National Forest requires broad-based dip construction to meet two primary engineering specifications to ensure that they function properly. First, the dip must be sufficiently deep to impede water from draining down the road (USDA Forest Service 1996); this specified cut depth, herein called Forest cut depth, is the vertical distance from the Forest profile grade to the center of the base of the dip (Figs. 3 and 4). The Forest profile grade is the original grade of the road extending from where dip excavation began to the lower boundary of the dip (Fig. 3). The Forest cut depth is related to the Forest profile grade in that as the grade increases so does the specified depth (Table 2). The second Forest

specification is that the base of the dip should be out-sloped 3 percent toward the fillslope (Fig. 4), though a range of 2-5 percent is allowed. Dips with too little of an outslope (<2%) are not steep enough to drain water, and dips with outslopes that are too extreme (>5) are too steep to accommodate vehicular traffic (W. Church, Monongahela National Forest, pers. comm.).

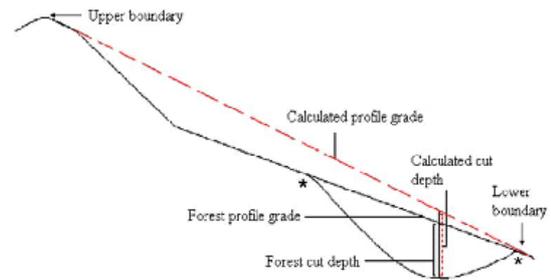


Figure 3. Exaggerated schematic of a broad-based dip showing the upper and lower boundaries, Forest profile grade, Forest cut depth, calculated profile grade, and calculated cut depth. The * symbols mark the beginning and end of dip excavation.

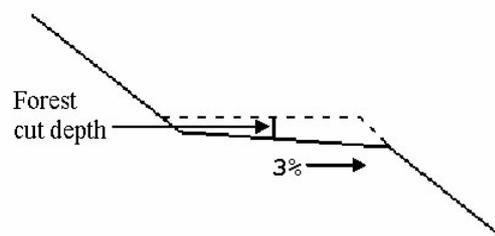


Figure 4. Schematic of a dip cross section displaying the Forest cut depth and 3% outslope (toward the fillslope).

Table 2. Forest profile grades and corresponding Forest cut depths allowed for dips constructed on the Monongahela National Forest. Road segments exceeding 9 percent grade may not be drained by broad-based dips in the Monongahela National Forest.

Forest profile grade range (%)	Cut depth range (cm)
<1	2 to <22
1 to <3	22 to <37
3 to <5	37 to <46
5 to <7	46 to <58
7 to <9	58 to <76

Data Processing and Statistical Analyses

The Forest profile grade was estimated by a calculated profile grade. Although the lower boundary point approximates the lower end of dip excavation, the upper point where dip excavation began could not be identified with certainty in the field, so the profile grade had to be estimated. Consequently, the calculated profile grade was measured from wheel track point in the upper boundary to the wheel track in the lower boundary (Fig. 3). Because two wheel tracks measurements were available, for consistency the upper/lower pair that comprised the longest length was used to define the calculated profile grade. By this method, calculated profile grade generally is higher than the Forest profile grade, but as long as there were no major grade breaks in the upper contributing length of the road it was a good estimate of the Forest profile grade.

Likewise a calculated cut depth was used to estimate the Forest cut depth. Calculated cut depth was the vertical distance from the wheel track in the base of the dip used for the calculated profile grade to the calculated profile grade (Fig. 3). The calculated cut depth was not determined in the center of the road because no center of the road measurement was made in the upper or lower dip boundaries, so no calculated profile grade could be calculated for the center of the road position.

The percent slope of the base of the dip also was determined from the bottom of the cutbank to the edge of the road (Fig. 2). Positive values indicate out-sloping dips, and negative values indicate dips that are in-sloped toward the cutbank.

Because the total station results represent only X, Y, and Z (elevation) values relative to the location and elevation of the instrument height, ArcMap™ 9.1 and Microsoft™ Excel were used to calculate additional slope length and distance measurements. These included the upper and lower contributing lengths, measured from the upper and lower boundary points, respectively, to the base of dip (Fig. 5), and the percent slope of both of those components, termed the upper and lower contributing slopes (Fig. 5).

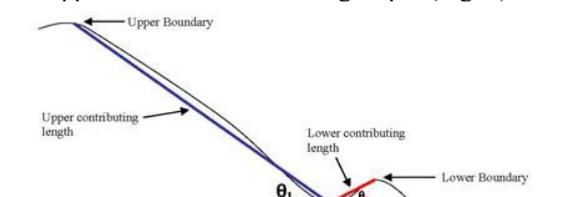


Figure 5. Schematic showing upper and lower contributing lengths and upper (θ_1) and lower (θ_2) contributing slopes.

Mean calculated cut depths and dip slopes were examined for differences among the three positions on the road using SAS at $\alpha=0.05$ (SAS Institute 1988). Stepwise regression also was run in SAS to identify variables that explained a significant portion of the variation in calculated cut depth and dip slope. The explanatory variables were azimuth, upper and lower contributing lengths, upper and lower contributing slopes, and soil texture. An alpha value of 0.15 was used so the analysis would not be too stringent to exclude variables with predictive power (SAS Institute 1988).

Results and Discussion

Cut Depth

Mean calculated cut depths were not significantly different among road positions (Table 3), so all data were pooled for further analyses. The distribution of dips in each profile grade by calculated cut depth is shown in Table 4. Twelve dips had calculated profile grades that exceeded the allowable Forest profile grade (>9%) for road segments with broad-based dips. No more than 30% of the dips in any single calculated profile road grade category met Forest cut depth specifications, and overall only 28 of the 130 total dips met Forest cut depth specifications. Of the dips that did not meet cut depth specifications, the majority of them had cut depths that were shallower than allowed, though most of those were at least 22 cm deep.

Table 3. Means and standard deviations of calculated cut depths and dip slopes on roads in the Monongahela National Forest. None of the calculated cut depths or dip slopes were statistically different among positions on the road at $\alpha=0.05$.

Position on the road	Calculated cut depth (cm)	Dip slope (%)
Cove	53.6 ± 21.4	3.35 ± 1.64
Nose	50.6 ± 32.6	3.99 ± 2.66
Other	42.9 ± 22.3	3.65 ± 1.95
All Positions	47.4 ± 25.6	3.67 ± 2.14

As noted previously, calculated cut depth was measured in the center of one of the wheel tracks rather than in the center of the road. One implication of using the wheel track positions for the calculated profile grades and the calculated cut depths is that the calculated cut depths probably were slightly greater

than the actual Forest cut depth. Thus, some dips, especially those that were near the upper or lower limit of a specific cut depth category, may be assigned to incorrect cells in Table 4. Additionally, the wide distribution of values across all of the calculated profile road grades suggests that there were many dips that would not have met Forest cut depth specifications even if actual Forest profile grades and Forest cut depths had been used.

Four variables explained a total of 48.7 percent of the variation in the calculated cut depth (Table 5). Lower and upper contributing slopes were positively related to calculated cut depth, so as the road grade and reverse grade of the broad-based dip increased, so did the cut depth. This is logical since dip construction on steeper roads necessarily requires a deeper cut for the dip to adequately impede longitudinal drainage down the road. The specifications shown in Table 2 illustrate this need. Likewise, based on the geometrical relationships of a right triangle, the lower contributing length (i.e., the hypotenuse) must increase as the lower contributing slope (Fig. 5) increases, assuming a constant horizontal distance from the base of the dip to the lower boundary of the dip. Thus, the relationships between the cut depth and other significant road geometry measurements appear to be attributable largely to the initial construction characteristics and subsequent maintenance.

The percentage of silt in the soil composing the base of the dip explains less than 2 percent of the variation in calculated cut depth. There is no clear explanation of why silt was a significant variable.

Table 4. Number and percentage of dips (in parentheses) for calculated cut depths. Values in grey cells indicate those that meet Monongahela National Forest specifications for the corresponding profile grade range.

Road grade (%)	Calculated cut depth (cm)							Total
	<2	2 to <22	22 to <37	37 to <46	46 to <58	58 to <76	>76	
<1	0	0 (0%)	0	1	0	0	1	2
1 to <3	0	2	3 (16.7%)	5	5	1	2	18
3 to <5	0	4	6	8 (25.8%)	8	4	1	31
5 to <7	0	3	11	8	11 (28.2%)	4	0	37
7 to <9	0	0	5	8	7	6 (15.4%)	4	30
>9	1	1	0	1	3	4	2	12
Total	1	10	25	31	34	19	10	130

Table 5. Independent variables with accompanied P-value and partial r² that significantly explain the variance of dependant variables measured on broad-based dips on roads in the Monongahela National Forest. Plus or negative signs indicates a positive or negative relationship between the dependent and independent variables. $\alpha=0.15$

Dependent variable	Independent variable	P value	Partial R ²
Calculated cut depth	Lower contributing length (+)	<0.0001	0.165
	Upper contributing slope (+)	<0.0001	0.154
	Lower contributing slope (+)	<0.0001	0.15
	Silt (-)	0.0727	0.018
Dip outslope	Azimuth (+)	0.0020	0.0936
	Lower contributing slope (-)	0.0744	0.0294
	Clay (-)	0.1472	0.0191

Dip Slopes

Mean slopes of the dips also were not significantly different across the three road positions (Table 3). Average dip outslope for each of the road positions was between 3 and 4 percent, which is within the 2-5 percent allowable range defined by the Forest engineers. The average dip outslope for all positions was 3.67 percent, but the high standard deviation (2.14 percent) indicates that many dips were outside of the allowable 2-5 percent range. In fact, almost half of the dips (42 percent) had slopes < 2 percent or >5 percent. Approximately 24 percent had dip slopes < 2 percent, and 18 percent were > 5 percent.

Dip slope variation was explained by three variables that collectively accounted for just over 14 percent of the variation. Azimuth explained the greatest amount of variability, about 9 percent. As azimuth increased from 0° to 359°, so did the percent of outslope (Fig. 6), indicating that the dominant control was whether the dip had an east-facing or west-facing component. Aspect has a strong influence on temperature and evapotranspiration (Haase, 1970), and the greater outslowing on western aspects probably exists because it is easier for dips to retain their designed ~3 percent outslope in drier conditions. During periods of use, higher evaporation rates would help keep west-facing soils and road surfaces dry and less apt to deformation by trafficking effects.

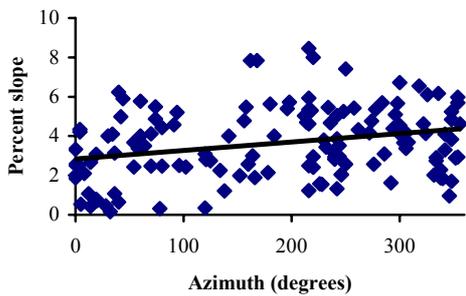


Figure 6. Linear regression relationship between azimuth and dip slope on roads in the Monongahela National Forest.

The inverse relationship between dip slope and lower contributing slopes may be partly a function of dip construction, because proper dip outslopes are easier to construct on gentler slopes, which also typically would require less steep lower contributing slopes. However, heavy equipment use on these haul roads also is believed to contribute to the inverse relationship between dip slope and lower contributing slopes. Log trucks and other heavy equipment tend to favor traveling toward the inside of the road because it is made of more stable residual soil material compared to less consolidated soils on the fillslope side of the road. It is not uncommon to see evidence of log truck tires running immediately along the bottom of the cutbank. As a result, the bottom of the cutbank receives repeated heavy travel that tends to compact the soil more than at the outside edge of the road. This problem may be exacerbated more in the base of the dip than anywhere else because of the effect that the reverse grade of the dip (i.e., the lower contributing slope) has on how vehicles move through the base of the dip. Trucks typically slow down as they approach the reverse grade, regardless of the direction they travel. Then as they travel through the base of the dip they must accelerate to go up the subsequent incline (either the lower or upper contributing lengths). The steeper those inclines become, the greater the potential for wheel slip and/or friction in the dip base, which can result in increased soil displacement and contribute to compaction and possibly rutting. The result of soil displacement and compaction is a reduction in the elevation of the inside of the base of the dip, while the edge of the road is less affected because it bears much less trafficking. Thus, since the slope of the dip was measured from the bottom of the cutbank to the outside edge of the road (Fig. 2), greater changes to the elevation at the base of the cutbank will reduce the dip slope.

Dip slope also was inversely related to the percent clay, though the amount of variation explained was less than 2 percent. The significance of clay content in the soil can be explained by the relationship of soil moisture, pore volume, and soil strength. Compared to sand and silt, clay generally has greater pore volume (Fisher and Binkley, 2000). When the soil is wet and vehicular traffic drives over it, soil strength is decreased and the susceptibility to compaction is increased (Greacen and Sands, 1980). Consequently, dips containing higher percentages of clay will be susceptible to changes in their constructed geometry, especially in the inside of the dip under the conditions of heavy equipment traffic described above.

Conclusions and Implications

Overall, 20 out of 130 total dips met Forestry cut depth specifications, and of those that did not, the majority had cut depths that were shallower than allowed. Just over half of the total dips met outslope specifications, with the majority being <2 percent. Cut depth was explained primarily by road geometry variables including upper and lower contributing slopes and upper contributing length. Dip slope was affected primarily by azimuth and soil clay content.

While much more variation in cut depth was explainable by the available independent variables compared to the slope of the dip, in both cases less than 50 percent of the variation was accounted for. This is not necessarily surprising since there were many factors that were not considered in this analysis, including road age, information on the types and frequencies of trafficking, and maintenance histories. However, the results of both the cut depths and dip slopes indicate the importance of proper initial construction and subsequent maintenance of dips. Cut depth was largely dependent upon road geometry variables, suggesting that it was less affected by environmental conditions than dip slope. Consequently, if proper attention is paid to the cut depth during construction, it will likely remain at an adequate depth for the long term. By contrast, dip slope was primarily affected by environmental variables and also probably road use related variables. Thus, retention of proper dip slope will require adequate maintenance during road use and before road closure.

Literature Cited

- Church, W. Personal communication, 24 January 2007. USDA Forest Service engineer.
- Cook, W.L., and J.D. Hewlett. 1979. The broad-based dip on Piedmont woods roads. *Southern Journal of Applied Forestry*. 3: 77-81
- Copstead, R.L., D.K. Johansen, and J. Moll. 1998. Water/road interaction: introduction to surface cross drains. San Dimas, Calif. USDA Forest service. San Dimas Technology and Development Center.
- Fisher, R.F. and D. Binkley. 2000. Ecology and Management of Forest Soils. New York: John Wiley and Sons, Inc.
- Gee, G.W., and J.W. Bauder. 1986. Particle-size analysis. p. 383-411. In A. Klute et al.(ed.) Methods of Soil Analysis. Part 1. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI
- Greacen, E.L. and R. Sands. 1980. Compaction of forest soils. A review. *Australian Journal of Soil Research*. 18: 163-189.
- Haase, E.F. 1970. Environmental fluctuations on south-facing slopes in the Santa Catalina Mountains of Arizona. *Ecology*. 51: 959-974.
- Hewlett, J.D. and J.E. Douglass. 1968. Blending Forest Uses. USDA For. Serv. Res. Pap. SE-137.
- Jones, J.A. and G.E. Grant. 1996. Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon. *Water Resources Research*. 32: 959-974.
- Packer, P.E. 1967. Criteria for designing and locating logging roads to control sediment. *Forest Science*. 13(1): 2-18.
- SAS Institute. 1998. SAS/STAT User's Guide, Release 9.1 edition, SAS Institute Inc., Cary NC, U.S.A.
- Stuart, G.W. and P.J. Edwards. 2006. Concepts about forests and water. *Northern Journal of Applied Forestry*. 23(1): 11-19.
- Swift L.W. Jr. 1985. Forest road design to minimize erosion in the southern Appalachians. In: Blackmon, B. G., ed. Proceedings of Forestry and Water Quality: a Mid-South Symposium, AR: University of Arkansas. 141-151.
- U.S. Department of Agriculture, Forest Service. 1996 Forest Service specifications for construction of roads and bridges. Engineering staff section 102. EM-7700-100 Washington DC.

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ASSESSMENT OF FOREST ROAD HYDROLOGY MODELING BY THE DISTRIBUTED HYDROLOGY SOIL VEGETATION MODEL (DHSVM) IN THE OAK CREEK CATCHMENT, CORVALLIS, OREGON

Christopher G. Surfleet, Arne E. Skaugset III, Amy Simmons

Abstract: The Distributive Hydrology Soil Vegetation Model (DHSVM) was analyzed for its ability to predict ditchflow from surface and sub-surface water intercepted by forest roads within a 630 hectare watershed of the headwaters of Oak Creek, Corvallis, Oregon. Within this catchment the Department of Forest Engineering, Oregon State University, has instrumented all culverts on the roads to determine road runoff during storms. Road ditchflow simulations from DHSVM were compared to observed road ditchflow from Oak Creek for 2003-2006. Model performance was judged based on its ability to predict storm volumes, peak flows, fit to the observed time series, and fit to 3 partitions of the hydrograph. The ratio of observed peak flows and DHSVM simulated peak flows for road ditches within Oak Creek was found to be 0.62 with 95% confidence interval [0.49, 0.76] after accounting for the intermittent or ephemeral classification of the road ditch. The mean ratio of observed storm volumes and DHSVM simulated storm volumes for road ditches within Oak Creek was found to be 0.21 with 95% confidence interval [0.14, 0.27]. DHSVM was found to over-predict peak flows and storm volumes for road ditchflow in Oak Creek. The mean ratio between observed peak flows and DHSVM simulated peak flows for the outlet of Oak Creek was found to be 1.19 with 95% confidence interval [0.98, 1.39]. Generally DHSVM simulations provided a reasonable fit to the time series for Oak Creek, with the fit of the time series diminishing for road ditchflow locations. DHSVM simulations provided good fit to the driven-quick portion of hydrographs for streamflow, but simulations fit poorly for road ditches. In a case study, the cumulative effects from roads in Oak Creek were predicted by DHSVM to increase peak flows for Claire Creek (55 hectares) and Oak Creek (630 hectares) an average of 3%. DHSVM predicted an average increase in storm runoff volume from roads for Claire Creek and Oak Creek of 1% and 2% respectively. Given the many uncertainties raised by this study we question whether the cumulative effects analysis of peak flows and storm volumes by DHSVM is appropriate for a catchment like Oak Creek with highly variable hillslope responses.

Key words: Forest roads, hydrology, distributive hydrologic modeling, forest hydrology.

Introduction

Forest roads can affect hillslope hydrologic processes by intercepting sub-surface flow paths and generating overland flow from compacted surfaces. These effects can extend stream channel networks (i.e. Wimple et al, 1996), re-distribute water on the hillslope resulting in changes in stream flow timing, sub-surface water flow, and soil moisture distributions (Megahan 1972; Wigmosta and Perkins, 2001), and alter peak flows at stream crossings (Toman, 2004). However, effects of roads on hydrology at the catchment scale have shown mixed results (i.e. Jones and Grant, 1996; Thomas and Megahan, 1998; Beschta et al, 2000; Wemple, 1998).

The effects of forest roads on catchment hydrology and sediment production are increasingly the focus of regulatory and scientific concerns. As a result assessment of forest roads effects on catchment

hydrology are increasingly being assessed by distributive hydrologic models, like the Distributive Hydrology Soil Vegetation Model (DHSVM) (Wigmosta et al, 1994; Wigmosta and Perkins, 2001). DHSVM is a physically based distributed parameter hydrologic model that allows the simulation of runoff processes in forested and mountainous watersheds (Wigmosta et al, 1994). Wigmosta and Perkins (2001) demonstrated the utility of the road network component of DHSVM in Carnation Creek for showing changes in peak flows and routing of water along road networks. Bowling and Lettenmaier (2001) tested DHSVM on 12 culverts within Hard and Ware Creeks and found the model generally simulated outlet peaks well, and culvert peaks approximately. Their results stated that DHSVM predicted peak flow changes within the catchment from the road network.

To date there has been limited use of distributive models, such as DHSVM, in researching catchment scale hydrologic effects from forest roads. In many of the examples of the use of DHSVM in examining forest road hydrologic effects, the authors conclude that more research needs to be done to better understand the effects that forest roads have on hydrologic processes (Wigmosta and Perkins, 2001; Bowling and Lettenmaier, 2001). This paper provides an assessment that utilizes hydrologic observations at multiple scales of road run-off observations and stream flow observations compared to DHSVM results.

Study Area

This study was conducted in the upper Oak Creek catchment (Figure 1). This portion of Oak Creek is 630 hectares in size and part of the McDonald/Dunn Forest, owned and managed by the College of Forestry, Oregon State University, Corvallis, Oregon. The roads within the catchment have a crowned road tread, with a portion of road treads and cutslopes draining to road ditches at the base of cutslopes. The water in the road ditches gets routed into stream channels or onto the hillslope through culverts in Oak Creek. A total of 97 culverts have been instrumented to collect road ditch flow for calculations of storm run-off since 2001. There are 23 road stream crossings and 74 cross-drain culverts (culverts which drain water from road ditches under the road). Of the 74 cross-drain culverts 45 have continuous electronic recording; the remaining 29 cross-drain culverts have crest gages that measure only the peak stage. The cross-drain culverts have been classified by whether its road ditch had intermittent flow (flows most of the winter) or ephemeral flow (typically only flows in response to precipitation events, often only large precipitation events). Of the 74 cross-drain culverts considered in this study 34 were classified as ephemeral and 40 were classified as intermittent.

A meteorological station is operated near the outlet of the study catchment; meteorological observations have been collected since February, 2003. This meteorological station collects continuous air temperature, relative humidity, solar radiation, wind speed, wind direction, and precipitation. In addition three other rain gages are located at spots throughout the catchment; locations vary by elevation and aspect. The weir at the outlet of the study catchment has continuous stage and turbidity and suspended sediment observations, collected since 2001 and 2003 respectively.

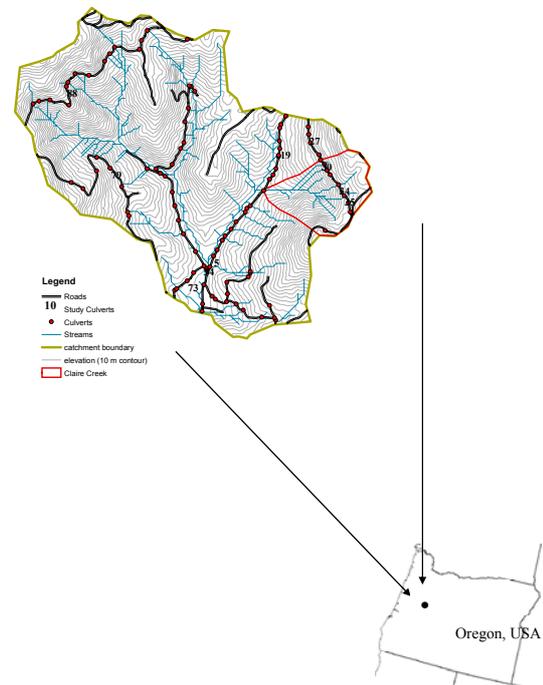


Figure 1. Upper Oak Creek Catchment, Corvallis, Oregon.

Methods

The examination of road hydrologic predictions from DHSVM utilized the hydrologic observations from the Oak Creek catchment (discussed previously). DHSVM simulations utilized a 30 meter digital elevation model (DEM) for its basic unit of calculation. The DHSVM application used a 3 hour time step for its calculations.

Meteorological inputs to DHSVM were taken from the meteorological station and precipitation gauges in the catchment. When meteorological inputs were missing from the Oak Creek station, data was filled in by observations from the Corvallis Agrimet weather station, Corvallis, Oregon maintained by the U.S. Bureau of Reclamation. Linear relationships between the Oak Creek and Agrimet meteorological observations were established to make adjustments to the Agrimet data used for the upper Oak Creek modeling. Soil inputs for the DHSVM application used the soil textures from the Benton County Soil Survey (Knezevich 1975). Vegetation in the catchment can be best described as Coastal Forest, a vegetation class within DHSVM. Although other minor areas of other vegetation types exist in the catchment, grass and

hardwoods, these areas are small and were not separated out for this application. The stream network for this DHSVM application was produced using the “createstreamnetwork.aml” script provided with DHSVM. The soil depth information used for this application was created by fitting a soil depth model that runs within the “createstream network.aml” to field observed soil depths.

DHSVM was calibrated using a systematic manual calibration using a technique similar to Whitaker et al (2003). The calibration time period was from October, 2005 through June, 2006; the time period with the greatest variety of stream flow magnitudes and the largest events of the time period analyzed. Fit of the model to stream hydrographs was evaluated quantitatively by: 1) volume error for predicted versus observed run-off; 2) model efficiency (Nash and Sutcliffe, 1970) and 3) coefficient of determination (D!) (see Whitaker et al, 2003). Fit of the model was also evaluated qualitatively for general fit of model observations to observed values. This was necessary because it was impossible to get good quantitative fits for the model output at the wide variety of scales used for the calibration, particularly the road locations. The resulting calibrated model used only one parameter set for this analysis.

To assess DHSVM’s ability to predict the instantaneous peak flow and total storm runoff volume from road ditches, 8 culverts were selected by a spatially balanced sample (Stevens and Olsen 2004) from the population of cross drain culverts with continuous records. The 8 culverts are numbers 5, 19, 27, 30, 54, 73, 79, and 88 (see Figure 1). In addition the streamflow at the outlet of Oak Creek was analyzed. The time period for this assessment was from February, 2003 (the beginning of meteorological observations in the catchment) until June, 2006. Linear regression was used to compare the observed and the DHSVM simulated values for the peak flows and storm volumes at the 8 culverts and the Oak Creek outlet. The regression analysis for the 8 culverts considered the intermittent or ephemeral ditchflow classifications. Of the 8 culverts analyzed 5 had ditchflow classified as intermittent flow (# 5, 27, 30, 54, 73) and 3 as ephemeral flow (19, 79, 88).

The simulated time series for the 8 culverts and the Oak Creek outlet streamflow was evaluated using the Nash and Sutcliffe Efficiency (NSE)(Nash and Sutcliffe, 1970):

$$NSE = \left[1 - \frac{\sum_{i=1}^n (Q_{obs_i} - Q_{sim_i})^2}{\sum_{i=1}^n (Q_{obs_i} - \overline{Q_{obs}})^2} \right]$$

Where: Q_{obs_i} = stream or road flow observation at the ith time.

Q_{sim_i} = stream or road flow DHSVM simulation at the ith time.

$\overline{Q_{obs}}$ = mean observed stream or road flow for entire time series.

NSE values that approach 1 represent the best fit, while values less than 0 suggest that the mean observation provides a better representation of the observed values than the simulated time series.

DHSVM model results were further evaluated for 3 separate portions of hydrographs following Boyle et al (2000) (Figure 2). The 3 partitions represent different physical responses of a catchment. These partitions are: 1) Driven quick flow, relating to streamflow quickly responding to precipitation; 2) Non-driven quick flow, relating to the receding limb of hydrograph following driven quick flow; and 3) Non-driven slow flow, relating to flow most affected by “base flow” conditions. This analysis was done for road and streamflow data from Claire Creek, a 55 hectare sub-catchment within Oak Creek (see Figure 1) and the outlet of Oak Creek. The road and stream points within Claire Creek and the outlet of the catchment represent the highest quality data within Oak Creek. The time period from the analysis was from November, 2005 through February, 2006; the most extreme and variable set of events of the Oak Creek data record. Of the 8 road culverts within Claire Creek we analyzed the 4 culverts with continuous hydrologic observations. The road NSE statistics for each of the 3 hydrograph partitions were combined results from all 4 culverts.

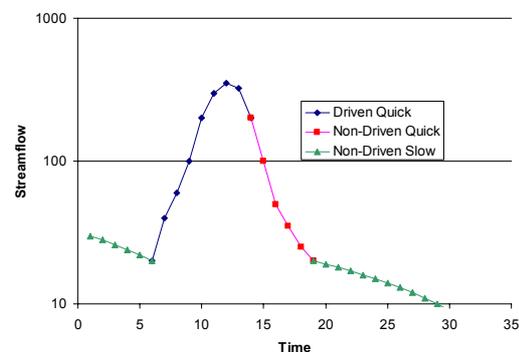


Figure 2. Three Partitions of the Hydrograph for Assessment of DHSVM (partitions following Boyle et al, 2000)

Finally we conducted a case study for DHSVM's ability to predict peak flow and storm volume change from forest roads. This analysis used road and stream flow data from Claire Creek and the outlet of Oak Creek. The analysis was done for the winter storm events from November, 2005 through February, 2006; the most extreme and variable set of events of the Oak Creek data set. Peak flow change was calculated from 2 stream crossings within Claire Creek (culverts 34 and 35) by dividing the ditch flow by the stream flow at the culvert (the streamflow is the total culvert flow minus the ditch flow). Culverts 34 and 35 are good road stream crossings for this case study because they have similar upslope contributing areas, road segment drainage lengths, and cutslope dimensions but different hydrologic response. The ditch flowing to culvert 34 was intermittent while culvert 35 had an ephemeral ditch.

DHSVM was run with and without roads for the Oak Creek catchment. The resulting difference in DHSVM output was considered the hydrologic change due to roads. The percent difference in peak flows and storm volumes were contrasted for the 2 stream crossings for DHSVM predicted differences and observed differences and for Claire Creek and Oak Creek.

Results and Discussions

The mean ratio between observed peak flows and DHSVM simulated peak flows for the outlet of Oak Creek was found to be 1.19 with a 95% confidence interval of 0.98 and 1.39 (p value <0.0001; adjusted $r^2 = 0.81$). The mean ratio between the observed storm volumes and DHSVM simulated storm volumes for the outlet of Oak Creek was found to be 0.87 with a 95% confidence interval of 0.58 and 1.16 (p value <0.0001; adjusted $r^2 = 0.55$). DHSVM, on average, slightly under-predicted peak flows while slightly over-predicting storm volumes at the outlet of Oak Creek. However, the analysis demonstrates that statistically there was no difference between observed and simulated values of peak flow and storm volume at the outlet of Oak Creek for the time period studied.

The ratio of observed peak flows and DHSVM simulated peak flows for road ditches within Oak Creek was found to be 0.62 with a 95% confidence interval of 0.49 and 0.76 after accounting for the intermittent or ephemeral classification of the road ditch (p value <0.0001; adjusted $r^2 = 0.33$). There was sufficient evidence at the 95% confidence level to prove the regression model that included the road ditch classification provided a better model than

without the road ditch classification (p value <0.0001). The regression model between observed and DHSVM simulated peak flows was:

$$\text{Observed road peak flow} = -5.47 + 0.62 * (\text{DHSVM road peak flow}) + 39.25 * (\text{road ditch classification})$$

Where: road ditch classification = 1 for intermittent
0 for ephemeral
units of the intercept and peak flow are cubic meters per 3 hours

The ratio of observed storm volumes and DHSVM simulated storm volumes for road ditches within Oak Creek was found to be 0.21 with a 95% confidence interval of 0.14 and 0.27 (p value <0.0001; adjusted $r^2 = 0.47$). For storm volumes there was not sufficient evidence that the regression model that considered road ditch classification (intermittent or ephemeral) provided a better model than without (p value <0.0001). The regression model between observed and DHSVM simulated road storm volumes was:

$$\text{Observed road storm volume} = 469.2 + 0.21 * (\text{storm volume for DHSVM simulated road ditchflow})$$

Where: units of the intercept and storm volume are cubic meters

For both road ditch peak flows and road ditch storm volumes DHSVM was found to over predict the hydrologic response. For road peak flows this response was explained by the ephemeral road ditches within Oak Creek. The ephemeral road ditches created circumstances where the road ditch often did not flow water even when other road ditches would. DHSVM typically predicted road ditch flow at the ephemeral ditch location, even when no flow was observed. When storm events for ephemeral road ditches were removed from the analysis we found that DHSVM, on average under predicted the peak flows (a ratio of observed to simulated peak flows of 1.32 compared to 0.62 with ephemeral ditches included). A similar response was observed in road ditch storm volumes, however, we found that even after removing the events from ephemeral road ditches DHSVM still over-predicted storm volumes in road ditches (a ratio of observed to simulated storm volumes of 0.86 compared to 0.21 with ephemeral ditches included).

The Nash and Sutcliffe Efficiency values (NSE) for the 8 road ditches and the weir are shown (Table 1)

as well as the time series plots of the outlet of Oak Creek and culvert 30 (Figure 3 and 4). Generally DHSVM was found to give a reasonable fit to the time series at the outlet of Oak Creek, with the fit of the time series diminishing at the road drainage locations. However, with the exception of 3 of the culverts all NSE values are close or above 0.5 suggesting that DHSVM is providing a fit to the observed time series, albeit not a good one. The 3 culverts with the lowest NSE values are the 3 road culverts that are classified with ephemeral ditch response. Indeed 2 of the ephemeral road ditch locations, culverts 19 and 79, have negative NSE values suggesting that an average value (a flat line time series) is better than the DHSVM simulated time series.

Table 1. Nash and Sutcliffe Efficiency Values for 8 Road Culverts and the Outlet of Oak Creek for February, 2003 through the June, 2006 (for mapped locations see Figure 1).

Location	Nash/Sutcliffe Efficiency
Culvert 88	0.39
Culvert 5	0.62
Culvert 19	-3.92
Culvert 27	0.50
Culvert 30	0.44
Culvert 54	0.47
Culvert 73	0.48
Culvert 79	-1205.32
Outlet of Oak Creek	0.68

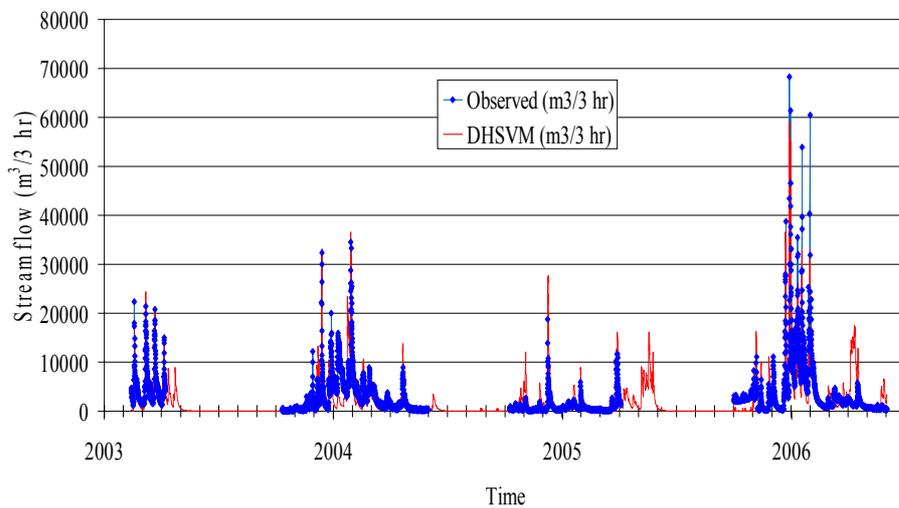


Figure 3. Observed and DHSVM Simulated Streamflow for Oak Creek.

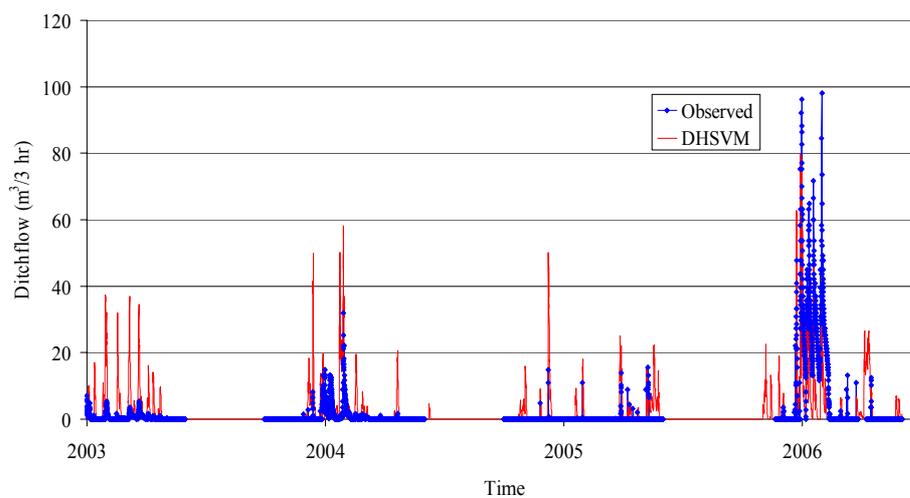


Figure 4. Observed and DHSVM Simulated Ditchflow for Culvert 30.

Sub-surface water routing within hillslopes of Oak Creek are highly variable as shown by road ditch responses that are either ephemeral or intermittent. All of the road ditches analyzed in this study have road cuts which can intercept hillslope water. In every road ditch of our sample, when large precipitation events occurred in the catchment water flow was observed in road ditches. It was in the smaller precipitation events that water often did not flow in ephemeral road ditches, yet DHSVM predicted water flow. We suggest that there are preferential flow paths and variable thresholds to sub-surface flow within Oak Creek that was not accounted for by DHSVM. This variable response of sub-surface water within the Oak Creek catchment makes hydrologic modeling of a road network by DHSVM inaccurate. Because DHSVM is a fully distributed model it may be possible to find parameter sets that provide a better fit to individual road cuts and hillslopes. However, this increases the complexity of

the modeling exercise perhaps beyond the scope of most decision based analysis.

The Nash and Sutcliffe Efficiency values (NSE) for the comparison between simulated and observed stream and road ditch flow for the 3 hydrograph partitions are shown (Table 2). DHSVM appears to have best simulated the portion of the hydrograph that responds to direct precipitation inputs, the driven quick flow portion. However, this response diminishes as the size of catchment decreases. The outlet of Oak Creek (630 hectares) and Claire Creek (55 hectares) have NSE values above 0.5 suggesting reasonable fit to the time series (1 is best), while Above 34 and Above 35 (approximately 4 hectares each) show little fit to observed values, though the NSE values are positive. At the smallest scale simulated, road ditch flow, the NSE values for the driven quick portion of the hydrograph are negative suggesting the mean observed value is a better predictor than the simulated time series.

Table 2. Nash and Sutcliffe Efficiency Values for 3 Partitions of the Hydrograph for Claire Creek Locations and the Outlet of Oak Creek for November, 2005 through February, 2006 (for mapped locations see Figure 1).

	Streamflow				Road Ditches
	Oak Creek	Claire Creek	Above 35	Above 34	
Driven Quick	0.67	0.53	0.11	0.01	-0.06
Non-Driven Quick	0.72	-0.19	-0.01	-9.3	-0.35
Non-Driven Slow	0.18	-0.24	0.35	-4.6	-0.02

During the non-driven quick flow portions of hydrographs, only the outlet of Oak Creek had a good fit with the observed time series values. For the non-driven slow portions (base flow between storms), none of the locations demonstrated a good fit to observed values. The streamflow at the outlet of Oak Creek and Above 35 have positive NSE values; however the NSE values are low suggesting poor fit. Boyle et al (2000) suggested that hydrologic models may be best calibrated for each of the 3 separate portions of the hydrograph. The differing physical processes controlling each hydrograph partition could dictate very different sets of parameters that simulate the differing hydrologic responses. The overall poor performance of using DHSVM with one parameter set to simulate runoff for the differing catchment scales and hydrograph partitions suggests consideration for using different parameter sets. Different parameter sets are likely needed for the different scales, processes, as well as the different hydrograph responses that DHSVM is used to simulate.

for the 2 road stream crossings within Claire Creek showed mixed results (Table 3). At culvert 34 observed peak flow increases from the road were on average 77% greater for the November, 2005 through February, 2006 time period. DHSVM model results suggested an average peak flow increase of 9% for the same time period. At culvert 35 DHSVM results were similar to observed peak flow increases, with increases of 18% and 17% respectively. Culvert 34 had an intermittent road ditch while culvert 35 had an ephemeral ditch. The differences in peak flow increase may be explained by this difference in ditch flow classification. DHSVM predicts a similar peak flow increase as observed for culvert 35 which is ephemeral and dominated by road surface run-off. At culvert 34 DHSVM sends more of the water from the hillslopes into the stream channel, when field observations suggest more water is being transmitted in the hillslope and intercepted at the road cut; creating an increased peak flow response from intercepted hillslope water.

The case study for DHSVM's performance in predicting peak flow and storm runoff volume changes

The intermittent versus ephemeral responses of culvert 34 and 35 do not explain differences for the

volume of storm runoff from each of the sites. Culverts 34 and 35 were observed to increase storm runoff volume at the road stream crossing an average of 75% and 74% respectively for November, 2005 through February, 2006. DHSVM significantly under predicts the storm runoff volume increases for these 2 road crossings. Culverts 34 and 35 were simulated by DHSVM for the same time period to increase storm runoff volume at the road stream crossing an average of 8% and 17% respectively. Culvert 34 storm volume responses may be explained by DHSVM sending more of the water from the hillslopes above culvert 34 into the stream channel, when observations suggest more water is being

transmitted in the hillslope and intercepted at the road cut. For the storms from November, 2005 through February, 2006 we found that DHSVM predicts around 50% more water volume during storm events in the stream channel than observed (2220 cubic meters compared to 3300 cubic meters). In the case of culvert 35, DHSVM under predicts both the stream and road runoff. In this situation sub-surface topography and flow paths might be greater than the modeled soil depth scenario DHSVM is doing its calculations with. At both road crossings it appears that preferential flow and sub-surface flow paths are not being adequately captured by DHSVM.

Table 3. Observed and DHSVM modeled peak flow and storm runoff volume increases due to roads for 2 road stream crossings, Claire Creek, and Oak Creek.

Location	Observed Peak Flow Increase	Modeled Peak Flow Increase	Observed Runoff Volume Increase	Modeled Runoff Volume Increase
Road Point 34	77%	9%	75%	8%
Road Point 35	18%	17%	74%	17%
Claire Creek	-	3%	-	1%
Oak Creek	-	3%	-	2%

DHSVM predicted an average increase in peak flow for Claire Creek and Oak Creek of 3% from roads. DHSVM predicted an average increase in storm runoff volume from roads for Claire Creek and Oak Creek of 1% and 2% respectively. These increases are very small but difficult to interpret given the substantial differences in model results that we have observed. One might make the argument that because DHSVM under predicted peak flow and storm runoff increases for culverts 34 and 35 in Claire Creek, the models cumulative predictions for both Claire Creek and Oak Creek may be under-predicted as well. However, the statistical analysis of road ditch flow for Oak Creek demonstrated that DHSVM was over-predicting peak flows and storm volumes. Given the many uncertainties raised by this study we question whether the cumulative effects analysis of peak flows and storm volumes is appropriate for a catchment like Oak Creek with highly variable hillslope responses.

Conclusions

DHSVM simulations of road ditchflow over predicted the hydrologic response of road ditches in Oak Creek. We found a reasonably good fit for DHSVM streamflow results at the outlet of Oak Creek, but this fit diminished for DHSVM results for individual road

ditches. DHSVM was found to best predict the driven quick portion of the hydrograph for stream-flow; this response diminishes for road ditches. DHSVM poorly predicted the non-driven quick portion and non-driven flow portion of the hydrographs, with the exception of the non-driven quick portion of the hydrograph simulated at the outlet of Oak Creek. DHSVM poorly predicted all portions of the hydrograph for road ditches within Claire Creek.

The cumulative effects from roads in Oak Creek were predicted by DHSVM to increase peak flows and storm volumes for Claire Creek and Oak Creek slightly. The variable results from this study suggest that this cumulative increase was difficult to interpret. How water is being stored and routed within Oak Creek must be better understood before we should make interpretations on the ability of DHSVM to accurately represent the road influences on hydrology at a catchment scale. Further, the use of one parameter set to attempt to model all of the variability inherent in Oak Creek or any catchment for that matter does not appear to be sufficient. We believe that further research in model uncertainty and use of multiple parameter sets is needed to better interpret cumulative effect assessments of road hydrologic effects with DHSVM.

Literature Cited

- Beschta, R.L., Pyles, M.R., Skaugset, A.E. and Surfleet, C.G., 2000. Peakflow responses to forest practices in the western Cascades of Oregon, USA. *Journal of Hydrology*, 233: 102-120.
- Bowling, L. and D. Lettenmaier. 2001. The effects of forest roads and harvest catchment hydrology in a mountainous maritime environment. In: *Land-Use and Watersheds: Human Influence on Hydrology and Geomorphology in Urban and Forest Areas*. Water and Science Application Volume 2; American Geophysical Union, 145-164.
- Boyle, D.P., H.V. Gupta, and S. Sorooshian. 2000. Toward improved calibration of hydrologic models: Combining the strengths of manual calibration and automatic methods. *Water Resources Research*, 36(12), 3663-3674.
- Knezevich, C.A. 1975. Soil Survey of Benton County Area, Oregon. United States Department of Agriculture, Soil Conservation Service, in cooperation with the Oregon Agricultural Experiment Station.
- Jones, J.A. and Grant, G.E., 1996. Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon. *Water Resources Research*, 32(4): 959-974.
- Megahan, W.F., 1972. Subsurface flow interception by a logging road in mountains of central Idaho, National Symposium on Watersheds in Transition, American Water Resources Association and Colorado State University, pp. 350-356.
- Nash, J. and J. Sutcliffe. 1970. River flow forecasting through conceptual models. Part I – a discussion of principles. *Journal of Hydrology* 10: 282-290.
- Stevens, D. and A. Olsen. 2004. Spatially balanced sampling of natural resources. *Journal of American Statistical Association*, Vol. 99, No. 465: 262-278
- Surfleet, C. 2005. Untitled paper on statistical analysis of road characteristics and hydrologic effects for 5 storms of 2003 in Oak Creek, Corvallis, Oregon. Statistics 512 class project, Oregon State University, Corvallis, Oregon.
- Toman, E. 2004. Forest road hydrology: the influence of forest roads on stream flow at stream crossings. Master of Science Thesis, Oregon State University, Corvallis, OR.
- Thomas, R.B. and Megahan, W.F., 1998. Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon: A second opinion. *Water Resources Research*, 34(12): 3393-3403.
- Wemple, B., J. Jones, and G. Grant. 1996. Channel network extension by logging roads in two basins, Western Cascades, Oregon. *Water Resources Bulletin* Vol. 32(6), 1195-1207.
- Wemple, B. 1998. Investigations of road runoff production and sedimentation on forest roads. Philosophy of Doctorate Dissertation, Oregon State University, Corvallis, OR.
- Whitaker, A., Y. Alila, J. Beckers, and D. Toews. 2003. Application of Distributive Hydrology Vegetation Model to Redfish Creek, British Columbia: model evaluation using internal catchment data. *Hydrological Processes*, 17, 0-0. Published online at www.interscience.wiley.com
- Wigmosta, M.S. and W. Perkins. 2001. Simulating the effects of forest roads on watershed hydrology. In: *Land Use and Watersheds: Human Influence on Hydrology and Geomorphology in Urban and Forest Areas* Water Science and Application, Vol. 2, pp. 127-143.
- Wigmosta, M.S., L. Vail, and D. P. Lettenmaier, 1994: A distributed hydrology-vegetation model for complex terrain, *Wat. Resour. Res.*, 30, 1665-1679.

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SESSION A.2:

FOREST FUEL REDUCTION AND BIOMASS HARVESTING

THE USE OF MONOCABLES IN THE HARVESTING OF SMALL TIMBER: A SOUTH AFRICAN PERSPECTIVE

Francois Oberholzer, Derek Howe

Abstract: There is a general decrease in the piece size of timber harvested in South Africa, due to shortened rotation ages and also timber being salvaged after fires and insect damage. Various other issues such as high labour turnover and high fuel costs also prohibit the use of complex systems in certain applications. This makes many of the current systems used expensive, and alternative methods that are suitable for use in small timber must be examined. Monocables have been in use since the late 1940's and are becoming increasingly popular again due to the ease of operation and low running cost. This paper deals with the use of one specific monocable yarder in clearfell and thinning operations.

Key words: Monocable, small timber harvesting, clearfell, thinnings

Introduction

There is a general decrease in the piece size of timber harvested in South Africa, due to shortened rotation ages and also timber being salvaged after fires and insect damage. This makes many of the systems used expensive, and alternative methods that are suitable for use in small timber must be examined. Monocables has been in use since the late 1940's, but the use of it has been limited. South Africa has also experienced a marked increase in fuel price in recent years, making fuel-efficient systems imperative. Many industries are also experiencing a high labour turnover rate that makes training of operators on technically complex machines difficult, often forcing timber harvesters to look for basic systems. These factors have led to monocables becoming increasingly popular again, and the correct implementation of these machines in both clearfell and thinning operations provides a cost competitive system that is easy to operate.

Derek Howe from Howeline in South Africa has been building cable yarders since 1986, and has been manufacturing monocable yarders in 1995. These yarders have been implemented in both clearfell and thinning operations, and this paper deals with the applicability of this system in these operations.

System Description

The Howeline monocable is a basic yarding system that is less complex than skyline and highlead systems. The monocable system consists of the following:

Monocable yarder

- The yarder is powered by an air-cooled diesel engine delivering 16.3 kW (22 Hp) at 3000 rpm.
- The yarder is fitted with a 30 cm (12 inch) horizontally mounted capstan winch.
- The engine powers a hydraulic pump that drives a hydraulic motor. This allows flow to be reversed in order to operate the capstan drum in both directions.

Cable

- A continuous cable of between 300 and 500 meters long is used where the ends of the cable can either be spliced back onto itself, or connected via special connectors that can run over the capstan winch. The connectors used by Howeline are still in the experimental phase, and could not be evaluated at the time of this paper.
- A 10mm ($\frac{3}{8}$ inch) swaged, compacted cable with wire core is used.

Rigging

- Clearfell:
 - Normal closed blocks are used as in other cable operations.
 - Normal choker chains are used as in other cable operations.
- Thinning:
 - Open sided blocks are used where the chokers can run through the blocks.
 - Twine is used to choke the logs that can easily slip through the open-sided blocks. The breaking strength of the twine range from 70 kg (154 lbs) for sisal twine through to 150 kg (330 lbs) for polypropylene twine.

Operation

The system is easy to set up, due to the simplicity of the equipment and light weight of the components. The system can handle a maximum of 3 tons of timber on the cable at any given time in a downhill operation, but 2.5 tons is recommended in order to keep strain on the system to a minimum. In an uphill operation the system could handle approximately 2 tons. The system is best used downhill, but can be used in uphill or flat application.

The yarder is held in position through two guy-ropes attached to stumps. Rack width in the monocable system is approximately 10 meters (32 feet) wide, but an area of 20 meters (64 feet) can be covered in clearfell operations. Due to the slack in the system the cable is simply pulled laterally to the logs, providing a swath width of 5 meters (16 feet) on either side of the cable. The setup for use in clearfell and thinning operations differ substantially.

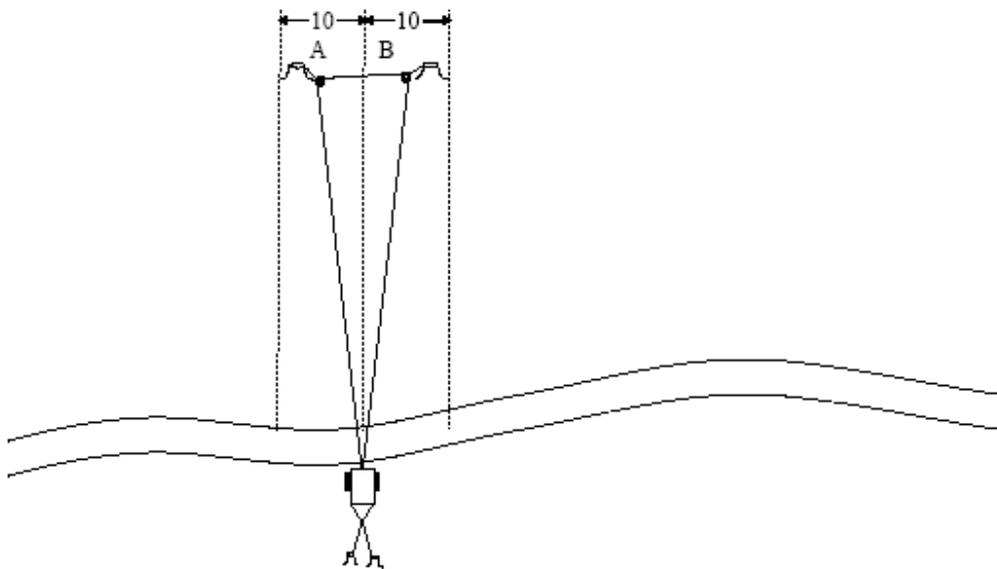


Figure 1: Layout of a monocable system in a clearfell operation

To either attach or release a log, the cable is stopped and does not move continuously as with certain monocable systems. Rack A is extracted first by moving the cable counterclockwise. Logs are attached to the cable using a choker chain that has been

Clearfell

The first study was conducted in a clearfell operation. Tree lengths were harvested, and the average weight per tree was 300kg, with some trees weighing up to 500 kg. The extraction distance was 150m, with a maximum of 200m.

The crew consists of the following:

- 3 choker setters
- 1 machine operator who releases chokers as well
- 1 chainsaw operator who fells
- 1 chainsaw operator who crosscuts timber on roadside
- 1 Bell logger operator who moves logs away from the front of the yarder, and stacks logs

The layout for the clearfell is simple. Instead of the normal zigzag layout associated with monocables, a layout similar to that of a highlead is used (figure 1). Two blocks are attached to stumps approximately 10 meters apart. After the cable has been laid out according to plan, it is wrapped three times around the capstan winch. The yarder is moved back manually to tension the line, and the final tension is obtained by tensioning the guy-ropes with a handheld winch.

wrapped three times around the cable and hooked back onto itself (figure 2). The empty choker chains are attached to the outgoing side of the cable to be moved back infield.



Figure 2: attaching choker chains to the monocable

When rack A is completed, the cable will be moved clockwise and the logs in rack B will be extracted. This allows the logs to travel a minimum distance to the landing, and the system does not require special corner blocks for logs to move through the blocks as is the case in thinnings.

The team obtained an average of 40 tons per day, pulling 120 trees per shift. Yarding downhill has the disadvantage of pulling slash onto the landing.

Thinning

The second study was conducted in a thinning operation. Trees were cut to short lengths of approximately 2.4 meters long (8 feet). The average weight per log was approximately 50 to 60 kg. The extraction distance can be over 1000 meters, but in this study a cable of 500 meters in length was used.

The crew consists of the following:

- 6 choker setters
- 1 machine operator who releases logs as well
- 1 chainsaw operator who fells
- 1 chainsaw operator who crosscuts logs on road-side.
- 1 Bell logger operator who moves the timber away from the front of the yarder, and stacks logs

A zigzag system was used for the thinning layout, as is traditionally the case with monocables. Alternatively a system similar to the one used in clearfells

described above can be used. Open blocks are attached to trees at approximately breast height with soft slings that limit the damage to the trees. After the cable has been laid out according to plan, it is wrapped three times around the capstan winch. The yarder is moved back manually to tension the line, and the final tension is obtained by tensioning the guy-ropes with a handheld winch.

To attach or remove a log from the cable, the cable is stopped and does not move continuously as with certain monocable systems. Logs are attached to the cable using twine. A continuous loop of twine is first attached to the cable by looping it through itself. A log is then attached to the twine by making a loop in the twine and pushing the end of the short log through the loop. The logs are released at the landing either manually by the operator who uses a sharp knife or similar tool, or by using a V-blade fitted below the cable at the landing to snag and cut the twines.

The cable will be rotated clockwise (figure 3) and the timber will be extracted continuously in one direction. A loop was added to the system to take up the slack in the line. The system can also be reversed if there is no impediment such as the bight in the cable caused by the blocks added to take up slack in the line.

Due to the increased number of choker setters, the team obtained an average of 38 tons per day, pulling 600 logs per shift.

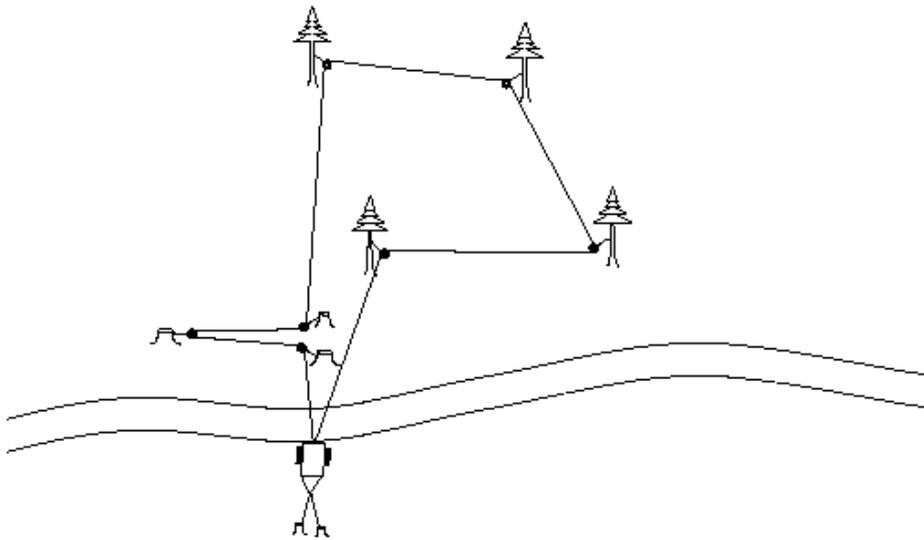


Figure 3: Layout of a monocable system in a thinning operation

Summary

The yarder uses approximately 6 to 7 liters (1.3 – 1.5 gallons) of diesel per day in a normal 9-hour shift in both the clearfell and thinning operations. Maintenance and repairs on the yarder and the system is very low. Due to the low tension in the system, cable life is long and is often in excess of one year or even longer. Working over a ridge did not prove to be a problem, since the tension in the line is low, and the cable rubs on debris lying on the ground.

The monocable is a cost efficient system that can be operated by a crew with minimal training. It is a labour intensive system suited for small-scale operations, but can produce a reasonable amount of timber in commercial applications. The system is flexible, as shown, and can be used in both clearfell and thinning operations. The cost per unit of this system is comparable to other systems working under the same conditions, e.g. terrain, tree size, etc.

The monocable system is also very safe, because the low tension in the cable does not cause trees to up-end, endangering choker setters in the field. The low tension also ensures that the cable seldom breaks and if it does so, it tends to fall straight to the ground and does not whiplash endangering workers.

The system is suitable for cost efficient harvesting of small timber in both thinning and clearfell operations.

Literature Cited

- Aulerich, S P. 1985. Monocable line skidding system for small wood. Forest Products Research Society Annual Fall conference, September 9-11, 1985, Spokane, Washington, United States of America.
- La Moure, Besse; Bergstrom, Garry; Studier, Don. 1994. Monocable Zigzag Yarding System. Timber Tech Tips, June 1994. Technology and Development Programme, United States Department of Agriculture Forest Service.
- Miyata, Edwin S; Aulerich, D Edward; Bergstrom, Gary C. 1986. A monocable system for handling small trees on steep, difficult terrain. In: Proceedings of the 9th Annual Council of Forest Engineering Meeting, September 29 – October 2, 1986, Mobile, Alabama, United States of America.

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NET ENERGY OUTPUT FROM HARVESTING SMALL-DIAMETER TREES USING A MECHANIZED SYSTEM

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Abstract: Use of forest biomass in direct-combustion systems for energy generation has been well established in the forest products industry. The ratio between energy output and input has raised questions when highly mechanized systems that consume fossil fuels are used to harvest and transport forest biomass for energy. What amount of extra energy could be generated after subtracting the total consumed to produce the biomass energy? We focused on forest biomass generated from fuel reduction treatments on pure ponderosa pine stands. The mechanized system (felling, skidding, loading, grinding, and hauling) was monitored for energy consumption. Potential energy output from harvested forest biomass was calculated based on hog fuel moisture content and heating value. A nine-day study showed positive net energy output of 3,471,376,292 Btu, net energy ratio of 10.41, and energy cost of \$8.69/million Btu. For each additional transportation mile, net energy ratio will decrease 0.0056 and energy cost would increase \$0.034/million Btu. \$1/gallon diesel price increase will add \$0.58/million Btu to the energy cost.

Key words: forest biomass, energy, net energy ratio

Introduction

Rising fuel costs and the scarcity of fossil fuels have renewed interest in the use of wood fuel in the United States (Arola and Miyata, 1980). Traditional forest and mill residues have received considerable attention as supplements to conventional fossil fuels during an earlier energy crisis and the use of forest and agricultural residues in direct-combustion systems for power and heat generation has been a well established practice in the forest products industry (Arola and Miyata, 1980; Han et al., 2002). Today, biomass sources provide about 3% of all energy consumed in the United States, while supplying more than half of all renewable energy generated in the country (Perlack et al., 2005).

In the past fifty years, successful fire suppression presented a dense understory throughout the forest (Han et al., 2002). These overstocked small-diameter stands generally require thinning from below to improve fire-tolerance and restore them to historical conditions (Graham et al., 2002). To ensure that a thinning operation reduces fire risk for the residual stand, the operation must either remove sub-merchantable trees and logging slash completely through biomass harvesting or carefully burn the fuels using a prescribed fire (Han et al., 2002). Traditional prescribed fire is increasingly limited due to liability concerns and regulations associated with smoke management. Using these small-diameter trees

in addition to utilization of traditional logging residue for power generation creates an additional opportunity for forest biomass energy (Bolding, 2002; Morris, 1999).

Mechanical harvesting, processing small-diameter trees, and transporting hog fuel not only are economically challenging, but also are associated with a question about the net energy contribution since it involves a process of producing biomass energy by consuming fossil fuels. The literature lacks of well-documented information on the net energy output in using mechanical systems to harvest small-diameter trees for energy.

This study applied net energy analysis to investigate the net energy output of harvesting, processing, and transporting small-diameter (DBH \leq 5.0 inches) ponderosa pine trees for energy when directly associated with a fuel reduction thinning treatment. Net energy analysis is a technique that seeks to compare the amount of energy delivered to society by a technology with the total energy required to find, extract, process, deliver, and otherwise upgrade that energy to a socially useful form (Cleveland and Costanza, 2006). The study objectives include examining the total energy input and output, determining the net energy ratio, and testing the effects of different variables on the net energy ratio, as well as the energy cost.

Method

Study site and harvesting system

The study sites were located in Springerville and Black Mesa, Arizona. The two sites were stocked with almost 100% ponderosa pine (*Pinus ponderosa*) trees. A mechanized whole-tree system was used to harvest the trees less than or equal to 5.0 inches in DBH. A three-wheel hot-saw feller-buncher (Valmet 603) felled trees prior to skidding them to a landing using a rubber-tire grapple skidder (CAT 525B). A

stationary log loader (Prentice RT-100) at the landing fed the whole trees into a remote-controlled horizontal grinder (Bandit Beast 3680). The processed hog fuel was loaded into a chip van directly through the grinder's conveyor. Chip vans that could be linked-up or disconnected from the truck were used for landing-to-market hauling. The hog fuel was sent to two local power plants. The one-way hauling distance ranged from 29.5 to 36 miles. The machine information and the hauling distance by cutting units are summarized in Tables 1 and 2.

Table 1: Engine horsepower, machine production time, diesel consumption amount, and diesel consumption rates.

	Feller-buncher	Skidder	Loader	Grinder	Chip van
Horsepower (hp)	130	160	130	500	400
Total production time (hr)	49.33	32.72	30.05	29.80	88.92
Total diesel used (gal)	294.9	165.5	80.2	519.9	977.0
Diesel consumption rate (gal/hr/hp)	0.046	0.032	0.021	0.035	0.027

Table 2: Road type, one-way distance, and average speed.

	Spur road (miles)	Unpaved road (miles)	Paved road (miles)	Highway (miles)	Total (miles)
Unit 1	1.5	8	2.5	17.5	29.5
Unit 2	0	10.5	1	22.5	34
Unit 3	0	0	0	35	35
Unit 4	0	0	0	36	36
Average speed (miles/hour) ^a	2.67	13.83	14.40	44.14	--

a: the average speed was calculated using the road distance divided by the time traveling on it.

Data collection and analysis

In this study, direct energy consumption consisted of fuel consumed for harvesting, processing small trees, and transporting the hog fuel. Amounts of diesel used by the feller-buncher, skidder, loader, and grinder were measured by an electronic fuel meter installed on the fueling gun. Readings on the electronic fuel meter were recorded each time machine fuel tanks were filled. All the machines were fueled before operation started in each unit. Truck diesel consumption was tested by the driver for each harvesting site. The reported truck diesel consumption rate of 0.4 gal per mile was applied for the entire transportation network, as it was impossible to segregate diesel consumption rate by road type.

This study did not directly measure the indirect energy input. The energy required for moving equipment and for crew transportation was considered as indirect energy input. Fuels spent for chainsaw and administration were omitted. Fuel

consumption in moving equipment was assumed to have the same diesel consumption rate as for hog fuel hauling as they both used trucks for transportation. Energy used for moving machines away from the site was not considered for this study because this part is typically assigned to the following project. Fuel expended by pickup trucks for crew transportation was measured by the operator for each harvesting site.

The direct and indirect input diesel consumption amounts were summed and converted to an equivalent heating value (British thermal unit, Btu) as the total energy input. The energy content was taken at 137,000 Btu per gallon for diesel, and 125,000 Btu per gallon for gasoline (Adams, 1983). Other energy inputs, such as energy consumed for conversion preparation in energy plants, were not considered because they appear in the hog fuel markets and are out of scale for this production study.

Energy output was defined as the total recoverable heating value from the produced hog fuel and was calculated using the following formula (Ince, 1979):

$$RHV = HHV \cdot (1 - MC_{wb}) - HL \quad (1)$$

where

RHV = recoverable heating value, Btu/lb
 HHV = higher heating value of hog fuel, Btu/lb
 MC_{wb} = wet-based moisture content, %
 HL = heat loss, Btu/lb

To test the higher heating value of the hog fuel (HHV), two random hog fuel samples were collected from each truckload. All the samples from the 32 truckloads were taken to the University of Idaho Forest Products Department lab to measure the HHV using a bomb calorimeter following the ASTM (American Society for Testing and Material) standard (ASTM, 2003). To determine the HHV testing frequency for each sample and the feasibility of an overall average HHV, one sample was selected for each cutting unit. These four samples were each measured for the HHV 12 times. One-way ANOVA analysis was performed to detect the variance between the samples and to compare the mean HHV of each sample.

Heat loss was estimated using a method introduced by Ince (1979) under the following assumptions: the combustion heat recovery system was operated with 40% excess air and a stack gas temperature of 260°C, which is typical for an industrial system. The ambient temperature of hog fuel before combustion (room temperature) was 20°C. A constant conventional heat loss factor of 4% and complete combustion also were assumed (Ince, 1979).

The total hog fuel weight was tracked from the energy plant tickets during the operation. Hog fuel moisture content also was tested in the lab following the ASTM guidelines. Each sample was measured for the moisture content three times, and the average value was applied in the calculation.

The sensitivity analysis included the tests of hauling distance influence on net energy ratio (energy output/energy input) and energy cost (\$/million Btu), and the effect of diesel price on energy cost. To test the effect of hauling distance on the net energy ratio, different one-way distances were simulated to estimate the corresponding energy input. Given a constant energy output, the net energy ratio change could be found.

The impact of travel distance on net energy cost was detected by setting distinct highway distances in developed hauling cycle time regression model while keeping all the other variables constant (Pan et al., 2007). The resulting value change in cycle time was then converted to a production cost (\$/GT) change. Combining the constant energy output with the production cost change, the energy cost change can be calculated. The effects of unpaved and spur road distance on the energy cost were not measured, but similar procedures could be performed. The diesel price influence on the energy cost was determined by assuming different diesel prices. The resulting production cost change was then transformed to corresponding energy cost change. Scatter plots showed how the net energy ratio and the energy cost changed with the corresponding value change in the test variables.

Results

Energy input

The diesel consumption amounts for each machine summarized in Table 3 showed a total direct diesel consumption of 2037.5 gallons, equivalent to 279,137,500 Btu. Truck hauling represented the highest percentage (47.95%) in the direct energy input due to the longest operation time with a relatively high horsepower engine. The skidder, loader, and grinder worked as a “hot” system, meaning they worked at the same time during the operation. The grinder consumed 25.52% of the total direct energy input, because the machine was powered by a 500 horsepower engine with the highest diesel consumption rate (gal/hr/hp, Table 1) in the hot system. Although the loader had an engine similar in horsepower to the skidder, it had a lower diesel consumption rate than did the skidder, resulted less diesel use. The independently worked feller-buncher had a long working time and the highest diesel consumption rate, which let to the third highest direct diesel consumption percentage (14.47%) in the system, despite having the least amount of horsepower.

Total indirect energy input was 667.8 gallons of diesel and gasoline, equal to 89,868,600 Btu (Table 4). The diesel used for moving machine accounted for 60.64% of the total indirect energy input. The pickup trucks for crew transportation expended 39.36% of the indirect input energy. This percentage was high because the crew traveled about 100 miles (one-way) to site 2 each day.

Table 3: Direct diesel input amount (gallons) for the 9-day operation.

		Feller-buncher	Skidder	Loader	Grinder	Chip van	Total
Direct diesel input (gallons)	Unit 1	44.4	27.5	16.6	93.3	148.0	329.8
	Unit 2	38.2	26.0	10.8	64.5	185.0	324.5
	Unit 3	145.8	88.1	39.8	276.1	483.0	1032.8
	Unit 4	66.5	23.9	13.0	86.0	161.0	350.4
	Total	294.9	165.5	80.2	519.9	977.0	2037.5
Heating value (Btu)		40,401,300	22,673,500	10,987,400	71,226,300	133,849,000	279,137,500
			0		0	0	
Average (gal/hr)		5.98	5.06	2.67	17.45	10.99	42.15
Percentage in total (%)		14.47	8.1	3.94	25.52	47.95	100.00

Table 4: Indirect fuel input amount (gallons) for the 9-day operation.

	Machine moving		Crew transportation		Total
	Diesel		Diesel	Gasoline	
Site 1	122.4		27	27	176.4
Site 2	275.4		108	108	491.4
Total	397.8		135	135	667.8
Average (gal/day)	44.2		15	15	74.2
Total heating value (Btu)	54,498,600		18,495,000	16,875,000	89,868,600
Percentage in total (%) ^a	60.64		20.58	18.78	100

a: equivalent heating value percentage in total.

Table 5: Total input fuel amounts (gallons) and the equivalent heating value (Btu).

	Direct energy input	Indirect energy input	Total
Diesel and gas amount (gal)	2,037.5	667.8	2,705.3
Equivalent heating value (Btu)	279,137,500	89,868,600	369,006,100
Percentage in total (%) ^a	75.65	24.35	100

a: equivalent heating value percentage in total.

The total input energy (Table 5) for the nine-day operation was 2705.3 gallons of fossil fuel. The total fuel input had an equivalent heating value of 369,006,100 Btu. The direct and indirect energy consumption represented 75.65% and 24.35% of the total energy input, respectively, in terms of equivalent heating value. Hog fuel hauling, the largest part of direct energy input, used 36.27% of the total input energy; while machine moving, the largest part of indirect energy input, consumed 14.77% of the total input energy.

Energy output

The lab-derived hog fuel HHV with 12 replications for each sample is summarized in Table 6. The descriptive statistics (Table 6) showed the variance from 30.08 to 43.15 within each hog fuel sample, which was less than 1% of the mean HHV. This meant that one experiment was sufficient for the rest of the samples instead of multi-replication. The one-way ANOVA analysis (Table 7) provided an F-value of 56.51 with a P-value less than 0.00001 ($\alpha = 0.05$),

indicating that the mean HHV of the four hog fuel samples had significant difference. The experiments showed that hog fuel HHV ranged from 8,885 to 9,273 Btu/lb with an average of 9,063 Btu/lb. The hog fuel from unit 3 had the lowest average HHV of 9,041 Btu/lb (Table 8). The ponderosa pine bark has higher HHV than the wood (Ince, 1979). The pre-harvest cruise found the trees in unit 3 had the smallest DBH (Pan et al., 2007), indicating the lowest bark thickness and percentage.

The sample hog fuel moisture content varied from 43.56% to 57.96%, having an average value of 52.75% (Table 8). The operation lasted from late July to early August, when monsoon rains saturated the fuel. However, during the operation in unit 3 no rain fell. As a consequence, unit 3 produced the driest hog fuel of the four units.

The average heat losses due to moisture content, hydrogen, dry gas and excess air, and conventional factor were 657.5, 318.0, 436.0, and 171.3 Btu/lb,

respectively. The total average heat loss was 1,582.8 Btu/lb. By applying formula (1), the recoverable heating value of the hog fuel was determined to be 2,699.4 Btu/lb. Despite having the lowest HHV, the hog fuel from unit 3 had the highest recoverable heating value of 2,917 Btu/lb, due to the lowest moisture content. Keeping the rain from soaking the wood is critical to ensure a high recoverable heating value.

For this study, total hog fuel production was 711.34 green tons or 1,422,680 lb. The total recoverable energy output was 3,840,382,392 Btu. Subtracting the input energy, the net energy output was determined to be 3,471,376,292 Btu. The net energy ratio between the recoverable energy output and the energy input was 10.41 (10.41:1).

Table 6: Sample hog fuel higher heating value (Btu/lb) with 12 replications and descriptive statistics.

	1	2	3	4	5	6	7	8	9	10	11	12	Mean	S.D.
Sample 1	9075	9067	9051	9113	9119	9018	9055	9067	9050	9039	9101	9079	9070	30.1
Sample 2	8976	8965	8930	9059	9002	9002	8975	8979	9008	9000	8994	9012	8992	31.1
Sample 3	8969	9000	9007	8991	8945	8946	8886	8876	8921	8904	8943	8960	8946	43.2
Sample 4	9059	9129	9104	9137	9106	9095	9126	9077	9100	9104	9076	9151	9105	27.1

Table 7: ANOVA source table.

	S.S. ^a	D.F. ^b	M.S. ^c	F ^d	P-value
Between	189,440	3	63,145	56.51	0.0000
Within	49,167	44	1,117.4		
Total	238,600	47	5,076.7		

a: S.S.— sum of squares.

b: D.F.— degrees of freedom.

c: M.S.— mean squares.

d: $F = M.S.(Between) / M.S.(Within)$

Table 8: Hog fuel characteristics by cutting unit.

	Tree DBH (inches)	Moisture content (green basis, %)	Higher heating value (Btu/lb)	Recoverable heating value (Btu/lb)	Ash content (%)
Unit 1	5.11	55.66	9,070	2,459	1.46
Unit 2	5.41	53.25	9,076	2,663	1.56
Unit 3	1.76	50.02	9,041	2,917	1.56
Unit 4	1.91	52.06	9,064	2,758	1.61
Average	3.55	52.75	9,063	2,699	1.55

Sensitivity analysis

Based on the diesel consumption reported by the truck driver, energy used for hauling was tested by setting the one-way distance to 25, 30, 35, and 40 miles. Sensitivity analysis showed a negative relationship between the hauling distance and the net energy ratio (Figure 1). For the assumed distances from 25 to 40 miles, the net energy ratio varied from 11.90 to 10.23. With each mile of hauling distance increase, the net energy ratio decreases, on average, 0.056.

A time study that accompanied this analysis (Pan et al., 2007) generated the following regression function for the hauling cycle time (from loading hog fuel at the landing to traveling empty back to the landing) with all the variables significant:

$$\begin{aligned}
 \text{Hauling cycle time (min)} = & 31.496 + 0.0011 (\text{Hog fuel weight, lb}) \\
 & + 2.6264 (\text{one-way highway distance in miles}) \\
 & + 9.9524 (\text{one-way unpaved road distance in miles}) \\
 & + 100.78 (\text{one-way spur road distance in miles}). \\
 & (\alpha = 0.05, P < 0.00001, r^2 = 0.9596)
 \end{aligned}$$

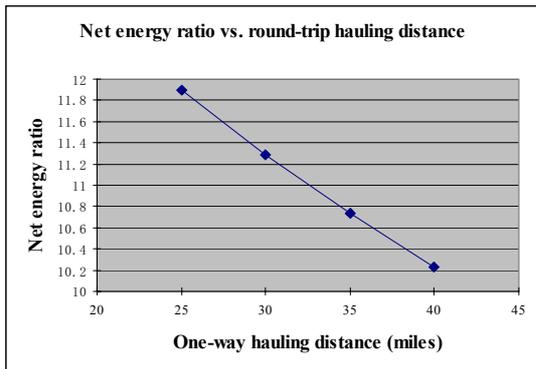


Figure 1: Sensitivity test – effect of one-way hauling distance on net energy ratio.

The production cost study found an average cost of \$46.91/GT, or \$0.023/lb for harvesting, processing, and transporting hog fuel (Pan et al., 2007). The recoverable heating value was 2,699.4 Btu/lb, giving

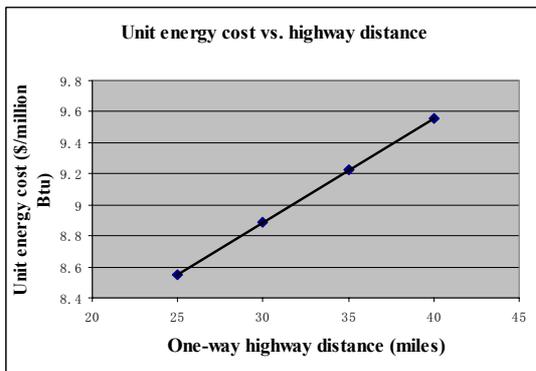


Figure 2: Sensitivity test – effect of one-way highway distance on energy cost.

Discussion

Adams (1983) studied cable system residue harvest, reporting net energy ratios from 18.2 to 25.0 for stems 4 to 8 inches in diameter and 4 to 10 feet in length. Energy used for hog fuel hauling was not included. In our study, if hauling energy input was excluded, the net energy ratio would have been 16.33. A lower production rate for harvesting smaller trees was the major reason influencing the lower net energy ratio because it required more time and energy to harvest the same weight of biomass. Harvesting larger sized biomass should result in higher net energy ratios.

The effects of unpaved road and spur road distances on the energy cost were not tested. Higher energy cost would be expected since the energy output would not change and the unpaved and spur roads distance would have stronger effects on travel time than did highways, as reflected by the regression

an energy cost of \$8.69/million Btu. When setting one-way highway distance to 25, 30, 35, and 40 miles, the energy cost was \$8.55, \$8.89, \$9.22, \$9.56/million Btu, respectively (Figure 2). Each additional highway mile will increase the energy cost by \$0.034/ million Btu.

Diesel price directly affects system production costs and, therefore, the energy cost. Market diesel prices in effect during the study period were \$2.90/gal for off-highway diesel and \$3.20/gal for on-highway diesel, resulting in an energy cost of \$8.69/million Btu for this study. In the sensitivity analysis, average diesel price was set at 1, 2, 3, and 4 dollars per gallon, omitting the price difference between on-highway and off-highway diesels. For each dollar per gallon diesel price increase, the overall energy cost increases \$0.58/million Btu (Figure 3).

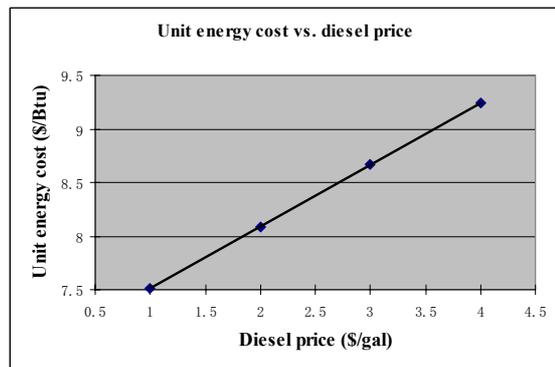


Figure 3: Sensitivity test – effect of diesel price on energy cost.

equation coefficients. In site planning, reducing off-highway hauling should receive more attention. The hauling energy input represented 36.27% of the total input energy, while the percentage for moving machines was 14.77%. High energy consumption percentages emphasize the importance of operation close to market and where machinery is readily available.

Use of forest biomass for energy compares well with other biomass sources in net energy ratio. Shapouri et. al (1995) found a net energy ratio of 1.24 when converting corns to ethanol. Other studies reported energy loss when producing corn-based ethanol (Keeney and Deluca, 1992; Pimentel, 1991). The major factors that can impede the use of forest biomass for energy will be the high production cost and energy cost associated with harvesting forest biomass for energy. The production cost of \$46.91/GT found by accompanied cost study was difficult to be broken even without subsidies given the current hog fuel

price in the market. The energy cost of \$8.69/million Btu did not include the costs for energy conversion and final delivery, which would lead to a high energy cost in the end.

Conclusion

This study monitored a 9-day operation for harvesting and processing ponderosa pine trees less than or equal to 5.0 inches in DBH, and for transporting processed hog fuel for energy. The total fossil fuel energy input equaled 369,006,100 Btu. Direct and indirect energy input represented 75.65% and 24.35% of the total energy input, respectively. Lab experiments found the average recoverable heating value of 2,699.4 Btu/lb for the processed hog fuel at the moisture content of 52.75%. The hog fuel from unit 3, the driest in the four units, had the highest recoverable heating value, despite of the smallest size. Keeping the rain from soaking the biomass fuel is critical to ensure a high recoverable heating value. The total recoverable energy output was 3,840,382,392 Btu for 711.34 green tons of hog fuel. The net energy output was 3,471,376,292 Btu with the net energy ratio of 10.41. Compared with findings from other forest biomass energy studies, this relatively low net energy ratio was a function of harvesting and processing smaller trees that had the effect of lowering the production rate. Harvesting larger size should improve the net energy ratio.

Energy used for hauling hog fuel represented the largest part (36.27%) of the total input energy. Sensitivity analysis found that each mile of hauling distance increase would decrease the net energy ratio by 0.056. Energy cost increases \$0.034/million Btu for each additional highway mile. Higher energy cost will be expended over longer unpaved and spur roads. This indicated the importance of operation close to market and reducing off-highway hauling. Energy consumed for moving machines accounted for 14.77% of the total energy input, emphasizing the value of nearby available machines.

Sensitivity analysis found that a \$1/gallon diesel price change positively affected the energy cost by \$0.58/million Btu. Because diesel price change can also positively affect the energy cost of diesel, under the conditions of this study, a diesel price lower than \$1.03/gallon would make burning diesel for energy more economically attractive than producing energy from forest biomass in terms of energy cost.

Compared with using other biomass sources, using forest biomass for energy is encouraging in terms of net energy ratio. The high production cost and energy

cost associated with mechanical harvesting of forest biomass are the major factors that can impede use of forest biomass for energy. Further research in lowering forest biomass production cost and energy cost is needed.

Literature Cited

- Adams, T.C. 1983. Operational costs of harvesting logging residues for use as energy. Final report to U.S. Department of Energy, Bonneville Power Administration, per Interagency Agreement De-AI51-81R000861. 64p.
- Arola, R.A. and E.S. Miyata. 1980. Harvesting wood for energy. USDA Forest Service, Research Paper NC-200. North Central Forest Experiment Station. USDA, Forest Service.
- ASTM. 2003. Standard test method for gross calorific value of refuse-derived fuel by the bomb calorimeter. Designation: E 711-87. Annual Book of ASTM (American Society of Testing and Material) Standards. Vol. 11.04. Environmental Assessment; Hazardous Substances and Oil Spill Responses; Waste Management.
- 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 p.
- Cleveland, C.J. and Robert Costanza. 2006. Net energy analysis. In: Encyclopedia of Earth. Accessed January 8, 2007 at: http://www.eoearth.org/article/Net_energy_analysis.
- Graham, R.T., A. Harvey, T. Jain, and J. Tonn. 2002. The effects of thinning and similar stand treatments on forest fire behavior in western forests. USDA Forest Service, Pacific Northwest Research Station, Portland, OR. PNW-GTR-463. 27p.
- Han, H.-S, J. Hinson, G. Jackson, R. Folk, H. Lee, L. Johnson, and T. Gorman. 2002. Economic feasibility of small wood harvesting and utilization on the Boise National Forest, Cascade, Idaho City, Emmett Ranger Districts: A report for Gem County Commissioners. University of Idaho, Forest Products Department, Moscow, ID. 62p.

- Ince, P.J. 1979. How to estimate recoverable heating energy in wood or bark fuels. USDA Forest Service, Forest Products Laboratory, General Technical Report FPL 29. 10p.
- Keeney, D.R. and T.H. Deluca. 1992. Biomass as an energy source for the Midwestern U.S. American Journal of Alternative Agriculture. Vol. 7: 137-143.
- Morris, G. 1999. The value of the benefits of U.S. biomass power. NREL/SR-570-27541.
- Pan, F., H.-S Han, and L.R. Johnson. 2007. Production and cost of harvesting and transportation small-diameter trees for energy. In process: International Mountain Logging and 13th Pacific Northwest Skyline Symposium. Corvallis, Oregon. April, 2007.
- Perlack, R.D., L. Wright, A. Turhollow, R. Graham, B. Stocks, and D. Erbach. 2005. Biomass as feedstock for a bio-energy and bio-products industry: the technical feasibility of a billion-ton annual supply. Oak Ridge National Laboratory. 78p.
- Pimentel, D. 1991. Ethanol fuels: energy security, economics, and the environment. Journal of Agricultural and Environmental Ethics. Vol. 4: 1-13.
- Shapouri, H., J.A. Duffield, and M.S. Graboski. 1995. Estimating the net energy balance of corn ethanol. U.S. Department of Agriculture, Economic Research Service, Office of Energy and New Uses. Agricultural Economic Report No. 721.

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CONCEPTUAL EVALUATION OF HARVESTING SYSTEMS FOR FUEL REDUCTION AND BIOMASS COLLECTION ON STEEP TERRAIN USING SYSTEM DYNAMICS

Tetsuhiko Yoshimura, Bruce Hartsough

Abstract: High fuel loadings have resulted in greater incidence of large, severe forest fires in dry forests in the western United States. Removal of small trees and slash from fuel reduction operations can provide revenue to offset some of the treatment costs, and supply biomass as a substitute for fossil fuels. To prevent forest fires and make more use of biomass, the productivity of biomass harvesting must be increased, especially on steep slopes, by innovative techniques. In this study, we propose some new concepts of cable harvesting systems, that is, the gondola cable system, draw-well system, double-track system and double-carriage system. We evaluated these concepts by using system dynamics simulation, which helps us understand the behavior of complex systems over time, and principles of materials handling. As a result, we were able to clarify advantages and disadvantages of these concepts and identify possible paths for developing improvements in the future.

Key words: biomass harvesting, cable system, conceptual evaluation, system dynamics, simulation

Introduction

There is a greater incidence of large, severe forest fires in dry forests due to high fuel loadings in the western United States. Fire danger can be reduced by carrying out thinning and/or prescribed burning, but limited budgets, personnel and equipment constrain how much area can be treated. Furthermore, the practice of prescribed burning can be limited by weather elements such as winds and humidity, air pollution caused by smoke and negative effects on activities of local residents and visitors. On the other hand, removal of small trees and slash from thinning operations can provide revenue to offset some of the treatment costs, and supply biomass as a substitute for fossil fuels. However, economic feasibility of harvesting forest biomass is highly limited by factors such as the small size of the material to be removed, area harvested, topography, distance to forest roads, and proximity of biomass power plants or other utilization facilities. To make more use of forest biomass, the productivity of biomass harvesting must be increased by innovative techniques, especially on steep slopes where operations are more expensive.

Developing such innovative techniques may require revolution rather than incremental improvements to existing cable systems. We proposed new concepts of cable systems that could improve the productivity of harvesting forest biomass. In this study, we estimated the productivities of these new concepts and considered the technical issues of them by using computer simulation before actual development.

Computer simulation is one of the best methods for analyzing timber harvesting operations because of the complexity of various harvesting systems (Wang and LeDoux 2003). Therefore, researchers have previously conducted studies that applied various kinds of computer simulation to estimate results of harvesting operations such as productivity, costs and work loads. For example, LeDoux and Butler (1981) developed a model of cable thinning; it combines Monte Carlo and system simulation to evaluate production rates and costs for various yarding, prebunching, and swinging machines, stand conditions, and silvicultural prescriptions. Randhawa et al. (1992) developed a microcomputer-based system, Timber Harvester, which matches the logging and market conditions of a user to a level of mechanization that would maximize the efficiency of the production operation by searching a set of databases containing information on available technology and its impact on production efficiency, economics, and the environment. Sasaki et al. (1996) conducted object-oriented simulation with stochastic data from field studies to estimate the productivity of an excavator-based swing yarder used on steep slope. Subsequently, Yoshimura et al. (1996) estimated energy consumption of forestry workers in the same framework. Wang et al. (1998) used interactive simulation to examine the interactions of a variety of stand, harvest, and machine features. Hartsough et al. (1998) developed a simulation model of stump-to-truck cost relations for ponderosa pine plantations by using data from many published studies, and Hartsough et al. (2001)

further constructed a model to estimate costs for six typical harvesting systems by combining the information from previous studies. Wang and LeDoux (2003) estimated and validated ground-based timber harvesting production through computer simulation with object-oriented modeling techniques.

In an effort to make a more flexible and customizable model to better fit the actual conditions, system dynamics simulation has been applied to estimate the productivity of harvesting operations or to select the best alternative from a set of harvesting systems. System dynamics also has the advantages of high compatibility, interchangeability, understandability and simplicity of models. McDonagh et al. (2004) applied system dynamics simulation to select an appropriate harvesting system for a given stand by comparing the productivity of several harvesting systems: manual fell/cable skid, mechanized fell/grapple skid, shovel bunching/grapple skid and cut-to-length harvesting/forwarding. Nitami (2006) applied system dynamics simulation to estimate the productivity of a harvesting system that included forest road construction, felling by chainsaw, extraction to forwarder trails by grapple-equipped excava-

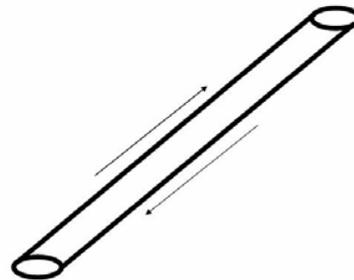
tor, bucking and delimiting by chainsaw, log collection by forwarder and log piling. The current analysis used system dynamics simulation to compare the productivities of the new concepts of cable systems and to find issues and possibilities associated with them before actual development of equipment.

New Harvesting Systems Concepts

We proposed some new concepts for cable harvesting systems: the gondola cable system, draw-well system, double-track system and double-carriage system. The gondola cable is similar to a ski lift in that the cable moves continuously rather than cycling back and forth while transporting logs (Figure 1). This system transports logs to the landing in a fashion similar to a belt conveyor used in factory or other settings. The zig-zag cable system (Hori 1974) is an example of a continuous-loop system, although we are thinking of a system of larger scale and without the zig-zag multispans supports. The greatest advantage of this system is that there is no waiting for the rigging to reach the landing and return.



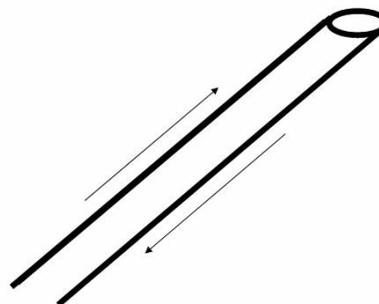
Figure 1. Concept of the gondola cable system.



The draw-well system models a well where a rope runs through a pulley, and two buckets – one on each end of the rope. In this system, there is a carriage at each end of the cable; one transports logs while the other returns empty (Figure 2). This system eliminates the separate time element for the empty carriage to return to a log-hooking point.



Figure 2. Concept of the draw-well system



It is natural that we think of separating the two cables of the draw-well system so they can move back and forth independently. The answer is the double-track system: one yarder has two skyline cables, and on each cable one carriage moves back and forth at its own pace (Figure 3). This system is much more flexible than the draw-well system, but requires four



Figure 3. Concept of the double-track system.

The time and labor for setting up two skylines would be a considerable disadvantage of the double-track system, and these requirements can be reduced by half if two carriages move on one cable. Figure 4 shows the double-carriage system that uses two carriages on one cable. Most carriages could not pass

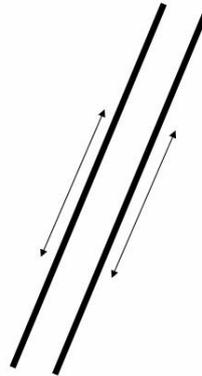


Figure 4. Concept of the double-carriage system.

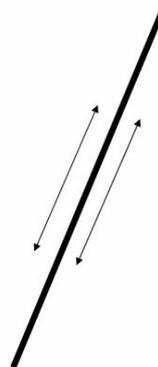
System Dynamics Simulation

We evaluated the new concepts of cable harvesting systems in terms of productivity by using system dynamics simulation, which helps us understand the behavior of complex systems over time. System dynamics is also characterized by its methodology for modeling complex feedback systems. Feedback systems mean a closed system influenced by its past

behavior, and has feedback loop structure that consists of closed paths of cause and effect (Agatstein et al. 2002). For modeling the new concepts of cable harvesting systems, we used STELLA 8.1 (ieee systems), a visual diagram-based simulation application program for system dynamics models. Figure 5 shows the four crucial components used in STELLA: stock, flow, converter and



each other, so one carriage restricts movement of the other. However, in this study, we also assume that two carriages can pass each other by using equipment similar to the open-sided trucks used to allow carriages to pass intermediate supports on multispan skylines.



behavior, and has feedback loop structure that consists of closed paths of cause and effect (Agatstein et al. 2002). For modeling the new concepts of cable harvesting systems, we used STELLA 8.1 (ieee systems), a visual diagram-based simulation application program for system dynamics models. Figure 5 shows the four crucial components used in STELLA: stock, flow, converter and

connector. The definitions of these components are explained as follows (Agatstein et al. 2002):

Stock: an element of a system that is accumulating or draining over time. Stocks are the memory of a system and are only affected by flows. Also known as levels, they are signified by rectangles in system dynamics diagrams.

Flow: Movement of a quantity from one stock to another.

Converter: A term used in the STELLA program, more generally known as an auxiliary variable. Converters do not accumulate flows and do not have memory, but rather are recalculated from scratch each time calculations are performed. Three types of converters define constants, algebra, or graphs. They are usually represented in diagrams by circles.

Connector: A building block that carries information from one element in a model to another element. "Information" may be a constant, an algebraic relationship, a graphical relationship (contained in converters or table functions), or a quantity (e.g. how many dollars in your savings account). "Information" flows through connectors to converters (auxiliary variables) or flows (rates), but not to stocks.

In addition, we used two more components derived from the stock for modeling cable harvesting systems (Figure 5):

Conveyor: A type of stock that represents a space into which material flows and stays for a fixed amount of time, then exits. Its associated parameters determine the transit time during which material stays in the conveyor. Material that flows in at a given time is not mixed with material that had flowed in earlier — whatever entered first will also leave first (Agatstein et al. 2002).

Oven: The oven acts like a stock with limited batch capacity. When the limit of the oven is reached, the oven closes and holds the inflow for a certain time. Then, the oven lets the contents out through the outflow. As soon as the oven becomes empty, it receives additional inflow and the entire process repeats.

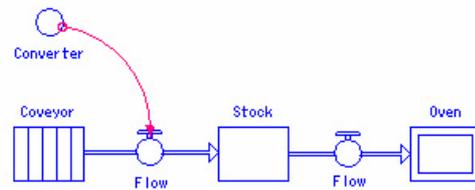


Figure 5. Four crucial components and two additional components derivative from the Stock, used in STELLA.

Simulation Method

We made a system dynamics simulation model of each cable harvesting systems as well as the conventional gravity-return system with, as an example, a Koller yarder and carriage. It is assumed that total volume of harvested logs is 36m^3 and yarding distance is 200m, both of which are common for all models. The speed of the carriage or cable is set at a reasonable value for each model. However, we made the other parameter values as uniform as possible for all models. To simplify the models, we did not consider empirical time relationships or stochastic time distributions. We do not believe that it is necessary to incorporate time distributions into the models because the goal of this study is conceptual evaluation of cable harvesting systems. Figure 6 shows the model of the conventional gravity system, and parameters used for this model are in Table 1. The uphill (travel loaded) and downhill (travel empty) carriage speeds are set to 2m/s and 4m/s, respectively. This system is widely used, but has the disadvantage of a long waiting time before the carriage returns to the log-hooking point. The simulation model of the gondola cable system, and parameters used for this model are shown in Figure 7 and Table 2, respectively. The maximum load of the continuously moving cable is set to 2m^3 in this study, and due to such maximum loads, the cable speed is 1m/s. This speed could be varied according to the machine power and variable payloads, but is considered constant in this study for simplification. The draw-well system is simulated by using the model shown in Figure 8 with parameters as listed in Table 3. The carriage speed is set to 2m/s. The carriage does not return to the log hooking point until it releases logs. This suggests that there is a disadvantage that requires long waiting time for the carriage to come back to the log-hooking point as with the conventional gravity system. Figure 9 illustrates the model of the double-track system.

The model of the double-carriage system conforms to this model as long as two carriages can pass each other on the same cable. Table 4 shows the parameters for this model. The upward and downward carriage speeds are set to 2m/s and 4m/s, respectively, as with the conventional gravity system. We assumed there is one choker setter at the hooking

point for two carriages and one chaser at the landing, so log hooking (log unhooking) for one carriage does not take place while the choker setter (or chaser) is occupied by log hooking (or log unhooking) for the other carriage.

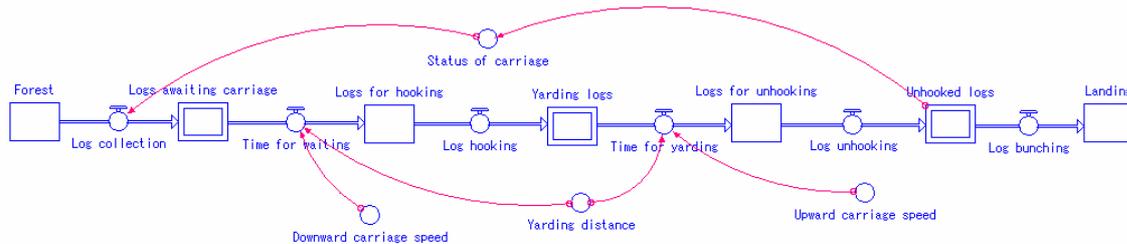


Figure 6. Simulation model of the conventional gravity system.

Table 1. Parameters for the simulation model of the conventional gravity system.

Component	Component type	Quantity or calculation
Forest (logs to be harvested)	Stock	36 m ³
Log collection	Flow	0.5 m ³ /s
Log awaiting carriage	Oven (capacity)	0.5 m ³
Time for waiting	Flow (cook time)	Yarding distance / Downward carriage speed
Log hooking	Flow	0.1 m ³ /s
Yarding logs	Oven (capacity)	0.5 m ³
Time for yarding	Flow (cook time)	Yarding distance / Upward carriage speed
Log unhooking	Flow	0.1 m ³ /s
Unhooked logs	Oven (capacity)	0.5 m ³
Log bunching	Flow (cook time)	1 s
Yarding distance	Converter	200 m
Downward carriage speed	Converter	4 m/s
Upward carriage speed	Converter	2 m/s

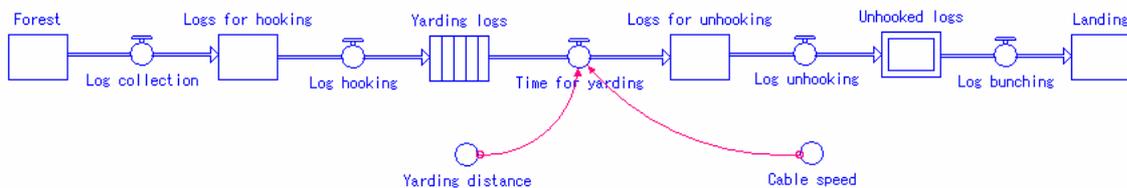


Figure 7. Simulation model of the gondola cable system.

Table 2. Parameters for the simulation model of the gondola cable system.

Component	Component type	Quantity or calculation
Forest (logs to be harvested)	Stock	36 m ³
Log collection	Flow	0.5 m ³ /s
Log hooking	Flow	0.1 m ³ /s
Yarding logs	Conveyor (capacity)	2 m ³
Time for yarding	Flow (transit time)	Yarding distance / Cable speed
Log unhooking	Flow	0.1 m ³ /s
Unhooked logs	Oven (capacity)	0.5 m ³
Log bunching	Flow (cook time)	1 s
Yarding distance	Converter	200 m
Cable speed	Converter	1 m/s

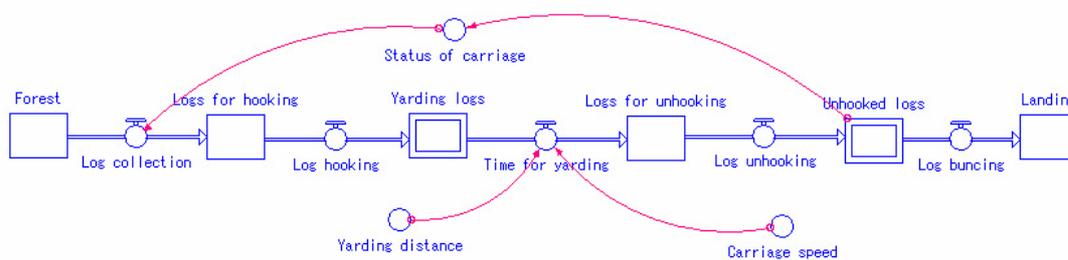


Figure 8. Simulation model of the draw-well system

Table 3. Parameters for the simulation model of the draw-well system.

Component	Component type	Quantity or calculation
Forest (logs to be harvested)	Stock	36 m ³
Log collection	Flow	0.5 m ³ /s
Log hooking	Flow	0.1 m ³ /s
Yarding logs	Oven (capacity)	0.5 m ³
Time for yarding	Flow (cook time)	Yarding distance / Carriage speed
Log unhooking	Flow	0.1 m ³ /s
Unhooked logs	Oven (capacity)	0.5 m ³
Log bunching	Flow (cook time)	1 s
Yarding distance	Converter	200 m
Carriage speed	Converter	2 m/s

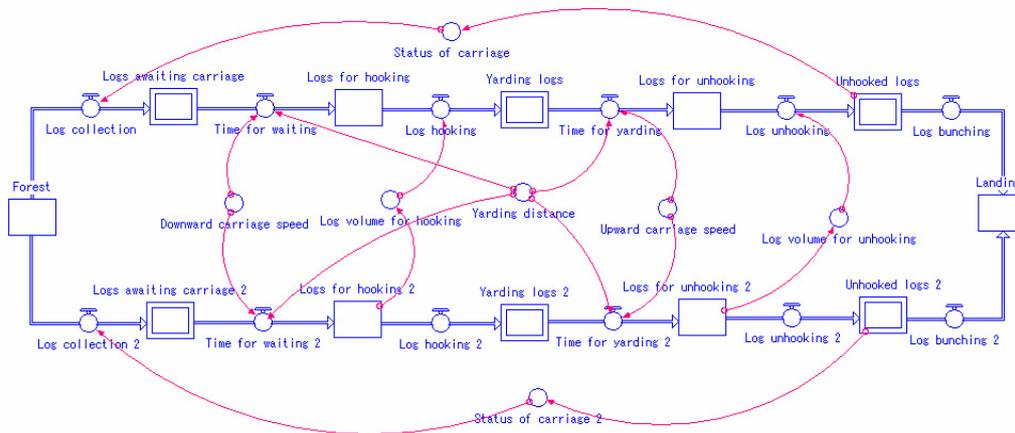


Figure 9. Simulation model of the double-track and double-carriage systems.

Table 4. Parameters for the simulation model of the double-track and double-carriage systems.

Component	Component type	Quantity or calculation
Forest (logs to be harvested)	Stock	36 m ³
Log collection	Flow	0.5 m ³ /s
Log hooking	Flow	0.1 m ³ /s
Yarding logs	Oven (capacity)	0.5 m ³
Time for yarding	Flow (cook time)	Yarding distance / Carriage speed
Log unhooking	Flow	0.1 m ³ /s
Unhooked logs	Oven (capacity)	0.5 m ³
Log bunching	Flow (cook time)	1 s
Yarding distance	Converter	200 m
Downward carriage speed	Converter	4 m/s
Upward carriage speed	Converter	2 m/s

Results and Discussion

Figure 10 shows the comparison of the productivity for the new cable harvesting systems concepts derived from system dynamics simulation. As shown, the gondola cable system had the highest productivity while the conventional gravity system had the lowest. This result suggests that waiting time for carriage return is a major factor that limits the productivity of cable harvesting. To develop the gondola cable system, there are some key issues to be solved. For example, it is necessary to pull logs laterally up to the continuously moving loop cable without stopping it. In addition, a very powerful yarder is required to drive the loop cable with heavy loads continuously. Worker safety is a crucial issue that must be addressed for any system that involves activities around moving lines. It may be possible to isolate the choker setters and chasers from the moving cables by using simple “robots” to automate the hooking function.

The second highest productivities were achieved by the double-track and double-carriage systems. The double-track system is relatively easy to be put into actual use, but it would need considerable time for setting up and removing two cables. Furthermore, if we use two yarders for this system, it would not be efficient in terms of the machine cost and labor cost of operators. The double-carriage system requires the development of a means for two carriages to pass each other on the same cable. We believe that this could be realized by using the mechanism similar to intermediate supports.

The draw-well system appears to have less productivity advantage than the other new concepts, but in terms of energy consumption, this system would have a slight advantage because the weight of the downward-traveling carriage compensates the force to pull the upward carriage. This advantage also applies to the gondola cable system.

We hope to further explore these new concepts of cable harvesting systems in future studies.

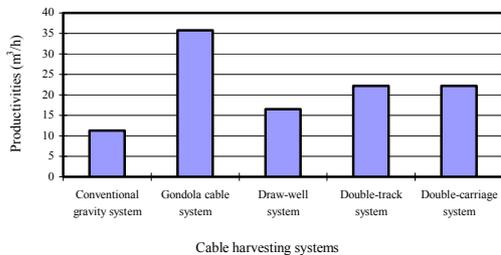


Figure 10. Comparison of productivities for cable harvesting system concepts.

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Literature Cited

- Agatstein, K., S. Albin, A. Ashford, L. Breierova, N. Choge, M. Choudhari, C. Chung, A. Coronado, A. Diamond, T. Duhon, S. Gary, M. Glick, M. Halbower, W. Glass-Husain, L. Lei, L. Martin, K. Msefer, A. Oh, M. Ratha, S. Samaranayake, L. Stanley, R. Wahba, J. Whelan, M. Zhang and H. Zhu. 2002. Road maps - a guide to learning system dynamics. System Dynamics in Education Project, System Dynamics Group, Sloan School of Management, Massachusetts Institute of Technology, Cambridge, MA. Accessed February 7, 2007 at <http://sysdyn.clechange.org/sdep/Roadmaps/RMGlossary/D-4498.pdf>.
- Hartsough, B.R., A. Gicqueau and R.D. Fight. 1998. Productivity and cost relationships for harvesting ponderosa pine plantations. *Forest Products Journal* 48(9):87-93.
- Hartsough, B.R., X. Zhang and R.D. Fight. 2001. Harvesting cost model for small trees in natural stands in the interior northwest. *Forest Products Journal* 51(4):54-61.
- Hori, T. 1974. Static study on the multiloaded multi-span monocable ropeway. *Journal of the Japanese Forestry Society* 56(2):43-54. (in Japanese with English summary)
- LeDoux, C.B. and D.A. Butler. 1981. Simulating cable thinning in young-growth stands. *Forest Science* 27(4):745-757.
- McDonagh, K.D., R.D. Meller, R.J.M. Visser and T.P. McDonald. 2004. Harvesting System Simulation Using a Systems Dynamic Model. *Southern Journal of Applied Forestry* 28(2):91-99.
- Nitami, T. 2006. Modeling of timber harvesting operation by system dynamics and the productivity estimation function. *Journal of Forest Engineering* 20(4):281-284. (in Japanese)
- Randhawa, S.U., T.M. Scott and E.D. Olsen. 1992. Timber harvester: a microcomputer-based system for automatic selection of timber harvesting equipment. *Applied Engineering in Agriculture* 8(1):121-127.
- Sasaki, S., T. Yoshimura, K. Numata, K. Kanzaki, and X. Zhou. 1996. An operation system using a newly-developed tower yarder altered from a power shovel (1) an application to thinning operations in the steep ground. *Journal of the Japan Forest Engineering Society* 11(1):29-36. (in Japanese with English summary)
- Yoshimura, T., S. Sasaki, T. Yamamoto and K. Kanzaki. 1996. An operation system using a newly-developed tower yarder altered from a power shovel (2) Evaluation of physiological loads of forestry workers using simulation. *Journal of the Japan Forest Engineering Society* 11(1):37-44. (in Japanese with English summary)
- Wang, J., W.D. Greene and B. Stokes. 1998. Stand, harvest, and equipment interactions in simulated harvesting prescriptions. *Forest Products Journal* 48(9):81-86.
- Wang, J. and C.B. LeDoux. 2003. Estimating and validating ground-based timber harvesting production through computer simulation. *Forest Science* 49(1):64-76.

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SESSION B.2:

ENVIRONMENTAL QUALITY IN MOUNTAIN LOGGING

THE EFFECT OF CONTEMPORARY FOREST PRACTICES ON HYDROLOGY, WATER QUALITY AND FISH: FIRST YEAR POST-TREATMENT RESULTS FROM THE HINKLE CREEK PAIRED WATERSHED STUDY

Arne Skaugset

Abstract: In recent years there has been a dramatic increase in the number of paired watershed studies that are either in place or planned in the Pacific Northwest. The number of contemporary paired watershed studies rivals the number that was in place following WWII when the seminal research on the response of watersheds to timber harvest was first carried out. However, these contemporary paired watershed studies have different objectives, time-lines, data collection technologies, and data analysis methods than their earlier incarnates. These studies should result in a breakthrough in understanding regarding how the response of watersheds to contemporary forest practices.

The objectives for these contemporary paired watershed studies generally fall into two categories. The first category is to determine the environmental effect of timber harvest adjacent to small, headwater, non-fish-bearing streams. The second category is to determine off-site or downstream effects of these headwater practices on downstream, main stem, fish-bearing streams. The research on these combined objectives is generally referred to as the study of cumulative watershed effects.

In addition to the specific research objectives these paired watershed studies also represent contemporary data points as a counterpoint to the historical paired watershed studies. As such these studies have the following common characteristics. They are virtually all on privately owned, intensively managed, and harvest-regenerated forest stands. They have compressed time frames (i.e. ~ 10 years), 3) and expanded spatial scales. They will study off-site or cumulative effects as well as direct effects. Finally, they use new data collection and management technologies and new analyses techniques. The new data collection technologies result in datasets that are spatially and temporally very rich. New analysis techniques will allow for detection of direct effects, in space and time, as well as detection of off-site or cumulative effects.

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CHANGES IN STREAM TEMPERATURE AND CANOPY CLOSURE FOLLOWING TIMBER HARVESTING ADJACENT TO NON-FISH BEARING HEADWATER STREAMS

Kelly M. Kibler, Arne E. Skaugset

Abstract: Summer stream temperatures were measured for four years in six headwater streams before four of the streams were clearcut without buffers according to modern forest practice rules. Stream temperatures were monitored for one additional year following the harvest treatment. Percent canopy closure was sampled along the streams before and following harvest and measurements taken after harvest measured shade provided by understory vegetation and logging debris as well as overstory vegetation. Stream temperatures in the four treatment streams responded variably to treatment as compared to the unharvested control streams. Two streams warmed significantly, one stream cooled significantly, and the fourth stream showed no significant change. Before and after stream canopy closure comparisons that considered only overstory vegetation indicated mean changes in canopy closure ranging from 81 to 94% in treatment streams and 3 to 5% in control streams whereas surveys that incorporated cover from understory vegetation and logging slash quantified mean changes in canopy closure ranging from 17 to 42% in treatment streams and 11 to 15% in control streams.

Key words: Stream temperature, timber harvest, aquatic habitat, salmonid, shade, percent canopy closure

Introduction

Anthropogenic actions such as dam construction, agriculture, and timber harvest can alter the thermal regime of aquatic ecosystems and lead to changes in aquatic ecology. Considerable research has focused on the effects of forest harvesting on stream temperatures, however, the majority of that seminal research occurred in the era of natural stand/old growth conversion and before the current suite of forest practice rules were put into place. An investigation of the effects of timber harvest on stream temperature on privately owned, intensively managed forest land with young, harvest-regenerated forest stands harvested using contemporary forest practices has rarely been undertaken.

Forest land supports many uses besides timber production that include but are not limited to recreation, water resources of high quality, and habitat for terrestrial and aquatic wildlife. Intensive forestry operations can degrade the suitability of forest land to provide some of these beneficial uses. In recent years, several populations of salmonids in the Pacific Northwest were listed as threatened or endangered under the provisions of the Endangered Species Act (Myers et al. 1998). Declines in populations of salmonids are correlated with habitat degradation associated with intensive forest management (Frissell 1993). Thermal regimes of streams can change in response to the management of forests

that are adjacent to streams and these changes in stream temperature may adversely affect aquatic habitat. Change in the thermal regime of a forest stream is a direct effect of the removal of streamside vegetation and has been studied extensively over the past four decades. Brown and Krygier's (1970) historic Alsea Watershed Study quantified an increase of 8 C in the average monthly maximum stream temperature the year following clearcutting of a small watershed in Oregon's Coast Range. In the same stream the daily fluctuation in stream temperature doubled after clearcutting.

Increases in stream temperature that occur in response to timber harvest can be mitigated by the application of Best Management Practices (BMPs), such retention of riparian vegetation (Bescheta et al. 1987, Brown and Krygier 1970, Brazier and Brown 1973). Brown and Krygier (1970) demonstrated that leaving buffer strips of undisturbed vegetation between harvest units and streams can reduce the impact on stream temperature when timber harvest occurs adjacent to streams. Brazier and Brown (1973) studied the characteristics of riparian buffer strips and reported that the mitigation of stream temperature changes provided by a buffer strip was directly proportional to the width of the buffer strip (up to 40 feet) and to canopy density.

The Forest Practice Rules in all western timber producing states have stream classification systems

and prescribe stream protection measures based on the size and beneficial uses of the streams. While every state has a unique system of stream classification, in general the streams are stratified into one of three categories: 1) perennial, fish-bearing streams, 2) intermittent, non-fish-bearing streams, 3) an intermediate stream size that transitions between the above two classifications. Minimum buffer strip widths and the requirement of commercial overstory species in the buffer strips is prescribed for all of the larger, fish-bearing streams. While the classification system and the width and composition of required buffer strips may vary, all states recognize the importance of perennial, fish-bearing streams and take steps to protect them during timber harvest adjacent to the streams. The same is not true for the non-fish-bearing streams. Some states require formal buffer strips containing merchantable, commercial overstory species and some do not. In some regions of Oregon there is no requirement for formal, fixed width buffer strips containing merchantable timber adjacent to small, non-fish-bearing streams.

Methods

The Hinkle Creek Paired Watershed Study was put into place to study the effects of contemporary harvest practices on fish and aquatic habitat. This investigation into the effects of timber harvest on stream temperature is one of the objectives of the Hinkle Creek Study. The study area consists of the headwaters of Hinkle Creek, a tributary of Calapooya Creek, which drains into the Umpqua River. Hinkle Creek is located in the foothills of the Cascades in southern Oregon, approximately 30 kilometers north-east of the city of Roseburg. The elevation of the study area ranges from 400 meters at the mouth of the watershed up to 1250 meters. The overstory vegetation in the Hinkle Creek watershed is primarily composed of 55-year old harvest-regenerated stands of Douglas fir (*Pseudotsuga menziesii*) but other overstory species include western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), red alder (*Alnus rubra*), and big leaf maple (*Acer macrophyllum*). Riparian vegetation consists of such understory species as huckleberry (*Vaccinium parvifolium*) and sword fern (*Polystichum munitum*). The fish-bearing portions of the stream network support a population of resident cutthroat trout (*Oncorhynchus clarki*), a salmonid native to the Northwest.

The Hinkle Creek Paired Watershed Study is a nested, paired watershed study and is comprised of the North Fork (control) and the South Fork (treatment) basins of Hinkle Creek, which are fourth

order stream basins. Within the North and South Fork basins of Hinkle Creek, six first- and second-order watersheds were instrumented for study (Figure 1). Two control watersheds are located in the North Fork basin and four treatment watersheds are located in the South Fork basin. The six instrumented streams are all classified as perennial, non-fish-bearing streams and these study areas are called headwater streams or watersheds for the purposes of this study. Summer stream temperatures of the six headwater streams were monitored from 2002 to 2005 before timber harvest occurred. Portions of the four headwater watersheds in the South Fork basin were clearcut during the winter of 2005 - 2006 (Table 1). Timber harvest was carried out using contemporary harvest equipment and practices. The trees were felled by hand, yarded to landings tree length and processed (cut into logs) at the landing. The yarding system was a skyline system that used a motorized carriage. The timber harvest was carried out in accordance with the current Oregon Forest Practice Rules and represents contemporary forest management.

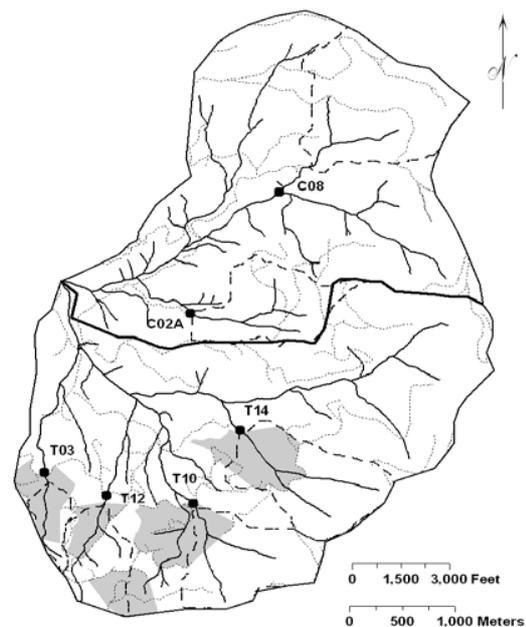


Figure 1: Hinkle Creek Paired Watershed. North Fork is control basin, South Fork is treatment basin.

One summer of post-treatment stream temperature data was collected. Changes in maximum daily stream temperatures (MDT) were detected using least squares regression of control and treatment MDT data. Temporal autocorrelation of consecutive daily maximum temperatures was addressed in data selection to ensure the independence of individual

data points. Data were selected for regression analysis based upon lag times derived from partial autocorrelation plots.

Table 1: Watershed Treatment- watershed areas, stream lengths and percent of each harvested for four treatment watersheds.

Stream	Watershed Area (ha)	Area Harvested (%)	Stream Length (m)	Stream Length Harvested (%)
Fenton	22.7	68	893	70
Russell	95.9	13	1,805	35
Clay	65.2	38	2,039	38
BB	111	31	2,275	47

The canopy closure provided by overstory vegetation was measured before and after timber harvest using a spherical densitometer held at waist height. During the summers of 2004 and 2006, percent canopy closure was thus measured every ten meters along the streams in the headwater watersheds. However in 2006, this method did not adequately quantify cover over the stream provided by logging slash located between the stream surface and waist height. Thus, digital photos were taken from a perspective of inches above the stream surface and analyzed to quantify cover over the stream provided by the logging slash.

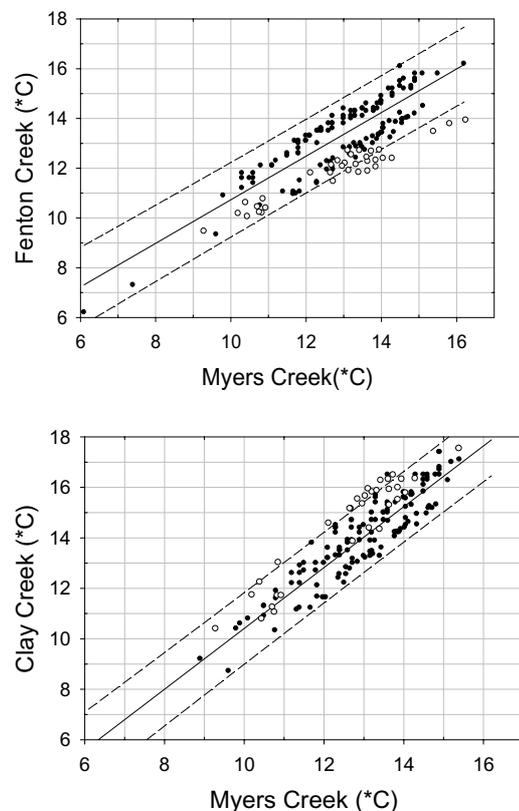
Results

Increases in MDT were observed at BB Creek and Clay Creek (Figures 2 and 3). Decreases in MDT were observed at Fenton Creek. MDTs at Russell Creek were not significantly affected by the treatment. Although changes to MDT were detected as a result of the treatment, the observed treatment effect appears to be less than the natural variability observed between the watersheds. Distributions of MDTs at treatment and control streams illustrate the variability in MDT due to year (control streams: Myers and Dem Creek) as compared to the variability due to treatment and year combined (treatment streams: Fenton, Clay, Russell, BB Creek) (Figure 3).

Mean and standard deviations of pre- and post-harvest percent canopy closure are presented for the six headwater watersheds (Table 2). Data from the digital photos taken in 2006 measures canopy closure provided by overstory vegetation and understory vegetation as well as from logging slash that covers the stream. Percent canopy closure in control streams and in unharvested portions of the treatment streams did not change appreciably between pre- and post-harvest surveys. Percent canopy closure in harvested

reaches of treatment streams as measured by spherical densitometer changed drastically as a result of the timber harvest while comparisons between 2004 canopy closure data and 2006 photo data reveal that when cover from the logging slash was considered, changes to canopy closure were less dramatic than the densitometer data would suggest.

The percent canopy closure data taken downstream of the harvest units, shown in Figure 4, illustrates the variability between crews collecting percent canopy closure data using a spherical densitometer. While there is operator error between the pre and post-harvest data, it appears the magnitude of the operator error is far less than the effect of treatment on percent canopy closure. Percent canopy closure data collected downstream of the harvest units and in the control watersheds where harvesting did not occur also allows for a comparison of the spherical densitometer and digital camera methods. The percent cover data from the digital photos indicates that a large portion of the cover over the streams following timber harvest was provided by logging slash that covered the stream. The data also indicate that the cover provided by the slash is highly variable in space.



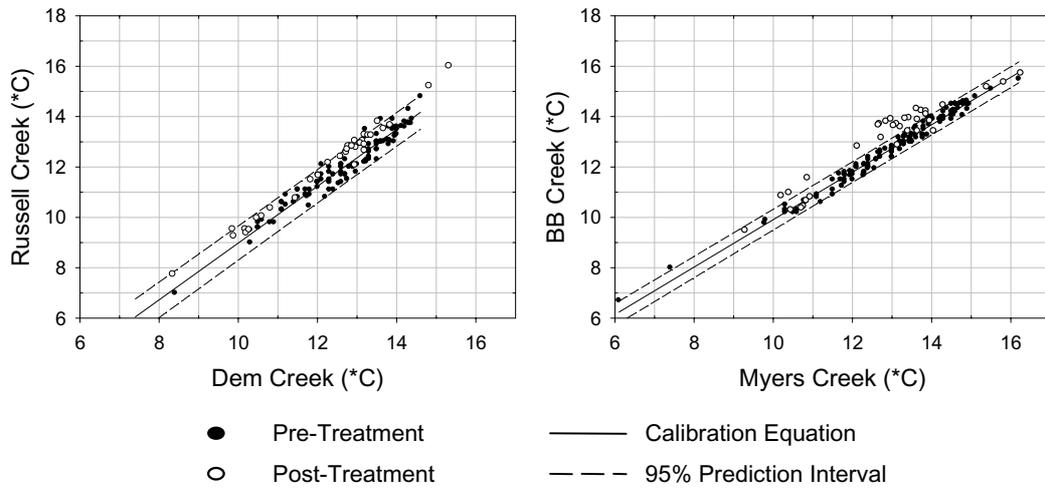


Figure 2: Calibration relationships and post treatment data for the four treated headwater streams.

MDT Distributions Before and After Harvesting

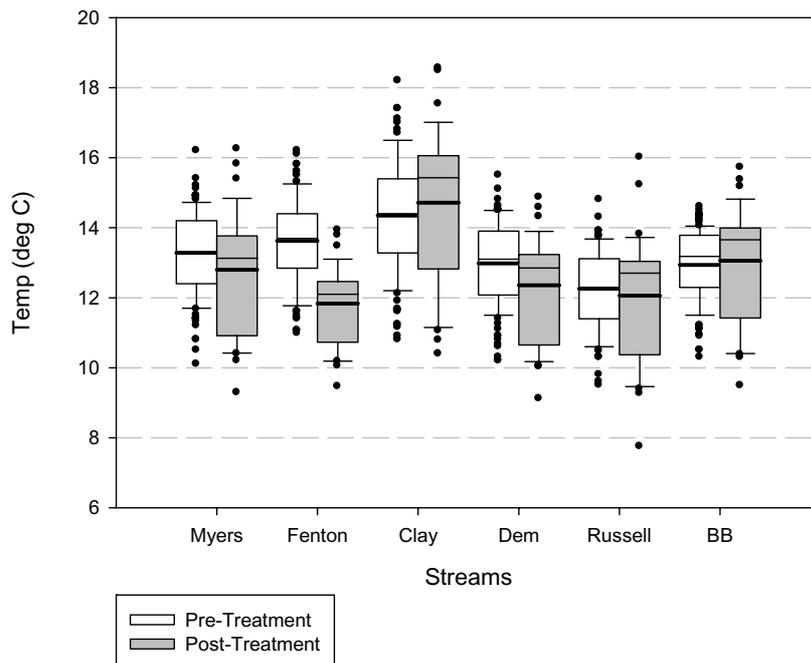


Figure 3: Distributions of control streams (Myers and Dem) illustrate MDT variability between to pre-treatment years (2002-2005) and post-treatment year (2006) while distributions of treatment streams (Fenton, Clay, Russell and BB) show variability due to both year and harvesting treatment.

Table 2: The mean and standard deviation of percent canopy closure for the four treated and two control headwater streams measured using a spherical densitometer during the summer of 2004 and measured using a spherical densitometer and digital camera after timber harvest in during the summer of 2006.

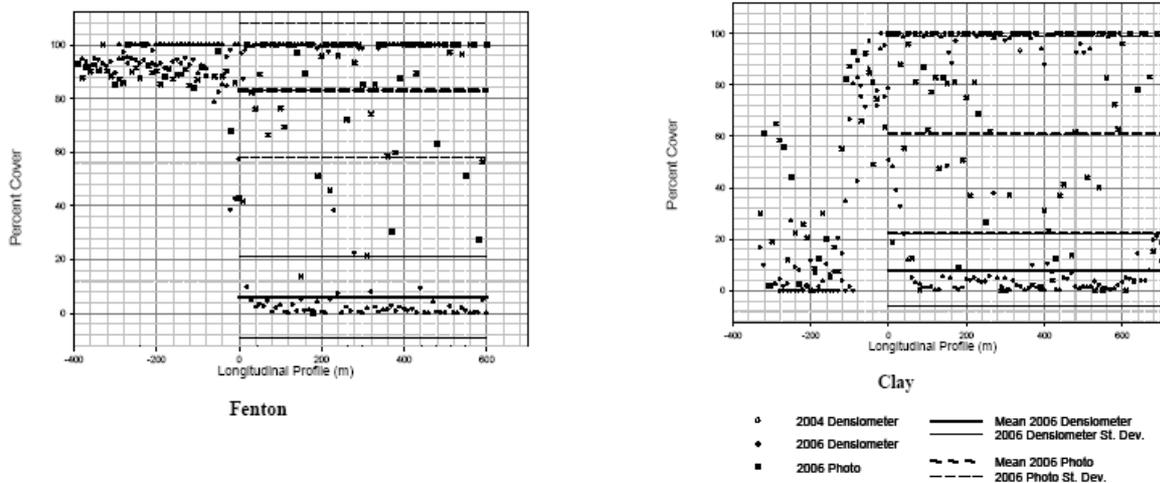
Stream	Percent Canopy Closure		
	Pre-harvest Densitometer (2004)	Post-harvest Densitometer (2006)	Post-harvest Photo (2006)
Fenton	100 ± 1	6 ± 15	83 ± 25
Russell	98 ± 3	17 ± 19	63 ± 38
Clay	99 ± 3	8 ± 14	61 ± 37
BB	98 ± 6	12 ± 16	56 ± 35
Myers	100 ± 2	95 ± 1	89 ± 3
Demerssemen	96 ± 7	93 ± 3	81 ± 8

Discussion

Historic paired watershed studies that investigated the effect of timber harvest on stream temperatures observed dramatic increases in maximum stream temperatures when riparian vegetation was removed. The two classic paired watershed temperature studies, the Alsea (Brown and Krygier 1970) and the HJ Andrews (Levno and Rothacher 1967) however were undertaken before the mandate of forest practice rules and demonstrate stream temperature changes that occur when a stream is exposed to high levels of solar radiation. In both the Alsea and the HJ Andrews, substantial temperature changes were observed where all riparian vegetation and logging slash were removed from streams. The Alsea logging treatment included a burn to remove logging debris and riparian vegetation while debris flows in the HJ Andrews scoured the stream to bedrock, effectively removing all streamside canopy closure. The observed increases in maximum stream temperatures were attributed to increased solar radiation received by the stream. Increases to stream temperatures that

result from greater inputs of solar radiation have been observed by several researchers (Brown 1969, Beschta et al. 1987, Johnson and Jones 2000, Johnson 2004). The preliminary results from the stream temperature and percent canopy closure data from the Hinkle Creek Paired Watershed Study further underscore the importance of solar radiation as a control to maximum daily stream temperatures.

Densitometer surveys of percent canopy closure in the vicinity of the streams show that levels of canopy closure provided by overstory vegetation were reduced dramatically following timber harvesting. However, surveys of after harvest percent canopy closure using a digital camera show that the actual amount of solar radiation reaching the stream did not change dramatically due to shade provided by the logging debris. It is plausible that the highly variable response of maximum daily stream temperature to treatment could be attributed, at least in part, to exclusion of solar radiation provided by the logging slash and debris that covered the streams.



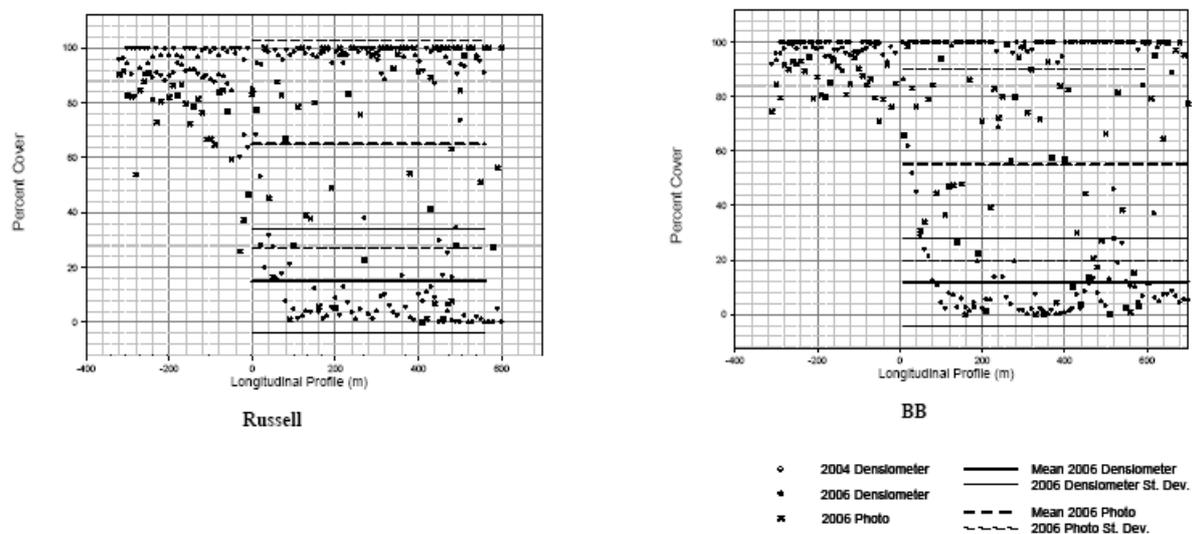


Figure 4: The percent canopy closure before harvest (2004) and after harvest (2006) measured using a spherical densitometer and a digital camera (2006) for Fenton, Clay, Russell and BB Creeks, respectively. The x-axis is the location of the sampling points along the longitudinal profile. The zero position marks the downstream boundary of the harvest unit. The mean and standard deviations of percent cover after timber harvest for data collected using a spherical densitometer and digital camera are shown.

Conclusion

Stream temperatures were measured for four years in six headwater streams before four of the streams were clearcut without buffers according to modern forest practice rules. Stream temperatures were measured for one additional year following the harvest treatment and significant quantities of logging debris covered the harvested streams after harvest. Percent canopy closure was sampled along the streams before and following harvest and measurements taken after harvest measured shade provided by understory vegetation and logging debris as well as overstory vegetation. Stream temperatures in the four treatment streams responded variably to treatment as compared to the unharvested control streams. Two streams warmed significantly, one stream cooled significantly, and the fourth stream showed no significant change. Before and after stream canopy closure comparisons that considered only overstory vegetation indicated mean changes in canopy closure ranging from 81 to 94% in treatment streams and 3 to 5% in control streams whereas surveys that incorporated canopy closure from understory vegetation and logging slash quantified mean changes in canopy closure ranging from 17 to 42% in treatment streams and 11 to 15% in control streams.

Literature Cited

- Beschta, R.L., R.E. Bilby, G.W. Brown, L.B. Holtby, and T.D. Hofstra. 1987. Stream Temperature and Aquatic Habitat: Fisheries and Forestry Interactions. In: Streamside Management: Forestry and Fishery Interactions, E.O. Salo and T.W. Cundy (eds.) University of Washington, Institute of Forest Resources. Contribution No. 57, Seattle, Washington. 191-232.
- Brazier, J.R. and G.W. Brown. 1973. Buffer Strips for Stream Temperature Control. Oregon State University. Corvallis, Oregon.
- Brown, G.W. 1969. Predicting Temperatures of Small Streams. *Water Resources Research*. 5(1):68-75.
- Brown, G.W. and J.T. Krygier. 1970. Effects of clearcutting on stream temperature. *Water Resources Research*. 6:1133-1139.
- Frissell, C. A. 1993. Topology of extinction and endangerment of native fishes in the Pacific Northwest and California (U.S.A.). *Conservation Biology* 7:342-354.

Johnson, S.L. and J.A. Jones. 2000. Stream temperature responses to forest harvest and debris flows in western Cascades, Oregon. *Canadian Journal of Fisheries and Aquatic Science*. 57(2):30-39.

Johnson, S.L. 2004. Factors influencing stream temperatures in small streams: substrate effects and a shading experiment. *Canadian Journal of Fisheries and Aquatic Science*. 61:913-923.

Levno, A. and J. Rothacher. 1967. Increases in Maximum Stream Temperature After Logging in Old-Growth Douglas fir Watersheds. Pacific Northwest Forest and Range Experimental Station. USDA Forest Service, Portland, Oregon. Research Note PNW-65.

Myers, J.M., Kope, R.G., Bryant, G.J., Teel, D., Lierheimer, L.J., Wainwright, T.C., Grant, W.S., Waknitz, F.W., Neely, K., Lindley, S.T., and Waples, R.S. 1998. Status review of Chinook salmon from Washington, Idaho, Oregon, and California. U.S. Dep. Commer. NOAA Tech. Memo. NMFS-NWFSC-35.

National Research Council. 1996. *Upstream: salmon and society in the Pacific Northwest*. National Academy Press, Washington, D.C.

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DOWNSTREAM TEMPERATURE IMPACTS OF HARVEST IN THE HINKLE CREEK PAIRED WATERSHED STUDY

Tim Otis, Arne E. Skaugset

Abstract: As a part of the Hinkle Creek Paired Watershed study, this research analyzes the cumulative impacts on stream temperature, downstream of clearcut harvest units. Hinkle Creek, located in the foothills of the Cascade Mountain about 25 miles northeast of Roseburg, Oregon, is privately owned, supporting a harvest-regenerated 55-year old stand of Douglas-fir. This study site contains four *treatment* and two *control* sub-watersheds, within larger control and treatment sides of the watershed, respectively. One year of calibration data and one year of post-harvest data are compared. Downstream effects are here evaluated using statistical tests, in the context of the *Before-After-Control-Impact* (BACI) study design. Traditional paired watershed studies, which evaluated stream temperature using one annual summer high temperature, required many years of calibration to find a statistically significant effect. This study evaluates change detection using Analysis of Covariance methods. Maximum Daily Temperatures, spaced three days apart to account for autocorrelation of model residuals, were compared for the two summer seasons. Tracer-dilution measurements of stream velocity, flowrate, and groundwater advection downstream of harvest units were used to account for differences in treatment effect between streams.

Stream temperatures at the clear-cut harvest boundary were found to vary in response to harvest for the four treatment streams. Using Myers Creek as the covariate control, Fenton Creek cooled by 0.6 °C, Clay, Russell, and Beebe Creeks warmed by 2.0, 0.4, and 0.6 °C respectively. Stream temperatures 306 m. (1000 ft) downstream showed decreased response to harvest, having no detectible (ND) response at Fenton, 0.5 °C at Clay, 0.2 °C at Russell, and ND response at Beebe. ND response was found at the confluence of the South fork (treatment) and North fork (control) streams.

Key words: Stream Temperature, Headwaters, Watershed, Downstream Effects

Introduction

Stream temperature is a water quality parameter of concern in Northwestern US forests. The Oregon Department of Environmental Quality (DEQ) has established criteria for Total Maximum Daily Loads (TMDL's) for temperature for Oregon streams and rivers. National Oceanic and Atmospheric Administration's (NOAA's) National Marine Fisheries Service has prepared recovery strategies for species listed under the Endangered Species Act (ESA), including salmonid species for which stream temperature is a monitored water quality parameter. Research has shown that stream temperatures can be elevated following timber harvest, primarily due to loss of shade over the stream channel (Brown and Kryger, 1970). The question of whether these temperature increases cause significant downstream effects has been the subject of research with sometimes conflicting results (Poole and Berman 2001, Zwieniecki and Newton 1999, Johnson and Jones, 2000), but propagation of heat downstream remains poorly understood. Although there is general agreement that solar radiation is the primary

influence on stream temperature in unshaded reaches (Brown and Kryger 1970, Webb and Zhang 1999), longitudinal changes in temperature after streams reenter the forest canopy are more complex and variable (Johnson 2004). Essentially a physics question, one approach would be a model of energy exchanges between the stream and its environment (Sinokrot and Stefan 1993). The stream, geographic, and weather data needed for complex headwater stream systems make this a significant task.

A first step in understanding this downstream process is to measure these temperature changes with enough spatial and temporal resolution to determine where further research and management effort should be focused. This study seeks to characterize the amount and variability of downstream temperature changes following the clear-cut harvest in across the watersheds of small non-fish bearing streams. Specifically, changes in Maximum Daily Temperature are analyzed between the last summer season pre-harvest (2005), and the first summer season post-harvest (2006). Stream temperatures at the harvest boundary are compared to measurements taken at intervals

downstream, as well as at the confluence of the treatment and control watersheds.

Methods

These temperature data are from the Hinkle Creek Watershed Study, located in the foothills of the Cascade Mountain about 25 miles northeast of Roseburg, Oregon. This 2000 ha watershed is privately owned, supporting a harvest-regenerated 55-year old stand of Douglas-fir. The study site contains four *treatment* and two *control* sub-watersheds, within larger control and treatment sides of the watershed, respectively. These six sub-watershed streams are classified under Oregon Forest Practice rules as perennial non-fish bearing streams.

The geology of the watersheds is basalt from the Siletz volcanics formation. The soils are Typic Palehumults or Typic Haplohumults, deep and well drained with loamy textures ranging from extremely gravelly to silty clay. The forest is predominately Douglas-fir with some western hemlock. The under-story is composed of swordfern, rhododendron, vine maple, salal, Oregon grape, and red huckleberry. The fish-bearing portions of these streams support a resident population of cutthroat trout. Elevation ranges from 400 meters at the confluence of the North and South forks of Hinkle Creek to 1200 meters at the top of the watershed. Mean annual precipitation ranges from 1,400 mm at the mouth of the watershed to 1,900 mm at the higher elevations.

Stream Temperature Data Sampling

Temperature data have been collected for four years during the pre-harvest calibration period (2002 – 2005) and for one year post-harvest (2006). In-stream temperature probes were deployed in the watershed as shown in Table 1. Temperature data were also collected at the eight flume locations as shown in Table 2. Hobo probes were checked for accuracy using a two-point comparison with a YSI field Temperature/Specific conductivity probe. PVC Solar shielding tubes were added to probes deployed in 2006.

Steady-state tracer-dilution studies were done on the four treatment streams during the 2005 and 2006 summer seasons, using Rhodamine WT dye and Turner Model AU Fluorometers. These studies characterized the flowrate, velocity, and advection of hillslope water for 300 meters downstream of the harvest units. Thirty Hobo temperature probes were installed at 10m spacing during each tracer test to

correlate advection of hillslope water with stream temperature changes. ISCO 3700 automated water samplers collected hourly samples at 25m, 75m, 150m, 225m, and 300m downstream of the dye injection site, and dye concentration was continuously monitored by a field fluorometer at 300m to track changes in dye concentration at the bottom of the study reach. When steady-state conditions were reached, grab samples of stream water were taken at the 10m spacing. Flowrates at these 10m intervals were calculated using a two-component mixing model.

Table 1. Temperature Probes (*Summer data, late May through early September, typically)

Probe locations	Number	Dates Deployed*	Brand	Interval (min)
Mainstem	2	2002-2004	Vemco	30 Min
		2005-2006	Hobo	10 min
Control	9	2002-2004	Vemco	30 Min
		2005-2006	Hobo	10 min
Treatment	11	2002-2004	Vemco	30 Min
		2005-2006	Hobo	10 min
Below Treatment Flumes	16	2005-2006	Hobo	10 min

Table 2. Temperature data collected at flumes (Continuous data)**

Flume locations	Number	Dates Deployed**	Brand	Interval (min)
Mainstem	2	12/03 to present	Campbell	10 min
Control	2	12/03 to present	Campbell	10 min
Treatment	4	12/03 to present	Campbell	10 min

Timber harvest was done during the autumn, winter and spring of 2005-2006, following Oregon Forest Practices rules. Harvest was done using both cut-to-length processor and shovel yarding, as well as hand felling, cable and carriage (whole tree) yarding with log processing at the landing.

Results and Discussion

Stream temperature fluctuates two primary cycles, seasonal and diurnal. Streams mean daily temperature have been shown to track with air temperature on the seasonal time scale (Sinokrot and Stefan 1993). Overlain on this variation is the diurnal cycle, which can vary widely between day and night, depending on climatic, geologic, and topographic factors. In addition, summers in western Oregon, though typically characterized by warm weather and clear skies, experience periods of warmer and cooler weather on a cycle of days to weeks. Figure 1 shows the stream

temperature for the South fork of Hinkle Creek for the summer of 2006, and illustrates these three cyclical patterns.

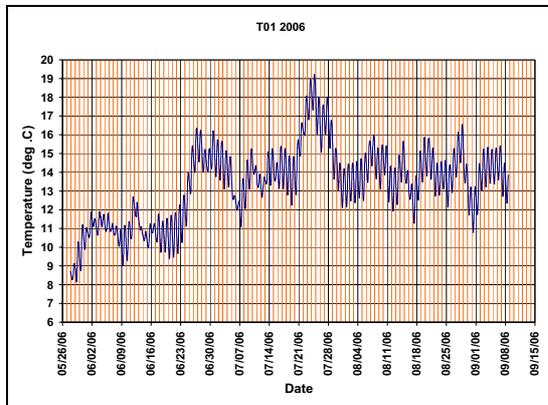


Figure 1. South Fork Hinkle Creek, Summer 2006

Downstream effects are here evaluated using statistical tests, in the context of the *Before-After-Control-Impact* (BACI) study design. Traditional paired watershed studies, which evaluated stream temperature using one annual summer high temperature, required many years of calibration to find a statistically significant effect. This analysis, however, documents changes in stream temperature pre- and post-harvest, using maximum daily stream temperatures of the four treatment streams for a single year before and after harvest. An Analysis of Covariance (ANCOVA) model compared 2005 data with 2006 for each stream, using Myers Creek data as the covariate control. This analysis was repeated for stream temperature data 306 m. (1000 ft.) below harvest boundaries. Finally, the two years were compared at the mouth of the treatment and control watersheds.

In modeling time series relationships between control and treatment streams, it is important to ensure that the assumptions of the statistical models are met. One concern with time series data such as this is that the residuals from the model may be autocorrelated in time. For example, if a pair of treatment/control daily maximum temperatures is above the regression line one day, it is more likely to be above it the next day. Another way to consider the data is that the departures from the regression relationship may not be random, but can follow multi-day departures, or follow some cyclic pattern. This has the result that

data from consecutive days may not be independent from each other. In this case, autocorrelation was found to have one or two days lag for all streams. To ensure independent data, a random start date was chosen, and every third day's maximum temperature was used for analysis. Another statistical concern is that the residuals from modeling be normally distributed and have equal variance. To improve the residual structure, early and late season data was not used. The analysis presented here uses daily maximum temperatures for the same 21 calendar days in July and August of 2005 and 2006.

Stream temperature response varied between streams. Figures 2 and 3 compare the distribution of maximum daily temperatures between years, at the harvest boundary and 306 meters (1000 ft.) downstream, respectively. Boxes represent 25th and 75th percentile, whiskers represent 5th and 95th percentiles, bold lines in boxes represent means, and light lines represent medians. Myers Creek, as noted above, was used as a control for this analysis. Two effects are apparent here. First, Fenton creek appears cooler while Clay creek appears warmer following harvest. Second, all effects are diminished downstream. The analysis of covariance quantifies these amounts. Figures 4 and 5 show the changes in the mean change in maximum daily temperature between years, after accounting for the mean change in the Myers creek control. Whiskers represent the 95% confidence interval for mean values. At the harvest boundary (Figure 4), Fenton creek cooled 0.63 °C, Clay creek warmed 2.0 °C, Russell creek warmed 0.42 °C, and Beebe creek warmed 0.63 °C. None of the confidence intervals include zero. At 306 meters (1000 ft.) downstream (Figure 5), Fenton creek and Beebe creeks show no detectible change between years. Clay creek has a 0.51 °C increase, and Russell creek has a 0.18 °C increase. However, the confidence intervals for these changes at Clay and Russell creeks extent nearly to zero, so there is only moderate evidence of a difference in temperatures. Figure 6 compares the distributions of maximum daily stream temperatures at the mouth of the treatment (South fork) and control (North fork) watersheds. No difference between years is evident from this data. To look for a treatment affect at this watershed scale, a time series model (not presented here) is being developed using three years of daily maximum temperature data for calibration, and one year of post harvest data.

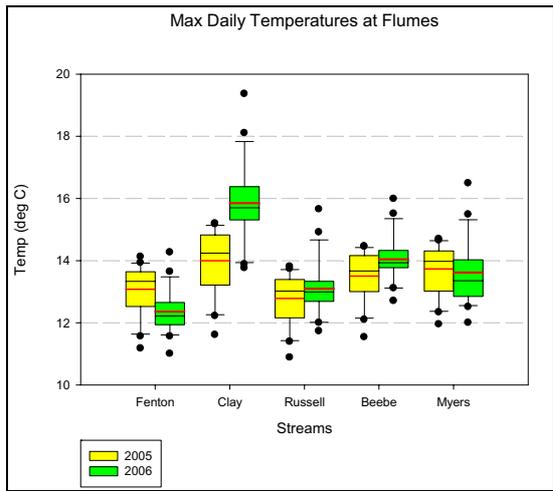


Figure 2. Stream Temp. Box Plots – Harvest Boundary

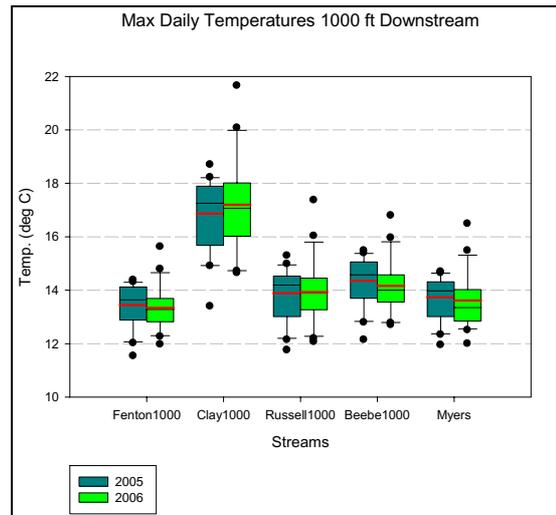


Figure 3. Stream Temp. Box Plots – 306 m (1000 ft) Downstream

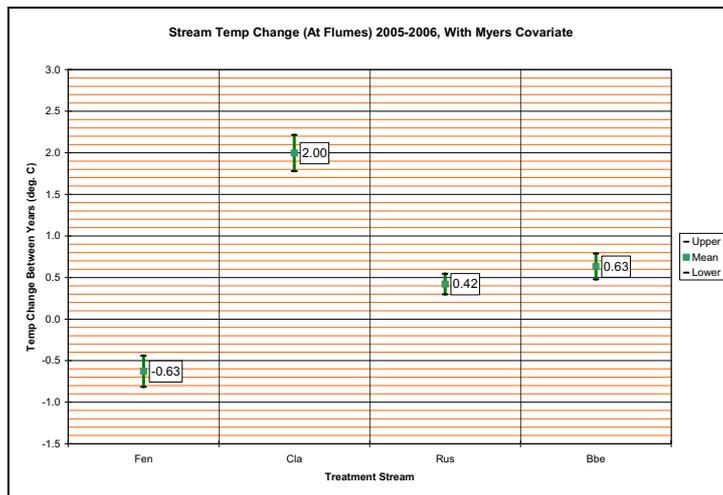


Figure 4. Temp. Change Between 2005 and 2006, At Harvest Boundary

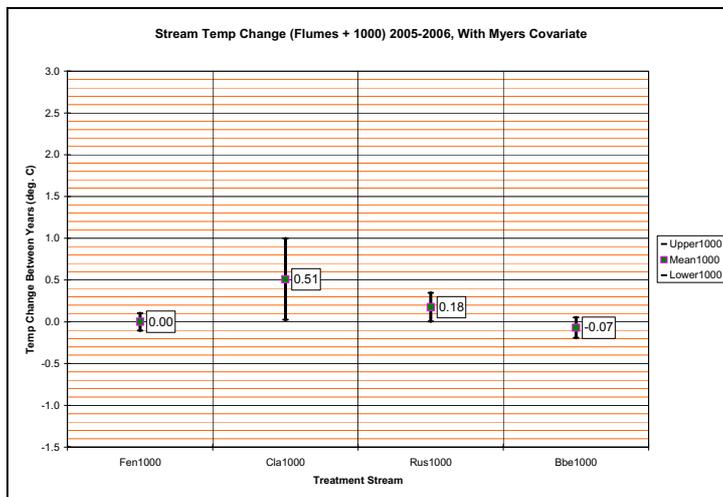


Figure 5. Temp. Change Between 2005 and 2006, 306m (1000 ft) downstream of Harvest

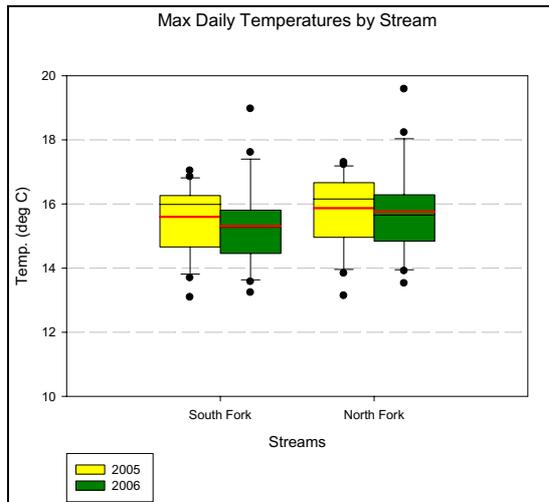


Figure 6. Max. Daily Stream Temperatures Mouth of Watersheds

Conclusions

Maximum daily stream temperatures were measured downstream of clearcut harvest units. Stream temperatures response between the last year pre-harvest and the first year following harvest varied by stream, after accounting for differences in an unharvested control stream. Harvest effects on stream temperature were smaller at 306m (1000 ft) downstream.

Literature Cited

- Brown, G.W. and J.T. Krygier, 1970. Effects of clearcutting on stream temperature. *Water Resources Research*. 6:1133-1139.
- Johnson, S.L. 2004. Factors influencing stream temperatures in small streams: substrate effects and a shading experiment. *Canadian Journal of Fisheries and Aquatic Science*. 61:913-923.

Johnson, S.L. and J.A. Jones. 2000. Stream temperature responses to forest harvest and debris flows in western Cascades, Oregon. *Canadian Journal of Fisheries and Aquatic Science*. 57(2):30-39.

Poole G.C. and C.A. Berman. 2001. An ecological perspective on in-stream temperature: natural heat dynamics and mechanisms of human-caused thermal degradation. *Environmental Management* 27(6): 787-802.

Sinokrot, B.A. and H.G. Stefan. 1993. Stream temperature dynamics: measurements and modeling. *Water Resources Research*. 29(7):2299-2312

Webb, B.W. and Y. Zhang. 1999. Water temperatures and heat budgets in Dorset chalk water courses. *Hydrol. Processes* 13:309-321.

Zwieniecki M.A. and M. Newton. 1999. Influence of streamside cover and stream features on temperature trends in forested streams of western Oregon. *Western Journal of Applied Forestry*. 14(2) 106-112.

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THE EFFECTS OF CONTEMPORARY FOREST HARVESTING PRACTICES ON HEADWATER HYDROLOGY: FIRST YEAR POST-HARVEST RESULTS FOR FENTON CREEK IN THE HINKLE CREEK PAIRED WATERSHED STUDY

Nicolas Zegre, Arne E. Skaugset, Lisa Ganio, Dan Moore

Abstract: First year post logging changes in catchment hydrology and sediment yield were evaluated to assess the effects of contemporary forest harvesting within the Hinkle Creek Paired Watershed Study in southwestern Oregon. The forested watershed is owned and managed entirely by Roseburg Forest Products and supports a harvest-regenerated stand of 55-year-old Douglas fir with an existing road network. Two years of pre-treatment stream discharge and sediment data were used to develop calibration equations used to identify the effects of logging at the headwater (non-fish bearing) scale. Given time constraints during the calibration period it was necessary to develop cutting edge analysis methods to discern the effects of timber harvest on water and sediment yield. Time series analysis, correcting for serial correlation, and Generalized Least Squares regression were used to fit pre-treatment data. Calibration equations were developed from mean daily discharge and total daily sediment load.

Preliminary results indicate an increase in mean daily discharge and daily sediment load in the treated watersheds relative to the control watersheds for the non-fish-bearing streams. These results for increases in mean daily discharge and total daily sediment load are consistent with the literature with regard to the effects of forest harvesting on watershed hydrology. The increase in sediment yield is hypothesized to be primarily a function of increases in mean daily flow.

Key words: forest hydrology, forest harvesting effects, time-series analysis

Introduction

The Hinkle Creek Paired Watershed Study is a nested, paired watershed study located 40-km northeast of Roseburg, Oregon in the foothills of the Cascades (Figure 1). The objective of the Hinkle Creek study is to evaluate the effects of contemporary forest harvesting practices on headwater and basin scale hydrology. Fenton Creek, a sub-watershed within the South Fork Hinkle Creek watershed, was used in this study to evaluate the effects of contemporary forest harvesting on hydrology and sediment load.

Methods

Study site and treatment description

The main study watershed is approximately 2,000-ha in area that is evenly divided into the North and South Forks of Hinkle Creek. The forested watershed is mostly owned and managed by Roseburg Forest Products and supports a harvest-regenerated, 55-year-old Douglas fir stand with an existing road network. The South Fork serves as the treatment watershed,

while the North Fork serves as the control watershed in the paired watershed study. Fenton Creek, the treatment headwater watershed, has an approximate area of 23 ha. Both DeMerresman and Meyers Creeks were used as control watersheds, with areas of 156 ha and 86 ha, respectively.

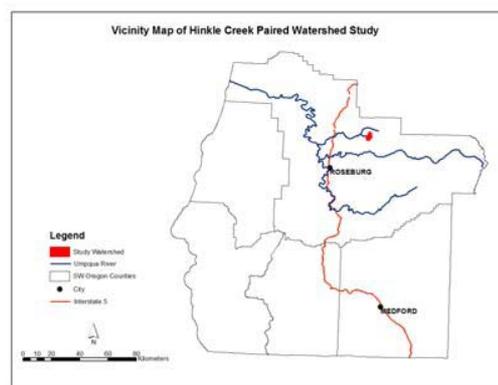


Figure 1: Vicinity map of the Hinkle Creek Paired Watershed Study, OR.

Forest harvesting started in mid-July 2005 and continued through January 2007. Approximately 68% of

Fenton Creek was harvested. Fenton Creek was clear-cut harvested according to current forest practices using a skyline logging system with a small component of shovel logging. Felled stems were manufactured with log processors at the landing and hauled using log trucks on existing road infrastructure.

Study design

The paired watershed approach is being used at Hinkle Creek to evaluate the influence of contemporary forest practices on water quality, aquatic habitat, and fish. The concept of this approach is based on determining statistical relationships of multiple hydrologic variables between control and treatment watersheds (watershed calibration). Within the North and South Forks, sub-watersheds have been instrumented to quantify inter-watershed activity. The use of headwater and main-stem monitoring sites along connected flow paths within each drainage offers a mechanism for detecting cumulative effects of a treatment signal (increased storm volume, discharge,

sediment) as it is propagated downstream from headwater harvesting units. Given time constraints during the calibration period it was necessary to develop cutting edge analysis methods to discern the effects of timber harvest on water and sediment yield. By addressing and removing autocorrelation from the time-series data, we were able to increase the power of our statistical models by increasing sample size.

Data Collection

Our primary approach to hydrology data collection in the Hinkle Creek Paired Watershed Study is driven by the Turbidity Threshold Sampling (TTS) system, developed by the Redwood Sciences Lab of the USDA Forest Service Pacific Southwest Research Station. Eight TTS stations were installed during summer 2003, with 2 stations (DEM, MEY) in headwater streams of the North Fork (control), 4 stations (BB, CLA, FEN, RUS) in headwater streams of the South Fork (treatment), and 2 stations at the confluence of the North and South Forks of Hinkle Creek (Figure 2).

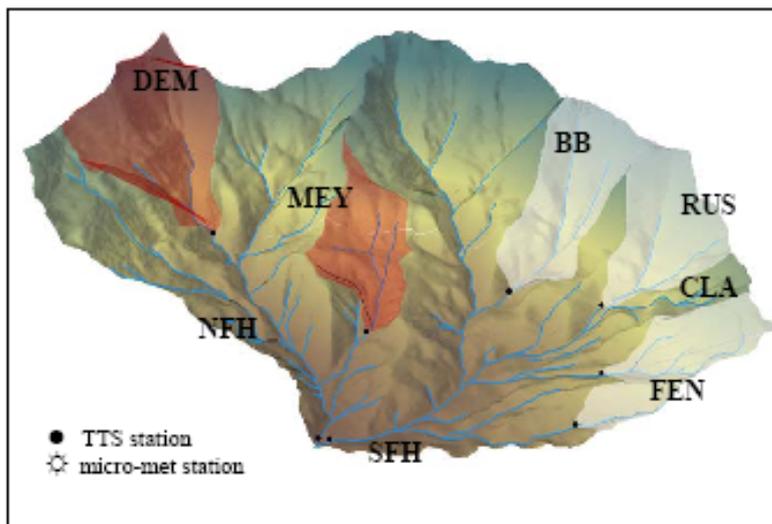


Figure 2: Control and treatment watersheds in the Hinkle Creek Paired Watershed Study

Watershed Calibration

Discharge and sediment yield data, analyzed at different temporal resolutions, are used to develop statistical relationships between watersheds at Hinkle Creek. Two years of pre-treatment discharge and sediment data were used to develop calibration equations used to identify the effects of logging at the headwater scale (non-fish bearing). Discharge and sediment, independent variables used for watershed

calibration, were measured at Fenton, Meyers, and DeMersseman Creeks. Meyers Creek and DeMersseman Creek serve as control watersheds while Fenton Creek serves as the treatment watershed. Time-series analysis and generalized least-squares (GLS) regression analyses were used to fit pre-treatment data. Calibration equations were constructed from mean daily discharge and total daily sediment yield. GLS was used to account for

residual serial autocorrelation, yielding a fitted model of

$$\log \hat{y}_t = \beta_0 + \beta_1 x_t + \beta_2 \sin(2j\pi/T) + \beta_3 \cos(2j\pi/T) + \varepsilon_t$$

where \hat{y}_t is the estimated mean daily discharge or total daily sediment yield at the treated watershed, x_t is the mean daily discharge or total daily sediment yield at the control watershed, β_0 , β_1 , β_2 , and β_3 are coefficients estimated by regression, j is the day of year ($j=1$ on 1st January), $T=365.25$, the number of days in a year, and ε_t is an error term.

Time-series analysis was used to remove autoregressive structure from GLS model residuals. Partial autocorrelation function plots of model residuals for mean daily discharge and total daily sediment were used to discern the degree of serial autocorrelation. Autocorrelation was removed from residuals by fitting a stochastic time-series model of the ARMA family (Salas, 1993), leaving just the “disturbances”. Disturbance is as measure of the component of the deviation which is specific to day t , with any component inherited from previous days being subtracted out by the autoregressive removal procedure (Watson et al., 2001). Disturbance is expressed as

$$a_t = (\log y_t - \log \hat{y}_t) - \phi(\log y_{t-1} - \log \hat{y}_{t-1})$$

where $(y_t - \hat{y}_t)$ is the residual from the log/log/sine GLS model at time t , and ϕ is the autoregression parameter estimated for lag i autocorrelation coefficient.

Results

Calibration equations for mean daily discharge and total daily sediment yield were developed through generalized least-squares regression (Table I). Best fit relationships for the selection of watershed calibration models were based on standard error of the estimates (*s_{e res}*). Standard error of the estimates suggests the pairing of Fenton Creek with DeMerresman Creek for mean daily discharge and Meyers for total daily sediment load (Table I). Time-series analysis was used to detect autocorrelation in residual variance structures. Three significant lags were observed for mean daily discharge and total daily sediment (Figure 3). Comparison of the mean daily flow generalized least-squares regression model and the GLS model with the AR (3) component removed suggests that the removal of serial autocorrelation reduces the variability and magnitude of residuals (Figure 4). A comparison of pre- and post-treatment disturbances suggests a 10% increase in mean daily flow (L/s) and a 5% increase in total daily sediment load (kg) (Figure 5 a&b). An increase in runoff was observed during and directly after forest harvesting treatment (Figure 6). A two-sample Kolmogorov-Smirnov Goodness of Fit Test suggests a statistically significant difference between pre- and post-treatment residual distributions for mean daily flow ($ks=0.703$, $p\text{-value}=0$) and total daily sediment load ($ks=0.3759$, $p\text{-value}=0$) (Figure 7 a&b).

Table I: Results of mean daily discharge and total daily sediment GLS regression analyses between control and treatment watersheds. The coefficients β_0 , β_1 , β_2 , and β_3 are estimates of regression coefficients, with significance levels (*p values*) shown in brackets, *s_{e res}* is the standard error of estimate, and ρ_i is the estimated lag-*i* autocorrelation of the error terms.

d.f	<i>k</i>	ρ_1	ρ_2	ρ_3	Mean Daily Flow (L/s)				<i>s_{e res}</i>	
					$\log \beta_0$ (<i>p value</i>)	$\log \beta_1$ (<i>p value</i>)	$\log \beta_2$ (<i>p value</i>)	$\log \beta_3$ (<i>p value</i>)		
FEN (DEM)	623	3	1.05	-0.30	0.15	-0.64 (0)	0.75 (0)	0.01 (0.8)	-0.02 (0.64)	0.17
Total Daily Sediment (kg)										
FEN (MEY)	623	3	0.77	-0.13	0.19	-0.10 (0)	0.79 (0)	-0.12 (0)	-0.03 (0.44)	0.20

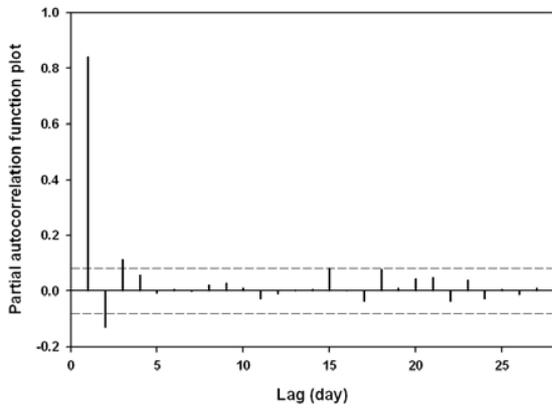


Figure 3: Partial autocorrelation function plot for mean daily discharge GLS model, showing statistically significant serial correlation up to 3-day lag.

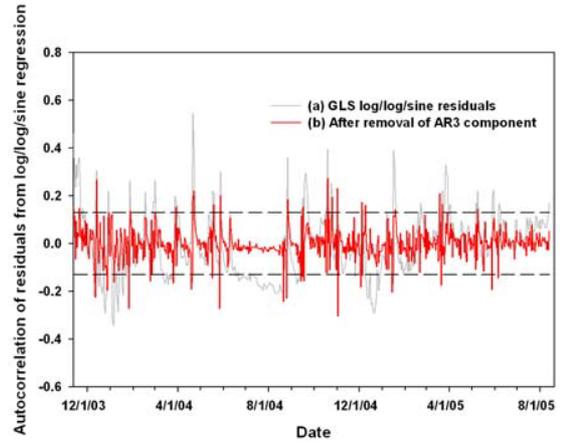


Figure 4: Correlogram of residuals from (a) log/log/sine GLS regression, showing significant serial correlation, and (b) log/log/sine GLS regression with AR3 component removed, showing no significant serial correlation ($\alpha = 0.05$).

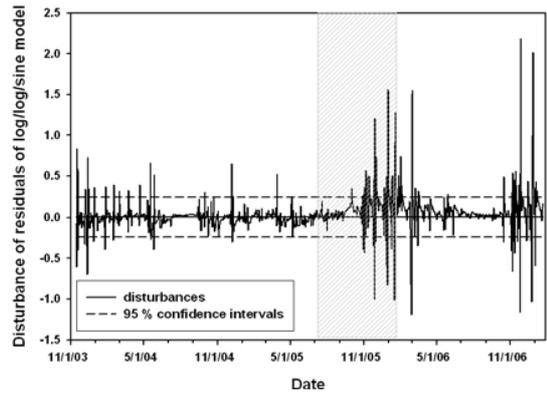
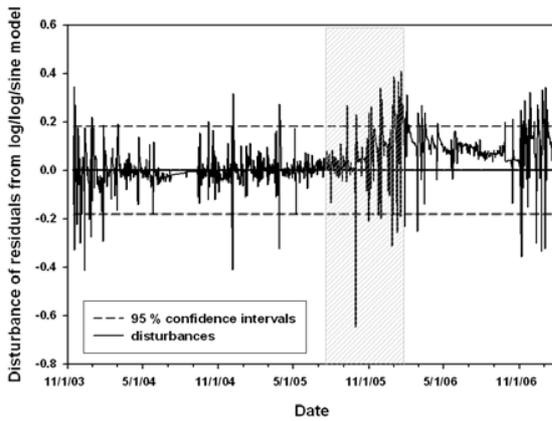


Figure 5: Fenton Creek disturbances for pre- and post-treatment (a) mean daily flow (L/s) and (b) total daily sediment (kg).

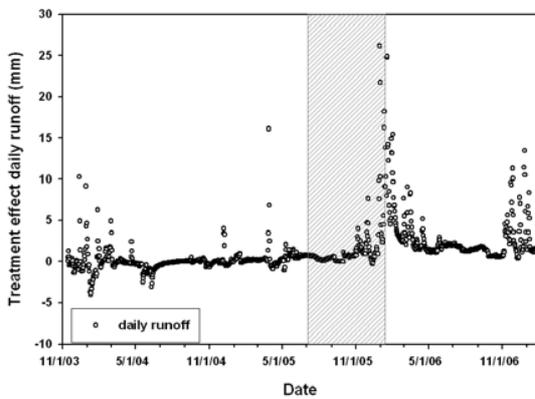


Figure 6: Fenton Creek treatment effects for mean daily runoff (mm).

Discussion

Mean daily flow and total daily sediment load were increased after clear-cut harvesting of Fenton Creek. Increases in mean daily flow may be attributed to changes in the water balance due to the removal of vegetation. Vegetation removal may increase stream-flow generation by reducing the amount of water lost to the atmosphere by evapotranspiration. The increase in mean daily flow is consistent with the current literature with regard to the effects of forest harvesting on watershed hydrology. Increases in sediment load are directly attributable to increases in daily flow. By increasing the volume of water moving through the stream network, the energy of in-channel water is increased, subsequently increasing stream-bank erosion and redistribution of sediment.

Literature Cited

- Watson, F., R. Vertessy, T. McMahon, B. Rhodes, and I. Watson, 2001. Improved methods to assess water yield changes from paired-catchment studies: application to the Maroondah catchments. *Forest Ecology and Management*, vol. 143, pp. 189-204.
- Salas, J.D., 1993. Analysis and modeling of hydrologic time series. In: Maidment, D.R. (Ed.), *Handbook of Hydrology*. McGraw-Hill, New York, pp. 19.1-19.72 (Chapter 19).

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SESSION C.1:

**HARVEST PLANNING AND
ASSESSMENTS**

SLOPERUNNER 1.0: A PROGRAM TO EVALUATE THE EFFECTIVENESS OF LANDING AND ROAD LOCATIONS FOR CABLE LOGGING

Woodam Chung, John Sessions, John Holub

Abstract: Planning cable logging operations requires consideration of the physical feasibility of the system, economic efficiency, and environmental impacts. It has been a challenge for forest engineers to find optimal tower locations and analyze ground profiles for logging feasibility because extensive ground survey is required. This paper introduces a computer program developed to provide forest engineers with an easy-to-use tool to analyze individual skyline corridors and evaluate the effectiveness of landings and roads for tower locations. Built on a previous cable logging feasibility analysis program, this program is able to extract topographic information from a high resolution DEM and evaluates cable logging feasibility by calculating the payload capacity of a given cable logging system at given landing locations. The program also facilitates data transfer to ArcGIS for further mapping and analyses. We have applied the program to a forest land managed by the Confederated Salish and Kootenai Tribes and used it in delineating cable logging units and evaluating the effectiveness of existing roads for harvest area analysis. The analytical functions of the program and the preliminary results of the application are presented.

Key words: Payload analysis, harvest area analysis, log landing, forest road location

Introduction

Cable logging systems are used to harvest timber in mountainous areas where ground slope is too steep for feasible operations of ground-based harvest equipment such as skidders. Laying out harvest unit boundaries for cable logging is a challenging task because unlike ground-based harvest systems, harvestable areas heavily depend on topographic conditions, head and tailspar locations, and the capacity of the yarding system.

LoggerPC (Jarmer and Sessions 1992) has been widely used as a tool for ground profile analysis for cable logging in North America. The program calculates the load carrying capacity of a given yarding system over specified ground profiles. Because LoggerPC requires field survey for each ground profile to be analyzed, the program has been used for a field check to ensure the feasibility of pre-selected skyline corridors, but hardly used in paper planning or harvest area analysis that may require evaluating "all" potential landings and skyline corridor locations in a large area.

CableAnalysis1.0 (Chung and Sessions 2003) was developed to help forest engineers with harvest area analysis for cable logging (e.g., delineating cable logging unit boundaries, selecting efficient landing locations, etc.) The program's ability to extract terrain conditions from a digital elevation model

(DEM) eliminates needs for ground survey and efficiently facilitates paper planning of cable logging operations. As previously described in Chung and Sessions (2003), the program is able to show the effectiveness of given landing locations by delineating harvestable areas from each landing. In addition, it provides optional functions to automatically consider full suspension requirements over the riparian management areas and to search for proper intermediate support locations along cable corridors for multiple span skylines.

The purpose of this paper is to introduce Slope Runner1.0, which is built on CableAnalysis1.0. SlopeRunner1.0 provides new functions to facilitate data transfer to ArcGIS and analyze the effectiveness of road locations from a cable logging standpoint. Road location is one of the important factors influencing the feasibility of cable logging, especially in the harvest areas where constructing landings and spur roads is not desirable due to environmental concerns. In such cases, landings have to be located on existing roads, and harvestable areas along forest roads are important information for harvest unit design and operations planning for cable logging. SlopeRunner1.0 analyzes the effectiveness of forest roads as tower locations and illustrates the effectiveness in terms of harvestable areas along the roads. This analysis may be important not only for determining new road locations when access roads are to be built in steep terrain for timber harvesting

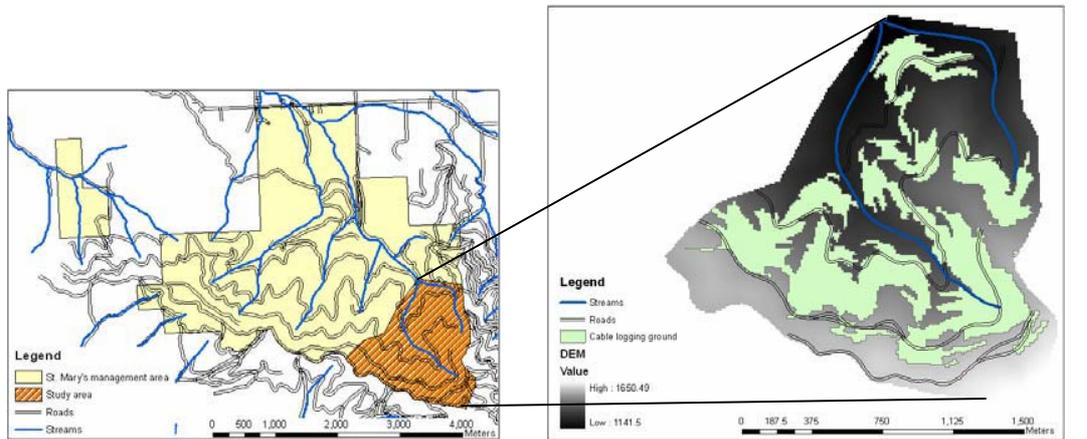
(Stückelberger et al. 2006), but also for decision making on road decommissioning because it can provide the usefulness of roads for future timber management activities.

SlopeRunner1.0 has been applied to a forest land managed by the Confederated Salish and Kootenai Tribes (CSKT) in western Montana for the purpose of delineating cable logging unit boundaries and analyzing the effectiveness of existing roads for cable logging operations. Algorithms employed in the program for estimating payload, determining cable logging feasibility, and selecting intermediate support locations were previously described in Chung and Sessions (2003). In this paper, analytical functions of the program with preliminary results of the applications are presented.

Applications

Study Area

SlopeRunner1.0 has been applied to a 268 ha (662 acres) forest, which is the southeastern part of the St. Mary's forest management area of the CSKT in western Montana (Figure 1a). The management area is scheduled to be harvested during summer 2007. All GIS layers including a 10m x 10m digital elevation model (DEM), roads, streams, management area, and cable ground were provided by the CSKT. Roads and streams layers were converted to raster-based maps in ArcGIS and entered to SlopeRunner1.0. The study area includes a total of 95 ha (235 acres) identified as cable ground through GIS analyses by the CSKT (Figure 1b). The study area includes 9.4 km of roads and 3.3 km of streams. Uphill yarding in a standing skyline configuration was considered for payload analysis in this application. A Link-Belt yarder was used as a yarding system (Table 1).



(a) Study area

(b) Cable logging ground within study area

Figure 1. Study area located in the St. Mary's management area of the CSKT in western Montana.

Table 1. Link-Belt yarder specifications and the payload requirement used in the application.

<i>Cable equipment specifications</i>	
Maximum external yarding distance (EYD)	500 m
Head spar height	15 m
Intermediate tree height	10 m
Tailspar tree height	10 m
Maximum allowable skyline tension	8,890 kg
Skyline unit weight	1.55 kg/m
Maximum allowable mainline tension	5,080 kg
Mainline unit weight	0.88 kg/m
Carriage depth	1 m
Carriage weight	318 kg
Effective choker length	3.3 m
<i>Log information</i>	
Log length	12 m
Log diameter	0.3 m
Minimum log-to-ground angle	10 degree
<i>Payload requirement</i>	
Design payload for one turn of logs	1,500 kg

Analyzing Individual Skyline Corridors
SlopeRunner1.0 provides a function to calculate the load carrying capacity along given skyline corridors (Figure 2). The program's interactive user interface facilitates data entry from users for yarding systems and head and tailspar locations on a DEM. The additional ground profile window displays the ground profile between head and tail spars, skyline configuration, and calculated load carrying capacity. Stream buffers are also displayed so that users can visually check whether or not the full suspension

requirement is met along stream buffers. The ground profile window also provides a function to automatically find the best intermediate support locations for a convex terrain. Users can interactively change the locations of intermediate supports and tail spar and analyze payload capacity of different skyline configurations. This analysis may be useful in determining the feasibility of individual skyline corridors at given tower and tail spar locations, such as parallel skyline corridors along roads.

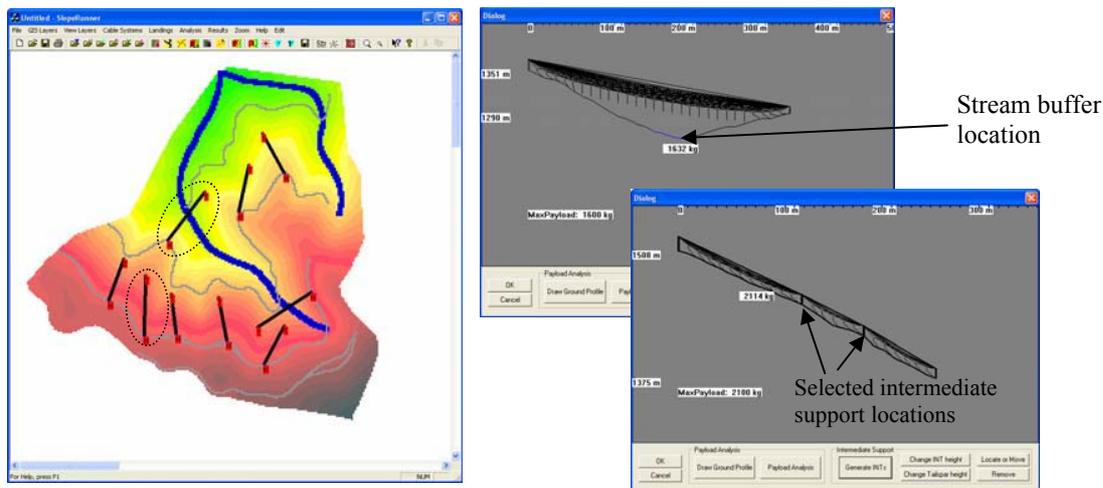


Figure 2. A screen picture of SlopeRunner1.0 (left) shows a DEM, roads, stream buffers, individual skyline corridors. The ground profile windows (right) demonstrate two different skyline corridors while presenting ground profile, maximum allowable payload, stream buffer, and intermediate support locations.

Analyzing the Effectiveness of Landing Locations

SlopeRunner1.0 provides a function to identify feasible cable logging areas (harvestable areas) from a specified landing location while considering minimum design payload and full suspension requirement over stream buffers. Figure 3 shows 12 selected landing locations along forest roads in the study area. The program automatically projects 36 skyline corridors at 10-degree intervals from each of the pre-selected landing locations. It then evaluates each of the projected skyline corridors for its logging feasibility and searches for a longest feasible skyline corridor configuration (Figure 3) that meets two requirements: 1) the user-defined minimum payload per yarding cycle and 2) the full suspension requirement over the riparian management areas.

The program then delineates a “harvestable” area from the landing by connecting tailspar locations of feasible skyline corridors (Figure 3). When users enter the maximum allowable number of intermediate supports, the program automatically places intermediate supports on convex terrain in order to ensure the minimum clearance of the skyline from the ground. Figures 3b and 3c present the harvestable areas from each landing when the maximum number of intermediate supports is limited to one and two per skyline corridor, respectively. The results confirm the fact that when intermediate supports can be used, harvestable areas become larger because of possible increase in skyline length. This function may be useful for designing fan-shaped cable logging units where efficient landing locations should be identified and a harvest unit boundary needs to be delineated for each landing.

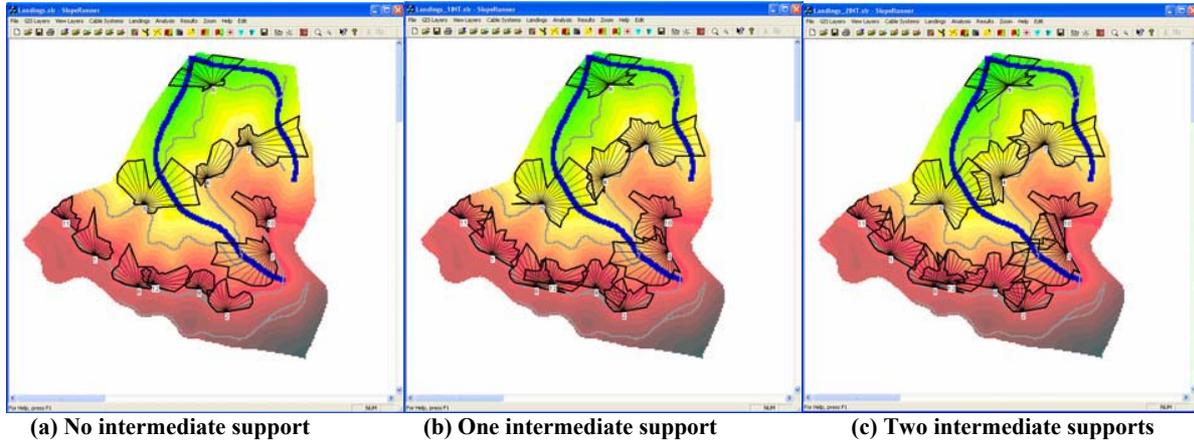


Figure 3. Harvestable areas identified by SlopeRunner1.0 with different limits of number of intermediate supports.

Analyzing the Effectiveness of Existing Roads

In this analysis, all the existing roads located in the study area are assumed to be candidate landings, and harvestable areas from each landing location are calculated. Technically, all the grid cells representing road surface on a raster-based road layer become potential tower locations, and harvestable area from each grid cell is drawn as a polygon (Figure 4). In this application, there were 1,182

potential tower locations (grid cells) analyzed along the existing roads of 9.4 km. All the polygons (harvestable areas) were then transferred to ArcGIS and dissolved into one contiguous polygon (Figure 5). When no intermediate support is allowed, the total harvestable area is 181.5 ha (67.7% of the study area), while it becomes 206.4 ha (77.0% of the study area) when a maximum two intermediate supports are allowed per skyline corridor.

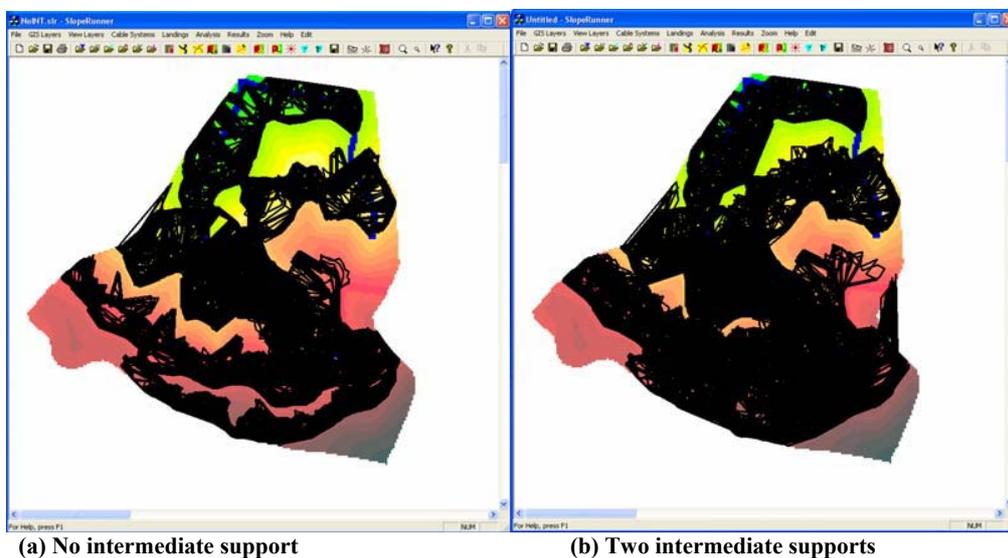
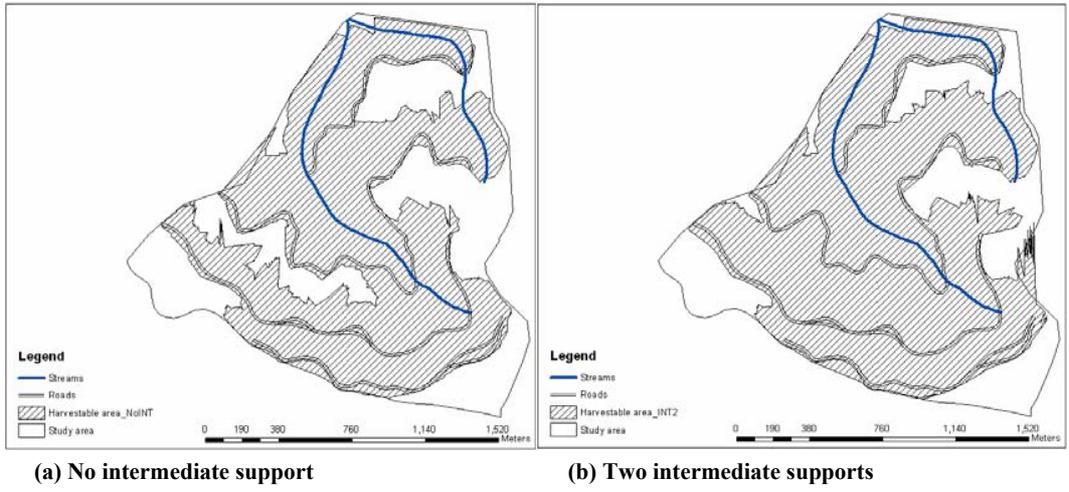


Figure 4. Harvestable areas from existing roads with different number of intermediate supports allowed.



(a) No intermediate support

(b) Two intermediate supports

Figure 5. Dissolved harvestable areas in ArcGIS.

We also used SlopeRunner1.0 to analyze two sets of closely parallel road sections for their effectiveness as tower locations, while assuming one set of road sections needs to be decommissioned (Alternative 1 or 2 in Figure 6). Each set of the road alternatives was entered into SlopeRunner1.0 as potential tower

locations, and total harvestable areas were calculated (Figure 7). The results show that total harvestable areas from alternatives 1 and 2 are 19.0 ha and 17.8 ha, respectively, which indicates that alternative 1 might be able to provide more efficient tower locations than alternative 2.

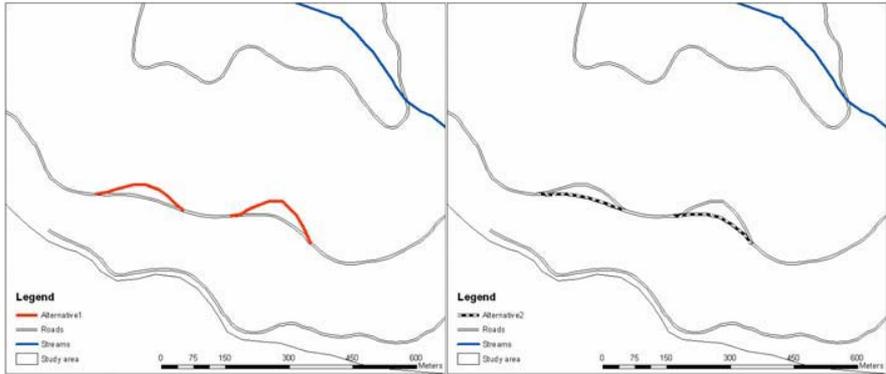


Figure 6. Two alternative road sections evaluated by SlopeRunner1.0.

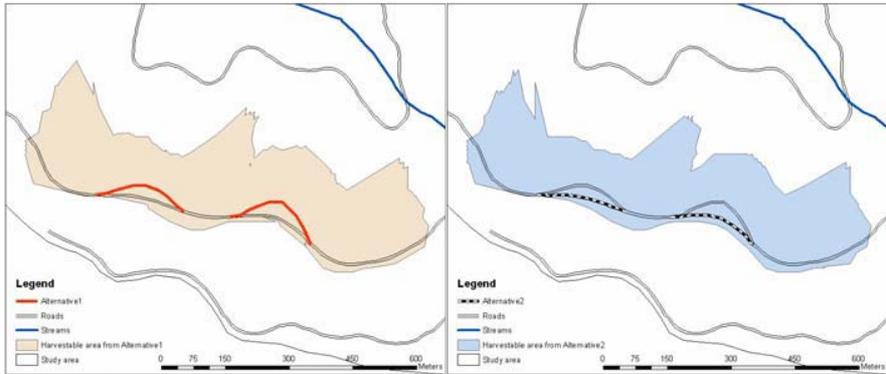


Figure 7. Harvestable areas from two alternative road sections.

Conclusions

SlopeRunner1.0 has been developed to provide forest engineers with an easy-to-use tool for harvest area analysis of cable logging operations using GIS data. Built on a previous cable logging feasibility analysis program (CableAnalysis1.0), SlopeRunner1.0 provides functions to analyze individual skyline corridors and the effectiveness of landing and road locations for various yarding systems. The program is also able to facilitate data transfer to ArcGIS for further mapping analyses.

Verification and validation of the program is currently on-going through student projects on CSKT forest lands as well as the Nez Perce National Forest in Idaho. Verification can be done by testing its results against other payload analysis programs, such as LoggerPC, on the same ground profiles. Field validation needs to be done by experienced forest engineers to ensure that the program outputs are applicable on the ground.

Program results heavily depend on the quality of input data and the assumptions employed in the program. Using inaccurate or low resolution GIS data will not provide meaningful results. But, as advanced remote sensing technologies provide spatial data at unprecedented resolutions and accuracy, this type of analytical tool can certainly become more useful for efficient cable logging operations analyses and design, especially for a large area.

Literature Cited

- Chung, W. and J. Sessions. 2003. A Computerized Method for Determining Cable Logging Feasibility Using a DEM. In 2003 Proceedings of the Council of Forest Engineering, September 7-10, Bar Harbor, ME.
- 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.
- Jurg Stuckelberger, H.R. Heinimann, W. Chung, and M. Ulber. 2006. Automatic road-network planning for multiple objectives. In Proceedings of the 2006 Council on Forest Engineering, July 30-Aug. 2, Coeur d'Alene, ID. pp. 233-248.

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A COMPUTER APPLICATION TO ESTIMATE FOREST ROAD CONSTRUCTION COST

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Abstract: A computer application has been developed to aid in the cost estimation of forest road construction for bid estimation and route analysis. The program uses Microsoft Excel with Visual Basic object oriented programming to arrange construction cost components logically and include advanced computer routines. The user is guided through road construction components and prompted for economic data, quantities, and survey information to define the construction environment and derive total construction cost. In addition, the program incorporates road design elements and site characteristics to optimize earthwork allocation, improving on the mass diagram. The program also estimates areas, surfacing volumes, and culvert lengths. This program is intended to enhance the decision making process for experienced forestry practitioners in new forest road construction regardless of region, company, or agency affiliation by accepting their inputs and performing the calculations.

Key words: Forest road construction, earthwork allocation, cost estimation

Introduction

Forest roads are an integral part of forest management and represent a significant investment for landowners. The construction and maintenance of forest roads is the most expensive and time consuming task involved in forest operations (Layton et al. 1992). These roads allow for the extraction and utilization of a variety of forest resources by an array of interests. Their location and density serve to allow access by timber harvesting systems based from the roads. Economic and environmental considerations are the primary elements affecting location and standards of forest roads (Goktepe and Lav 2004). The early stages of transportation planning involve the estimation of costs for the various components of road construction. Many factors including variable topography, soils, rock outcrops, machinery used, and special design requirements make road construction cost estimation very difficult (Layton et al. 1992). This estimate is developed to reflect the costs that public works contractors would most likely face at the time of construction. The magnitude of each of these cost components depends on the nature, size, and location of the project as well as the management organization, among many considerations. The construction contractor is interested in maximizing profit, while the owner is interested in achieving the lowest possible overall project cost that is consistent with their investment objectives.

In a study on forest roads in Virginia conducted by Aust and Shaffer (2000), activities related to the compliance of Best Management Practice guidelines (BMP's) resulted in a 10% increase in the total cost of construction. Examples of these practices are the placement of roads away from streams, use of equipment that can more precisely excavate and place materials, improvement in road drainage in both sizing and frequency, added emphasis on road maintenance and maintaining drainage features, and controlling access and use of roads (Kramer 2001). These increasing costs and greater demands for engineering require better cost estimates and decision making capabilities. Layton et al. (1992) suggested the need for a cost prediction method that can be used in combination with other stand and forest level planning models, combining the cost estimation of road sections with other algorithms in a forest management planning tool. The primary objective of this project is to provide a standardized means of estimating forest road construction cost that is easy, saves time, and enhances to the users existing skills. This cost estimating program is flexible to incorporate a variety of road design standards, but was designed around the typical construction standards of a single-lane low volume road.

Methodology

The cost estimations of road construction components have been developed through a synthesis of information collected in an intensive literature review and interviews with practitioners for

commonly used estimation and construction techniques in low volume forest road construction. The program was developed using that knowledge to prompt users for specific inputs under the categories of incidentals, surveys, clearing and grubbing, excavation, drainage and stream crossings, stabilization, and surfacing. The program can also derive quantities and areas from survey data that is input once the horizontal alignment of the road has been established. This data requires only slight adjustment of typical survey methods, and can also be taken from the output of road design programs such as RoadEng. In any case the user can select to input their own unit costs for quick calculation, or choose to employ the program's advanced estimation routines in earthwork allocation, culvert length estimation, and clearing and stabilization area estimation. Results from the program are compiled itemizing details in each component's cost as well as the total, and the user is able to save and print the results in a presentable format. What follows is a demonstration of the procedures the program uses in each cost component to derive a construction estimate.

Visual Basic for Applications

To develop the cost estimating program into a stand alone application and to imbed the earthwork optimization capability, VBA is used within a Microsoft Excel spreadsheet. VBA is a programming language, similar to Microsoft Visual Basic, but works within an application using code to solve complicated problems (Rea 2005). By writing code call complicated algorithms at the click of the mouse, VBA can enhance the power of a spreadsheet within a format such as Excel that many are familiar with.

In this project VBA is used first to organize and separate road construction cost components into objects that calculate and display results in a systematic fashion. The word "object" in VBA terms refers to the collections of predefined worksheets that independently calculate component costs, and which are organized into the complete object model by classes (Rea 2005). Objects are also the individual pieces of the VBA application such as check boxes, list boxes, and command controls.

The user begins by opening the workbook in Excel where a flash screen is loaded and prompting the user

to start a new project or continue an existing one. The user is transferred between the interface and spreadsheets as they navigate through the construction components. The totals in each class are stored and displayed in a printable report that itemizes each step and includes the optimized earthwork allocation information.

The earthwork allocation portion of the program employs the use of a dynamically linked library (DLL) that is included with the original Excel file. This DLL is tasked with running the simplex algorithm and solving the allocation problem. The DLL was created to extend the capabilities of Excel in handling very large linear programming problems.

Survey Data Inputs

The survey information input by the user forms the foundation for the advanced routines of the program. This information's primary purpose is to develop cross sections at each station along the roadway to institute certain design controls, such as cut and fill slope ratio limits based on soil classifications from available information. Survey measurements such as road width, sideslope, ground and road elevations at centerline, road gradient, and section length are required to develop the dimensions for ten potential cross section types (See Figure 6). These cross sections are then used in determining the quantities in the individual components, such as volumes in earthwork.

As with any design program, care must be taken in collecting the survey information, as the program output is only as good as its input. The user must be aware that accuracy increases with precision in the field measurements and by decreasing the distance between stations.

Clearing and Grubbing Cost

The program approaches clearing and grubbing component as a single unit cost applied to a given clearing area between consecutive stations (See Figures 1 and 2). This area is automatically calculated for the user from the survey data, but can be overridden. The formulation of the clearing area uses the equations developed by Durston and Ou (1983), but averages the clearing widths at consecutive stations.

The formulation for calculating clearing area is:

$$AC = (WC_1 + WC_2) * L / 43560 \quad (1)$$

where

AC = clearing area (acres)

WC = $C_1 + C_2 + SC * DC + W + SF * DF$

C_1 = Clearing distance beyond top of cut (ft)

C_2 = Clearing distance below toe of fill (ft)

W = Subgrade width

SF = Fill slope ratio

SC = Cut slope ratio

SG = Ground slope (decimal)

DF = Fill depth (ft)

L = Section length (ft)

The clearing and grubbing cost is then estimated by multiplying the basic unit cost per acre by adjustment factors and area in acres. A method for determining the unit cost per acre is provided based on the USDA

Forest Service (2007) information, which provides figures depending on the right of way timber volume and adjusts according to the slash treatment method and topography. Again, these figures may be used or overridden for the component cost calculation.

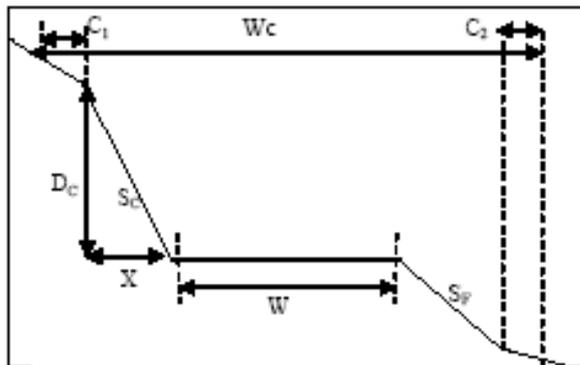


Figure 1. Cross section for clearing area calculation in a Balanced section.

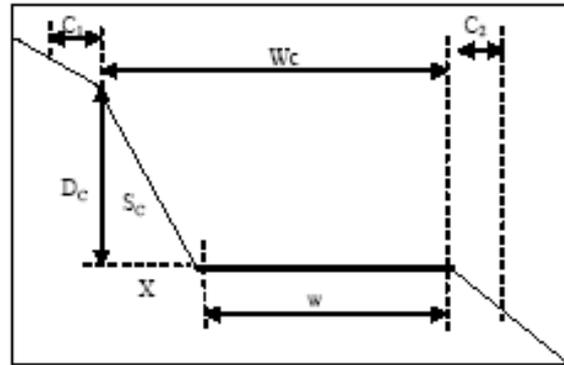


Figure 2. Cross section for clearing area calculation in Full bench section.

Stabilization Cost

In calculating the cost of stabilizing a roadway following construction it is common to calculate the area of the cut and fill slopes that require grass seeding, fertilizing, or mulching (See Figure 3). The basic unit costs of material and their application (includes overhead, equipment, transportation, and labor costs) per acre can be obtained from local economic data and is required input from the user. The area calculations for this component were also taken from Durston and Ou (1983).

The formulation for stabilization area is:

$$AS = (W_1 + W_2) * L / 8.25 \quad (2)$$

where

AS = Stabilization area (acres)

$W_1 = DC / \cos(\tan^{-1} SC)$

$W_2 = DF / \cos(\tan^{-1} SF)$

Additional stabilizations measures, such as silt fencing or straw bales, may be included in this component cost by including their material and installation costs.

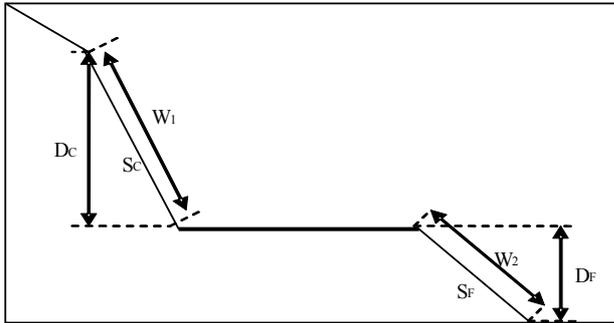


Figure 3. Cross section of roadway illustrating calculation of stabilization area.

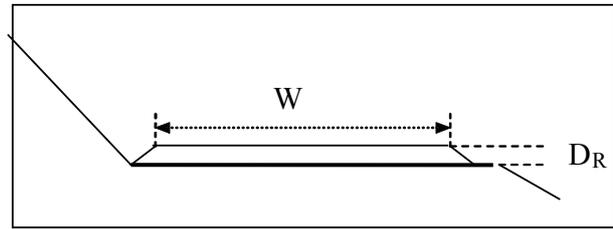


Figure 4. Cross section of roadway illustrating aggregate surface volume calculation.

Rock Surfacing Cost

The program calculates surfacing cost by first estimating surfacing dimensions for each section based on road width, depth, and section length. The method used by Durston and Ou (1983) estimates volume of each course (See Figure 4).

The formulations for rock surfacing volumes are:

$$\text{Base: } V_r = (W_r + W_s)/2 / 2 * L(D_{sr}/12) / 27 \quad (3)$$

$$\text{Surface: } V_r = (W_s + (W_r + W_s)/2) / 2 * L(D_{br}/12) / 27 \quad (4)$$

where

V_r = volume of surface rock (yd³)

D_{br} = depth of base rock (in)

D_{sr} = depth of surface rock (in)

W_r = surface width (ft)

W_s = subgrade width (ft)

L = section length (ft)

The user can choose to include the costs of a base course and gravel surface if applicable. The program repeats the formulation for the number of specified number of layers and applies unit costs obtained from the user for material, haul, and application of aggregate surfacing to attain a total surfacing cost.

The material cost can be input directly or determined by appropriating a dollar per cubic yard cost to the rock development processes relevant; including drilling and shooting, breaking oversize, ripping, crushing and screening, stockpiling, pit run, pit development, waste.

A load and apply cost is then factored in which includes a dollar per cubic yard estimate for loading,

spreading, rolling, grading, compaction, and watering.

To determine the hauling cost of the rock per cubic yard of material, the user first must select relevant the truck size (12 or 20 cubic yards). If machine rates have been input they can be inserted into the calculation. Next a truck cycle time is developed though entering the average round trip speed and round trip distance for as many as four road segments, load time, and dump. A list of swell factors is provided to adjust the trucked volumes that establish the total hours of trucking cycles.

Drainage Cost

The drainage portion of the program includes the material and installation costs of ditch relief, roadway drainage, and drainage crossing structures as well as erosion and sediment control measures. Costs for dips, waterbars, and fords are a simple unit cost per structure specified by the user and multiplied by the number of structures. The costs for culverts and bridges are calculated by asking the user the type and dimensions of the structure and the unit cost of installation per foot. It is up to the user to determine the appropriate size, type, and number of structures. Installation costs of structures may include additional material costs such as down drains, elbows, anchors, and rip rap that are added to the total by a unit cost per quantity required and applied.

The main contribution of this component is the culvert length estimate provided by the program depending on the cross section type at the specific station where a culvert is identified by a true or false statement. The program calculates culvert using a

modification of the formulation by Durston and Ou (1983), which uses sideslope and cross section type for three situations; cut and fill, full bench, and through fill. The formulations are as follows:

Balanced section with downdrain:

$$L_C = \left[D_F^2 + (W + S_F D_m)^2 \right]^{1/2} + L_A + L_{A2} \quad (5)$$

Balanced section without downdrain:

$$L_C = \left[D_m^2 + (W + S_F D_m)^2 \right]^{1/2} + (D_F - D_m) / \sin \left[\tan^{-1} \left(\frac{1}{S_F} \right) \right] + L_A + L_{A2} \quad (6)$$

And full bench section,

$$L_C = W + L_A \quad (7)$$

where

L_C = length of the culvert (ft)

L_A = additional length required beyond daylight point and ditchline (ft)

$$D_m = 0.3W / (1 - 0.3S_F)$$

S_F = fill slope ratio

W = road surface width

For through fill section and drainage crossings,

$$L_C = \left[(V + W + X)^2 + (Y - U)^2 \right]^{1/2} + L_{A1} + L_{A2} \quad (8)$$

where

$$V = \left[S_F H_F - \left(\frac{W}{2} \right) S_X S_F \right] / (1 + S_X S_F)$$

$$X = \left[S_F H_F + \left(\frac{W}{2} \right) S_X S_F \right] / (1 - S_X S_F)$$

$$U = H_F - \left(\frac{W}{2} + V \right) S_X$$

$$Y = H_F + \left(\frac{W}{2} + X \right) S_X$$

S_X = gradient of culvert (decimal %)

H_F = height of fill at centerline (ft)

L_{A1} = additional length required on upstream side of fill (ft)

L_{A2} = additional length required on downstream side of fill (ft)

The culvert gradient is assumed to be equal to the original sideslope up to a maximum allowable

gradient of 30%. If the calculated gradient would exceed 30%, it is assumed that a downdrain would be installed. The downdrain is simply an additional length of culvert extending from the daylight point to the toe of the fill. Culvert skew in degrees from perpendicular to the roadway is also considered by dividing the estimated length by the cosine of the skew angle in degrees.

The program prompts the user for unit costs of material and installation for sizes ranging from 12 – 60 inches. Material prices for culverts and accessories must be obtained from the distributor, and prices for different varieties of culverts are not considered.

To aid in culvert size selection, a form has been incorporated into the program to recommend a culvert diameter based on watershed characteristics, storm event, and drainage area using Talbot's Formula (Walbridge et al. 1984):

$$A = C * M^{3/4} \quad (9)$$

where:

C = watershed roughness coefficient

M = watershed acres

The result of Talbot's Formula is the area of a waterway based on a 2.5 inch rainfall event. This waterway area is used to recommend the correct culvert size illustrated in Table 1.

Table 1. Round pipe size recommended for respective area of waterway.

Waterway Area (ft ²)	Culvert Diameter (inches)
1.25	15
1.8	18
3.1	24
4.9	30
7.1	36
9.6	42
12.6	48

Earthwork

As previously stated, the survey data entered into the program plays a critical role in framing the earthwork allocation model within the program. Each segment consists of roadway and terrain characteristics that alter construction activities including width, sideslope, gradeline elevations, and excavation material. The material type is characterized based on user input that defines the percentage of common, loose rock, and solid rock (See Table 2). The program uses this information to set cut and fill slopes as well as calculate and adjust excavation

quantities through determining the cross section type and end area at each station (See Figure 5). This determination is made by the program through a series of equations illustrated in Figure 6, and in doing so the program assumes that the road template is a flat surface, horizontal alignment of the roadway is fixed, and ditch volume is ignored. In full bench construction, the sideslope limit is set by the user forcing cross sections to adjust accordingly. Excavation quantities are estimated for each road section using the average end area method and including run-out distances.

Table 2. Classification of excavation materials in cut sections to weight excavation and loading costs. Shrinkage and swell factors of excavation materials adjust haul and embankment quantities.

Section	Excavated Material			
	Common	Loose Rock	Solid Rock	
			Rippable	Blasted
1				
2	75%	15%	5%	5%
3	75%	20%	5%	
4				
Swell	1.3	1.3	1.4	1.5
Shrinkage	0.8	0.9	1.0	1.0

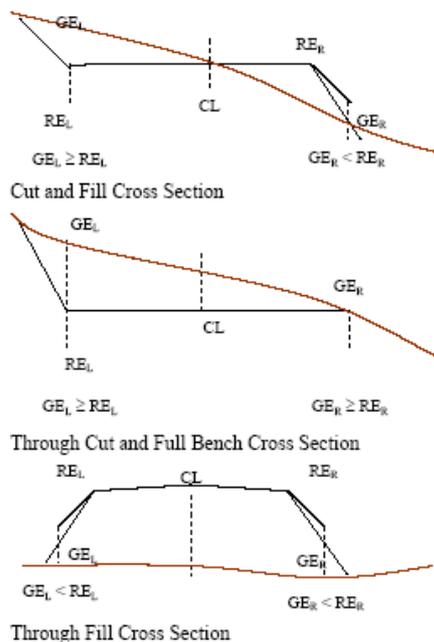
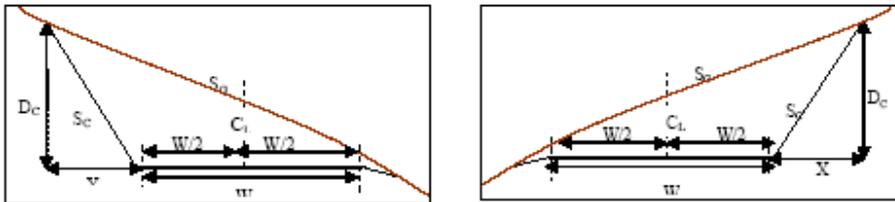


Figure 5. Cross sections used to set the road on the ground profile are cut and fill, through cut, through fill, and full bench sections. In this figure, RER and REL are the road elevations at the right and left road edge points, while GER and GEL are the ground elevations at these points, respectively.

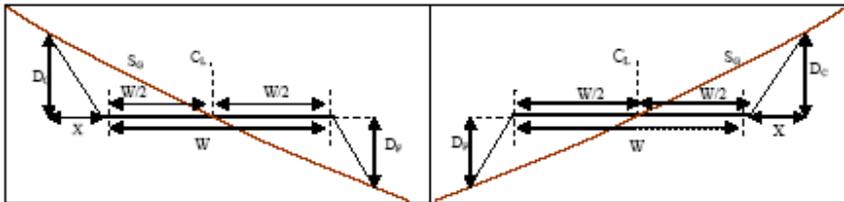
Once excavation quantities are calculated for each station, these amounts are input into an optimization model that allocates cut volumes to the appropriate fill areas and minimizes costs of excavation, embankment and haul using the simplex method. Included in the optimization model are the possibilities of borrow and waste sites, their proximity to the project, and also the option to side cast material.

Another feature of the model is the option to constrain the use of excavation equipment in transporting materials between sections. While movement within the section is free, different unit costs for a dozer, excavator, and a dump truck are applied based on haul distance (\$/yd³/unit distance) beyond that section. For example, the dozer would be constrained to distances of 200 or 300 feet; otherwise the trucking costs would apply. Distance constraints and unit costs would also be specified by the user. The final result provides the user with the amount of material moved, where it is to be moved, by what machinery, and the cost to do so.

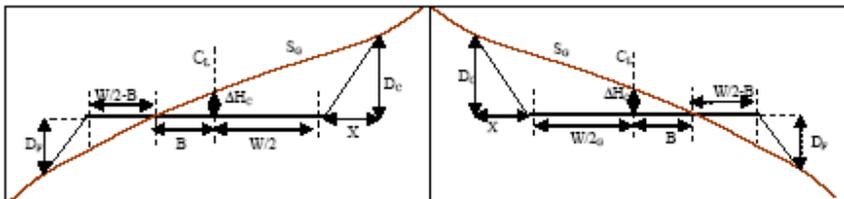
The economic distribution of cut and fill quantities is determined using a modified linear programming method developed by Mayer and Stark (1981), including possible borrow and waste locations and various material types along the roadway. In order to incorporate this method into the model, a linear programming code using the idea of the simplex algorithm (Bowman and Fetter, 1957) was developed.



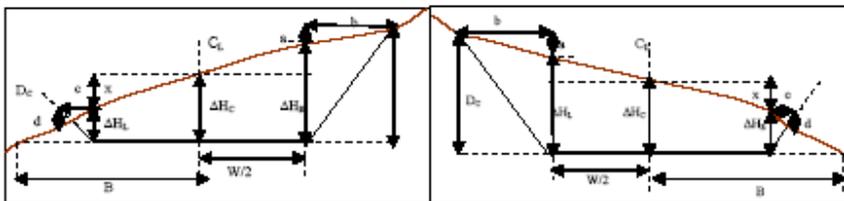
Full-bench cross sections for right to left and left to right road stations when $SG > 50\%$ (for example) and $B = (W/2)$.



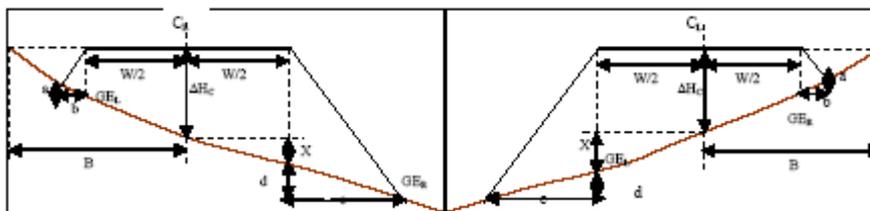
Cut and fill cross sections for right to left and left to right road stations when $GE_{CL} = RE_{CL}$.



Cut and fill cross sections for right to left and left to right road stations when $GE_{CL} > RE_{CL}$, $B < W/2$.



Through cut cross sections for right to left and left to right road stations when $GE_{CL} > RE_{CL}$ and $B > W/2$.



Through Fill cross sections for right to left and left to right road stations when $GE_{CL} < RE_{CL}$.

Figure 6. Determining cross section dimensions for end area calculation where D_c is the depth of cut, D_f is the depth of fill, SG is the ground slope, SC is the cut slope, SF is the fill slope, W is the road width, CL is the centerline, ΔH is the elevation difference at CL , and B is the horizontal distance from the daylight point to CL .

In the method, it is assumed that the unit costs do not vary with the amount of material moved. It is also

assumed that the unit cost of hauling is linearly proportional to the hauling distance. The specific unit

costs for earthwork activities including excavation, haul, and embankment are defined based on the soil type data for each road stage. Swell factor of the material moved from cut section i , and shrinkage factor of the material compacted into fill section j , are considered to determine haul and fill quantities. Therefore, the objective function is stated as follows:

$$\begin{aligned} \text{Min } Z = & \\ & \sum_i \sum_j C(i, j)X(i, j) + \sum_i \sum_k CD(i, k)XD(i, k) \\ & + \sum_p \sum_j CB(p, j)XB(p, j) \end{aligned} \quad (10)$$

subject to the following constraints:

$$(1) \sum_j X(i, j) + \sum_k XD(i, k) = Q_c(i) \quad (11)$$

where $X(i, j)$ (the amount of cut moved from cut section i to fill section j) plus $XD(i, k)$ (the amount of cut moved from cut section i to landfill area k) are equal to the available amount of cut, $Q_c(i)$, at cut section i .

$$(2) \sum_i s_{ij}^f X(i, j) + \sum_p s_{pj}^f XB(p, j) = Q_f(j) \quad (12)$$

where $s_{ij}^f X(i, j)$ (the adjusted amount of cut moved from cut section i to fill section j) plus $s_{pj}^f XB(p, j)$ (the adjusted amount of material moved from borrow area p to fill section j) are equal to the amount of fill required, $Q_f(j)$, at fill section j . The shrinkage factors for material moved from cut section i and borrow area p are defined as s_{ij}^f and s_{pj}^f , respectively.

$$(3) \sum_i s_{ik}^f XD(i, k) \leq Q_D(k) \quad (13)$$

where $s_{ik}^f XD(i, k)$ (the adjusted amount of cut moved from cut section i to landfill area k) is equal to or less than the capacity of the landfill k , $Q_D(k)$. s_{ik}^f is the swell factor for material moved from cut section i and wasted in landfill area k .

$$(4) \sum_j XB(p, j) \leq Q_B(p) \quad (14)$$

where $XB(p, j)$ (the amount of material moved from borrow area p to fill section j) is equal to or less than the material available in borrow area p , $Q_B(p)$.

$$(5) X(i, j), XD(i, k), \text{ and } XB(p, j) \geq 0 \quad (15)$$

where non-negative conditions are represented.

The unit cost of moving and compacting the material from cut section i to fill section j , $C(i, j)$, is estimated based on unit cost of each operation including excavation (u_e), hauling (u_h), and compacting (u_c),

assuming that the costs are linearly proportional to the quantities. The formulation for adjusted quantities is:

$$C(i, j) = u_e + s_i^h (u_h d_{ij} + u_c) \quad (16)$$

where d_{ij} is the distance between the center of cut section i and the fill section j . For each road stage, the model computes the distance between the beginning of the road section and the middle point of this road stage. The distance between the beginning of the road section and the middle point of cut section i and fill section j are denoted by Lb_i and Lb_j , respectively. Then, d_{ij} is equal to $|Lb_i - Lb_j|$. The unit cost of borrow, $C_B(p, j)$, and disposal, $C_D(i, k)$, are determined similarly. In this program the inclusion of a second haul option essentially doubles the objective function and constraints, but was not included for simplicity.

The cross sections used in earthwork calculations do not include extra volume for a ditch. It is necessary for the user to specify if a ditch will be constructed and for which road sections, then a unit cost for ditch construction will be applied. Turnouts are features that add extra earthwork volume and additional surfacing. To account for the extra width of a turnout the user must include stationing at opposing ends of the turnout and increase the road width to include the turnout dimensions.

The development of survey cost follows the example of the USDA Forest Service Cost Estimating Guide (2007). The user is expected to enter the basic unit costs per mile according to the desired level of accuracy for preliminary and/or L-line surveys and additional requirements such as slope staking. This unit cost is then adjusted by selecting from a range of sideslope and ground cover characteristics, and multiplied by the project length. The formulation of the field survey cost, C_{fs} , in a road stage r is (Akay 2003):

$$C_{fs} = U_{PL} + U_{LL}(1 + f)L_r \quad (17)$$

where U_{PL} and U_{LL} are the basic unit survey costs, f is the sum of adjustment factors, and L_r is the length of the road.

The ground cover factor should reflect the most common density of the forest and brush along the proposed roadway. The terrain factor is also reflective of the average sideslope along the roadway. Additional costs such as travel and per diem are assumed to be reflected in the unit cost estimate.

Mobilization

The formulation of mobilization cost follows the approach of the STHarvest program. Here the cost of mobilization is a function of move in distance, travel speeds loaded and unloaded, travel times loaded and unloaded, load time, truck rate, truck driver rate, and equipment ownership costs. This formulation has been simplified by ignoring travel speeds and simply asking for a moving time estimate for a lowboy loaded and unloaded.

The user is first asked to specify the type and number of equipment being mobilized within the general range of small to large excavators, dozers, graders, compactors, dump trucks, and water trucks. They are then transferred to a spreadsheet and prompted to input machine rate figures for the selected equipment. These machine rates are factored into the move-in-loaded calculation, as well as other cost components. If the selected equipment would be transported using a lowboy, the mobilization cost includes a fixed and variable cost to move-in and a backhaul charge for the lowboy's return trip. A move-out charge is assumed to be charged to the following project and is ignored. The formulations are as follows:

$$\text{Fixed cost: } M_F = (U_{lb} + E_{own} + M_L) * L_{lb} \quad (18)$$

$$\text{Variable cost: } M_V = (U_{lb} + E_{own}) * T_1 \quad (19)$$

$$\text{Backhaul: } M_{BH} = U_{lb} * T_2 \quad (20)$$

where U_{lb} is the hourly cost of the lowboy (includes the hourly rate of the truck and driver), E_{own} is the transported equipment ownership cost, M_L is the move in labor, L_{lb} is the loading hours, and T_1 and T_2 are the respective times for travel loaded and empty. The mobilization of equipment that does not require the use of a lowboy is as follows:

$$\text{Fixed cost: } M_F = E_{own} \quad (21)$$

$$\text{Variable cost: } M_V = (E_{op} + E_{own} + D) * T_1 \quad (22)$$

where D is the driver's hourly rate.

If an aggregate surfacing is applied the road, the mobilization of crushing equipment should be applied under that component if applicable in the derivation of rock cost.

Incidental Costs

The incidental costs are included in the program as both unit cost formulations and simple additions to total construction costs. These costs include permits, dust abatement, gates and signs, as well as a miscellaneous section. For the majority of these cost items, the user simply defines each item under its heading, and enters the unit cost and quantity. The dust abatement section goes a step further to list a series of common treatments, recommended application rates, and calculates a quantity and cost based on the specified materials.

Application

A contractor has compiled the following cost and project information to estimate the cost of a short spur road. The road surface will be outsloped, and for the purpose of this example the road will include a gravel surface and drainage crossing. The survey data that is required as input for the program is provided in Table 3. The road consists of five stations and four road sections that are 100 feet in length each. Road and ground elevations are determined for the final road alignment.

Table 3. Example survey data inputs for the program.

Station ID	Section Length (ft)	Subgrade Width (ft)	Running Surface Width (ft)	% Sideslope	Ground Elevation @ CL	Road Gradient %	Road Elevation @ CL
0 + 00	0	16	14	25%	100		110
1 + 00	100	16	14	25%	105	2%	112
2 + 00	100	16	14	25%	125	2%	114
3 + 00	100	16	14	25%	119	-3%	111
4 + 00	100	16	14	25%	99	-3%	108

A clearing and grubbing cost of \$1049 is calculated from a clearing area of approximately ½ acre, with slash windrowing, and moderate terrain at a base cost of \$2220/acre.

A stabilization cost of \$176 is estimated for dry seeding of 4/10 of an acre at \$450/acre. The program estimates that a volume of 111 cubic yards (CY) of gravel (139 loose) are needed to surface the road with a depth of six inches. This rock will be purchased from a supplier at \$4.50/loose CY, loaded at \$0.83/loose CY, and spread for \$0.39/loose CY. The required volume of rock is will be hauled for a roundtrip distance of 20 miles at an average speed of 25 mph, equating to a \$0.51 fixed cost for the truck and \$0.61 variable cost for haul (\$12.71/loose CY). The total rock cost is estimated at \$2562.

A culvert is to be installed for a drainage crossing at station 1+00. The program estimates a 42 foot culvert will be necessary given a seven foot fill height, 16 foot road width, and 1.5:1 fill slopes. The

culvert is sized according to the watershed characteristics (moderate slopes, light soils, dense cover), a four inch per hour rainstorm event, and a contributing area of 75 acres; recommending a 36 inch roundpipe. The total cost to install the culvert is estimated at \$3990 with a material cost of \$48/foot and installation cost of \$47/foot.

The user estimates earthwork by first describing the excavation materials in cut sections 2 and 3. A diagram of the earthwork problem based on the survey information is provided in Figure 7. To solve this allocation problem the program estimates the end areas, runout distances, and section volumes between stations (See Table 4). The unit costs of earthwork are Excavation (including loading): common and borrow- \$2.17/C; loose rock-\$3.01/CY; ripped rock-\$5.30/CY; blasted rock-\$11.12/CY. Embankment (placement and compaction): \$0.82/CY. Haul: \$0.51/CY fixed and \$0.61/CY-mile variable. In this example a borrow pit exists 200 feet from the start of the project, while a waste area is 200 feet from the end.

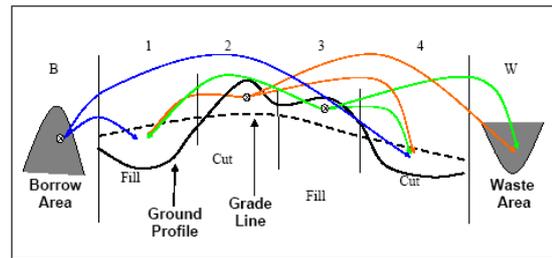


Figure 7. Earthwork allocation example illustrating earthmoving possibilities between cut, fill, borrow, and waste areas.

This example has been formulated into a format that can be solved using Excel Solver that employs the simplex algorithm to minimize earthmoving costs between sections. The algorithm provides the solution of moving 39 CY from cut 2 to fill 1, 549 CY from cut 3 to fill 1, 56 CY from cut 3 to fill 4, and 100 CY from borrow to fill 1 for a cost of \$2844. A within station cost of excavation of \$131 in balancing section 2 must be added to reach a total earthwork cost of \$2976.

To include the cost of field surveys the unit cost of for a P-line (\$1600) and L-line survey (\$1600) are added. Adjusting by 0.9 for light terrain and brush factors provides a cost of \$196.

Mobilization is calculated for all construction equipment including a dozer, excavator, grader, and two 12 CY dump trucks. The construction equipment owning costs are as follows: medium dozer-\$29/hour, small excavator-\$47/hour, and small grader-\$29/hour. A lowboy cost of \$106/hour (including driver) is included in the move-in cost. Move-in travel time is estimated at one hour while move-out empty will take ¾ of an hour. The total mobilization cost of \$1802 includes the move-in cost for the dump trucks (\$83/hour).

The program estimates the total cost for the road as \$12751.

Conclusion

The purpose of this paper was to present a program that can improve the road construction cost estimation process through simplification of the component calculations, enhancement of the estimates in the variable and costly components, and displaying and saving the results. The combination of object-oriented programming and spreadsheet format allows for quick input and calculation, while expanding the capabilities of the average Excel user. The program is transparent in explaining the inputs required and methods used in the individual component cost sections.

The following are noteworthy contributions of the program:

1. The calculation of culvert length from cross section information at each station. The culvert length calculation follows standard design and installation principles that include separate calculations under different sideslope scenarios, and includes a maximum culvert gradient, addition of a drowndrain, and skew angle. Also within the culvert component is a module that aids in estimating culvert diameter using a modification of Talbot's formula.
2. The estimation of earthwork quantities and minimization of earthwork allocation between road sections using linear programming. This method improves upon the mass diagram through the consideration of varying soil characteristics along the roadway, inclusion of borrow and waste areas, the differentiation of earthmoving operations between excavation equipment and trucks.
3. The estimation of clearing and stabilization area along the roadway, and cost calculations that adjust for site characteristics.
4. The estimation of aggregate surfacing volumes by tons or cubic yards, as well as the adjustment based on rock type for loading, hauling, and application.

The program also includes the cost components of surveys, mobilization, and incidental costs to derive a complete road construction cost estimate. Future work will focus on refining and expanding the program to accommodate additional construction scenarios, such as in the earthwork portion where it is assumed that volumes of cut materials are suitable for transfer to fill areas. The program can be modified to suit a user's specific needs, and comments or suggestions are welcome.

Literature Cited

- Akay, A.E. 2003. Minimizing total cost of construction, maintenance, and transportation costs with computer-aided forest road design. Ph.D. thesis, Oregon State University, Corvallis, OR. 229 p.
- Aust, W.M., R.M. Shaffer. 2000. Costs of Planning, Locating, and Constructing a Minimum Standard Forest Road to Meet BMP Guidelines in the Appalachian Mountains of Virginia. Proceedings of a symposium at the COFE-CWF Conference. CWFI 3499 FDC 383.
- Bowman, E.H. and R.B. Fetter. 1957. Analysis for production and operations management. Richard D. Irwin, Inc. Homewood, Illinois.
- Durston, T.A., F.L. Ou. 1983. Simplified Cost-Estimating Method for Low-Volume Roads. Transportation Research Record.
- Goktepe, A.B., A.M. ASCE, and A. Hilimi Lav. 2004. Method for Optimizing Earthwork Considering Soil Properties in the Geometric Design of Highways. Journal of Survey Engineering. 11: 183-190.
- Kramer, B.W. 2001. Forest Road Contracting, Construction, and Maintenance for Small Forest Woodland Owners. Forest Research Laboratory, Oregon State University. Corvallis, Oregon.
- Layton, D.B., C.B. LeDoux, C.C. Hassler. 1992. Cost Estimators For Construction of Forest Roads in Central Appalachians. USDA Forest Service Research Paper NE-665. Washington D.C.
- Mayer, R.H., Jr., R.M Stark. 1981. Earthmoving Logistics. ASCE Journal of Construction Division. 107(CO2): 297-312.
- Rea, A.I. 2005. Microsoft Visual Basic for Applications 2003. Plus Series. McGraw Hill, New York.
- USDA Forest Service, 2007. Cost Estimating Guide for Road Construction. Region 1 Cost Guide. 128 p.
- Walbridge, T.A., B.D. Franklin, R.C. Griffiths, and W. Jarck. 1984. Forest road engineering. P. 1041-1087. In: Forestry handbook. Wenger, K.E. (ed.). Wiley, New York.

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SPECTRAL BASED MODELING OF FOREST RESOURCES AND ITS POTENTIAL USE IN HARVESTING

Muhittin Inan

Abstract: The information about spatial distribution of forest stand parameters and their statistical characteristics are required for the estimation of forest resources with dynamic structure. This information is also necessary for the forest resource planning and sustainable management.

In this research, the multiple linear regression models were developed by using the relationships between forest stand parameters and Landsat ETM+ images. These models were used for the estimation of volume, basal area, average stand height and average stand diameter related to forest resources in Yuvacik Watershed Basin located in Turkey.

The established models that have been developed by relating limited ground sample data to remote sensing data could be applied on different areas that belong to the same Landsat image frame.

These spectral based linear models are very effective tools for determining the forest stand parameters like forest stand volume, etc. And the information gathered from these models will be very useful data for forest harvesting and transportation planning issues.

Key words: Forest resource estimation, spectral modeling, regression analysis, Landsat ETM+ images, harvesting planning

Introduction

Traditional inventory of forest stand parameters based on fieldwork is often difficult, time consuming and costly to conduct in wide areas. Remote sensing may be the only feasible way to acquire forest stand parameter information at a reasonable cost, with acceptable accuracy because of its data advantages which include repeat data collection, multi-spectral images, fast digital processing of large quantities of data, and compatibility with geographic information systems. Modern remote sensing techniques and integration of remote sensing and field inventory data make remotely sensing data the primary source of many applications, such as land use/land cover classification, change detection and forest stand parameters.

Remote sensing data are commonly used for collecting rapid data related to the forest areas. Most of the studies devoted to forest areas are related to determination of land use, change of land cover and deforestation process. These studies are generally based on spectral reflection patterns and neglect the spatial data related to forest resources. Structural characteristics of the forests are also not commonly examined. (Peterson et al. 1996, Nelson et al. 1998, Ripple et al. 1991, Oza et al. 1989). Most results of the structural

characteristics of the forest studies also differ according to remote sensing images used in the study and methodology. For this reason, the relationships between the forest stand parameters and varied remote sensing data are the focus in the study.

Six ETM+ bands and twenty two vegetation indices were used in this research to identify the ETM+ bands and vegetation indices that were most strongly correlated with stand parameters, as well as to explore the impacts of stand characteristics on ETM+ response and stand parameter relationship. The research, by using this relationship, focus on developing the spectral based models and proposing the potential land use for forest resources.

Study Areas

The study area selected for this research is located between 40° 32' to 40° 41' N and 29° 29' to 30° 08' E in the Yuvacik Watershed Basin located in Turkey (Figure 1). The study area has a total area of 25,759 ha; including 3,615 ha of non-forest area and 1,302 ha of coniferous forest, 17,760 ha of deciduous forest and 2,929 ha of degenerated forest and 155 ha of water bodies (Inan, 2004). The largest part of the Yuvacik Basin is located in the National Directorate of Forest District in both Pamukova and Yuvacik.

Approximately 80% of the basin area is covered by *Fagus orientalis* that is dominant species in the area. *Quercus* species are locally formed pure and mixed forest types. The coniferous trees were planted in the area. The topography of the area is steep and undulated and the altitude of the area is 843 meters. About 16,229 ha of the area has 30% or higher slopes.

The land uses of Yuvacık Basin are traditionally mostly for agricultural and settlement purposes. The area is covered by villages with a population of 4,000 people. Agricultural areas cover the 17% of the study areas and main crops include corn, wheat and fruits.

The average annual rainfall is 1039 mm in the Yuvacık Basin. The average annual temperature of this area is 14.8 °C, that reaches the highest average in July (23 °C), and lowest average in January (6 °C).

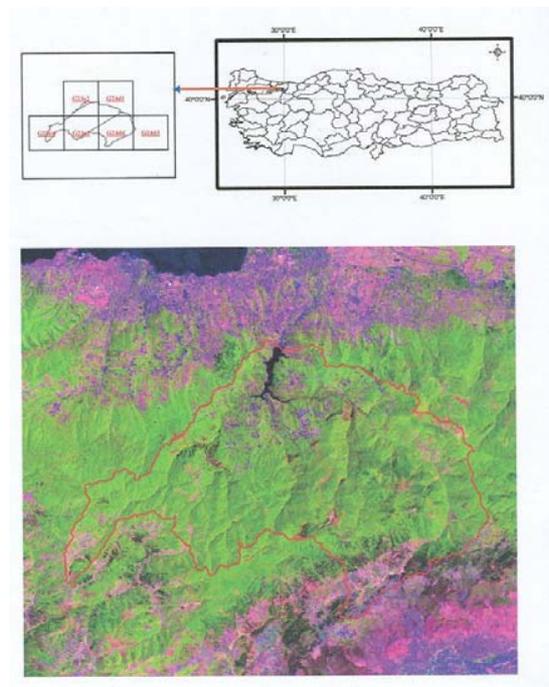


Figure 1. Geographical location of the study area and ETM (543) images

Methods

Field Data Collection and Analysis

In the field data collection phase of the study, systematic sampling has been used in order to correlate with forest management plans in Turkey. Sample plots were chosen in forest areas with 300 x 300 m. intervals and 600 or 800 m² in size depending on the forest characteristics. In each sampling site, all individual trees with diameter at breast height (DBH) greater than 8 cm were identified and measured for DBH, stem height (the height of first major branch) and total height.

During the field work, Landsat ETM⁺ color composites were used to allocate the sample sites and every sample site was registered with a global positioning system (GPS) device to allow further integration with spatial data in a geographic information system (GIS) and image processing system. No differential correction was needed because the inaccuracy of sample size of the field work was greater than the one observed in the regular GPS measurements.

A total of 7,200 trees were measured and registered from 217 reliably positioned sample plots in the field. A SQL database was developed to store and manage the field inventory data. Based on the database, field inventory data was randomly divided into two groups. The first group was used to calculate the required stand parameters for defining forest resources, used in statistical assessment and formed the spectral models related to Landsat ETM⁺ images. Another group was used for accuracy assessment.

Table 1 provides a summary of collected data in these two study areas.

Table 1. Summary of data collection from study area

	Pamukova Region		Yuvac k Region		Total	
	Measured	Selected	Measured	Selected	Measured	Selected
Quantity of Sites	136	63	81	46	217	109
Number of measured trees	4593	2057	2677	1600	7270	3657
Date of field data collection	2003–2004		2002–2003			
Other data collected: Land use history, topographic maps, aerial photo, etc.						

Based on Kalipsız (1998) and Spurr (1952), the following formulas were used for calculating the four forest stand parameters of the sampling sites.

Average Stand Height (SH; m):

$$SH = \sum h / N \quad (1)$$

Average Stand Diameter (SD; cm):

$$SD = \sqrt{\sum d^2 / N} \quad (2)$$

Basal Area (G; m²/ha):

$$BA = \sum \frac{\pi}{4} d_{1.30}^2 = \sum g_{1.30} / A \quad (3)$$

Average Stand Volume (SV; m³/ha):

$$SV = \sum v / A \quad (4)$$

Where: N is the total tree number of site, h is the total height of individual trees, d is the diameter at breast height of individual trees, g is the basal area of individual trees, A is the total area of sites and v is the volume of individual trees.

Landsat ETM⁺ Images Processing

Geometric rectification, atmospheric and topographic corrections are generally applied to the studies in where remotely sensed data is used. In studies that relate remote sensing data with field inventory data together, in addition to the importance of accurate geometric rectification, atmospheric and topographic corrections are also very important for gathering accurate truth reflection data of the field.

In this research, Landsat ETM⁺ image was acquired in July 2001 for the Yuvacik Watershed Basin. This image was geometrically rectified into the UTM (WGS84 Zone 36 North) projection type using ground control points taken from topographic maps at 1/25,000 scale. A nearest-neighbor re-sampling tech-

nique was used and a root-mean-square (RMS) error of less than 0.5 pixels was obtained for the Landsat ETM⁺ image (Yener et al. 2006, Erdas 1998).

The ETM⁺ images were adjusted using atmospheric and topographic considerations so that it reflected environmental conditions that were present on the ground. To do this, the ETM⁺ images were processed using the ATCOR3 module of the Imagine 8.6 image processing software. This application increases the homogeneity of the forest stand and decreases spectral reflection differences in the stand. In addition, it strengthens the relationship between stand parameters and ETM⁺ images (Inan, 2004).

After geometric rectification, atmospheric and topographic correction; vegetation indices were calculated for study area. Vegetation indices are intended to enhance the vegetation signal, while minimizing solar irradiance and soil background effects (Jackson and Huete, 1991)

Vegetation indices could be divided into two groups; ratio-based indices and soil-line based indices or orthogonal indices (Lawrence et al. 1998). The most commonly used ratio-based indices exploit the characteristic of chlorophyll absorption by vegetation in the red portion of the spectrum and high reflectance by vegetation in the near-infrared portion (Tucker, 1979). Ratio-based indices include simple ratio (SR) developed by Jordan (1969), the normalized difference vegetation index (NDVI) developed by Kriegler et al. (1969) and various modified versions of NDVI designed to address its sensitivity to varied factors such as soil variability and atmospheric condition.

Soil-line based indices are based on there being a line in spectral space along which bare soil of different brightness will lie. Vegetation increases perpendicularly to the soil line. Soil-line based indices include the atmospherically resistant vegetation index (ARVI) developed by Kaufman et al. (1992), atmospheric and soil vegetation Index (ASVI) developed

by Qi et al. (1994), Soil adjusted vegetation index (SAVI) developed by Huete (1998), and the Modified soil adjusted vegetation index (MSAVI) developed by Qi et al. (1994). In addition, the Tasseled Cap Transformation (TCT) was developed by Kauth and Thomas in 1976 for Landsat MSS images and was adapted to Landsat TM images by Crist and Cicone in 1986. This method is based on the linear combination of multiple bands principle.

ETM⁺ original bands and 22 different vegetation indices were used in this study. The formula for vegetation indices used in the research is given in Table 2. The images of vegetation indices were formed by

preparing proper graphics models for each vegetation index formula in Imagine 8.6 software.

Three types of vegetation indices were grouped and used in the study:

- Ratio-based indices, such as SR, ETM5/3, ETM5/7, ETM5/4, NDVI, ND32, ND54, ND53, ND57
- Soil-line based indices, such as ARVI, ASVI, SAVI, MSAVI
- Linear combination of multiple bands, such as TCT, Albedo, MID57; VIS123, PCA (Principal component analysis)

Table 2. Vegetation index used in research

Index	Formula
ARVI	$(NIR-2Red+Blue) / (NIR+2Red-Blue)$
ASVI	$((2NIR+1) - ((2NIR+1)^2 - 8(NIR-2Red+Blue)/2))^{1/2}$
MSAVI	$((2NIR+1) - (2NIR+1)^2 - 8(NIR-2RED))^{1/2}$
SAVI	$(NIR-RED) / (NIR+RED+L)(1+L), L=0.5$
SR	$ETM4/ETM3$
ETM5/3	$ETM5/ETM3$
ETM5/4	$ETM5/ETM4$
ETM5/7	$ETM5/ETM7$
NDVI	$ETM4 - ETM3 / ETM4 + ETM3$
ND53	$ETM5 - ETM3 / ETM5 + ETM3$
ND54	$ETM5 - ETM4 / ETM5 + ETM4$
ND57	$ETM5 - ETM7 / ETM5 + ETM7$
ND32	$ETM3 - ETM2 / ETM3 + ETM2$
TCT1	$0.3561ETM1+0.3972ETM2+0.3904ETM3+0.6966ETM4+ 0.228ETM5+ 0.1596ETM7$
TCT2	$-0.3344ETM1-0.3544ETM2+0.4556ETM3+0.6966ETM4-0.0242ETM5-0.263ETM7$
TCT3	$0.2626ETM1+0.2141ETM2+0.0926ETM3+0.0656ETM4-0.7629ETM5 -0.5388ETM7$
PCA 1,2,3	
VIS123	$ETM1+ETM2+ETM3$
MID57	$ETM5+ETM7$
Albedo	$ETM1+ETM2+ETM3+ETM4+ETM5+ETM7$

Integration of Stand Parameters and Landsat ETM⁺ Images

Remote sensing data could give detailed information about characteristics of forests. Different stand characteristics have different reflection values in

varied wavelengths. So, the relationship between remote sensing data and forest stand parameters shows differences. In the analyzing if this relationship, Pearson's correlation analysis has been used. Correlation analysis is the expression of the ratio relationship between dependent and independent variables.

In this study, multiple regression models that related remote sensing data with stand parameters have been developed by using stand diameters, heights, basal areas and stand volumes as independent variables; and remote sensing data such as original ETM⁺ bands and vegetation indices as dependent variables.

The coefficient of determination (R^2) measures the percent of variation explained by the regression model and is an indicator that it can be used to determine if the regression model is adequate. In this situation, the aim of the regression analysis is to form models with high R^2 values. Stepwise regression analysis is used to find the best independent variable combination for given stand parameters.

Results and Discussion

Table 3 summarizes the correlation coefficients between stand parameters and ETM⁺ bands. All stand parameters have negative correlation with ETM bands. ETM4 (near infrared wavelength) and ETM5 (middle infrared wavelength) are significantly negatively related to stand volume, basal area, stand diameter and stand height. These bands are followed by ETM7 (middle infrared wavelength). ETM1 that goes into visible wavelength category is not significantly correlated with all stand parameters. While ETM2 only shows the relation to stand volume, ETM3 is only related to stand heights. In general, the correlation between the ETM bands, basal area and stand volume is greater than the one between ETM bands, diameter and stand height. These differences are likely due to stand volume and basal area being properties of the stand while diameter and height are highly influenced by growing conditions of individual trees.

Compared to ETM5 band, ETM4 band has lower correlation with stand parameters. The reason for this condition is the sensitivity of ETM4 to color pigment

differences in vegetation and reflection differences in habitat conditions (Roy et al., 1996).

From examination of Table 4, it could be seen that most of the vegetation indices do not have important correlations with stand parameters. The best vegetation indices that have high correlation coefficients ($0.83 \leq R \leq 0.75$) with stand parameters are TCT1, PCA1, MID57, TCT3, ASVI and Albedo.

Except ASVI, soil-line based indices have very weak ($R < 0.50$) correlation with stand parameters. Generally, compared to the diameter and stand height, stand volume and basal area have greater correlation with vegetation indices.

Linear band combinations such as PCA1, TCT1 and Albedo have significant correlations with stand volume, basal area and stand height. These bands, because they include the ETM5 and ETM4 bands that show the highest correlation with stand parameters, transport most information through linear transforms from different bands.

Simple linear regression was used to initiate analyses of single ETM⁺ bands, a single vegetation index and combination of different image bands. For each band and index, analysis of residuals was used to guide potential improvements in the regression fits and R^2 were examined to determine the amount of variability explained by the best fitting models.

Table 5 shows the best linear regression models that define the stand parameters with the individual independent variables or combination of these variables. The regression models were obtained by relating Landsat ETM data with limited field inventory data and demonstrate the estimation possibility of the forest resources by using linear multiple regression models based on the spectral data.

Table 3. Correlation coefficients between stand parameters and ETM⁺ bands

	Stand Volume	Basal Area	Stand Height	Stand Diameter
ETM1	-0.32	-0.31	-0.45	-0.24
ETM2	-0.60	-0.55	-0.59	-0.49
ETM3	-0.45	-0.47	-0.63	-0.35
ETM4	-0.78	-0.72	-0.64	-0.61
ETM5	-0.82	-0.81	-0.78	-0.60
ETM7	-0.64	-0.66	-0.71	-0.46

Table 4. Correlation coefficients between stand parameters and vegetation indices

Vegetation Indices	Stand Volume	Basal Area	Stand Height	Stand Diameter
ARVI	0.27	0.31	0.45	0.21
ASVI	-0.78	-0.72	-0.64	-0.61
MSAVI	-0.39	-0.31	-0.14	-0.32
SAVI	-0.39	-0.31	-0.14	-0.32
SR	-0.40	-0.32	-0.15	-0.33
ETM5/3	-0.44	-0.40	-0.23	-0.31
ETM5/4	0.13	0.04	-0.03	0.17
ETM5/7	-0.11	-0.05	0.06	-0.10
NDVI	-0.39	-0.31	-0.14	-0.32
ND53	-0.18	-0.13	0.02	-0.07
ND54	0.16	0.07	-0.01	0.19
ND57	-0.10	-0.05	0.08	-0.09
ND32	-0.24	-0.30	-0.44	-0.16
TCT1	-0.83	-0.79	-0.76	-0.65
TCT2	-0.57	-0.50	-0.36	-0.46
TCT3	0.76	0.77	0.74	0.54
PCA1	-0.78	-0.78	-0.81	-0.57
PCA2	-0.80	-0.75	-0.66	-0.62
PCA3	0.48	0.39	0.38	0.43
VIS123	-0.55	-0.53	-0.66	-0.43
MID57	-0.79	-0.79	-0.79	-0.57
ALBEDO	-0.84	-0.81	-0.81	-0.64

Combination of ETM bands with vegetation indices, result in minor improvement in R^2 . Because the independent variables have high correlation values between themselves, it maybe not necessary to seek two or more independent variables in order to improve the relationship between stand parameters and remotely sensed data.

Figure 2 show the spatial distribution of estimated result of stand volume (m^3/ha), basal area (m^2/ha), average stand diameter (cm) and average stand diameters (m) derived from the spectral based models in the Yuvacik Basin. The images derived from spectral based models could be used as primary data in different forestry application such as harvesting planning and forest resources management.

Table 5. Models for estimating stand parameters

Stand Parameters	Regression Models	Regression Coefficients
Stand Volume	$899.792-7.779*ETM5$	0.821
	$1089.735-5.354*TCT1$	0.835
	$1070.925-5.186*TCT1-0.321*ETM5$	0.845
Basal Area	$106.5-0.865*ETM5$	0.811
	$123.155-0.569*TCT1$	0.788
	$105.319-0.843*ETM5-0.158*TCT1$	0.820
Stand Height	$39.083-0.241*ETM5$	0.775
	$47.390-0.243*PCA1$	0.813
	$38.893-0.231*PCA1-0.013*ETM5$	0.797
Stand Diameters	$59.559-0.336*ETM4$	0.613
	$80.862-0.358*TCT1$	0.648
	$80.967-0.347*TCT1-0.020*ETM4$	0.644

Combination of ETM bands with vegetation indices, result in minor improvement in R^2 . Because the independent variables have high correlation values between themselves, it maybe not necessary to seek two or more independent variables in order to improve the relationship between stand parameters and remotely sensed data.

Figure 2 show the spatial distribution of estimated result of stand volume (m^3/ha), basal area (m^2/ha), average stand diameter (cm) and average stand diameters (m) derived from the spectral based models in the Yuvacik Basin. The images derived from spectral based models could be used as primary data in different forestry application such as harvesting planning and forest resources management.

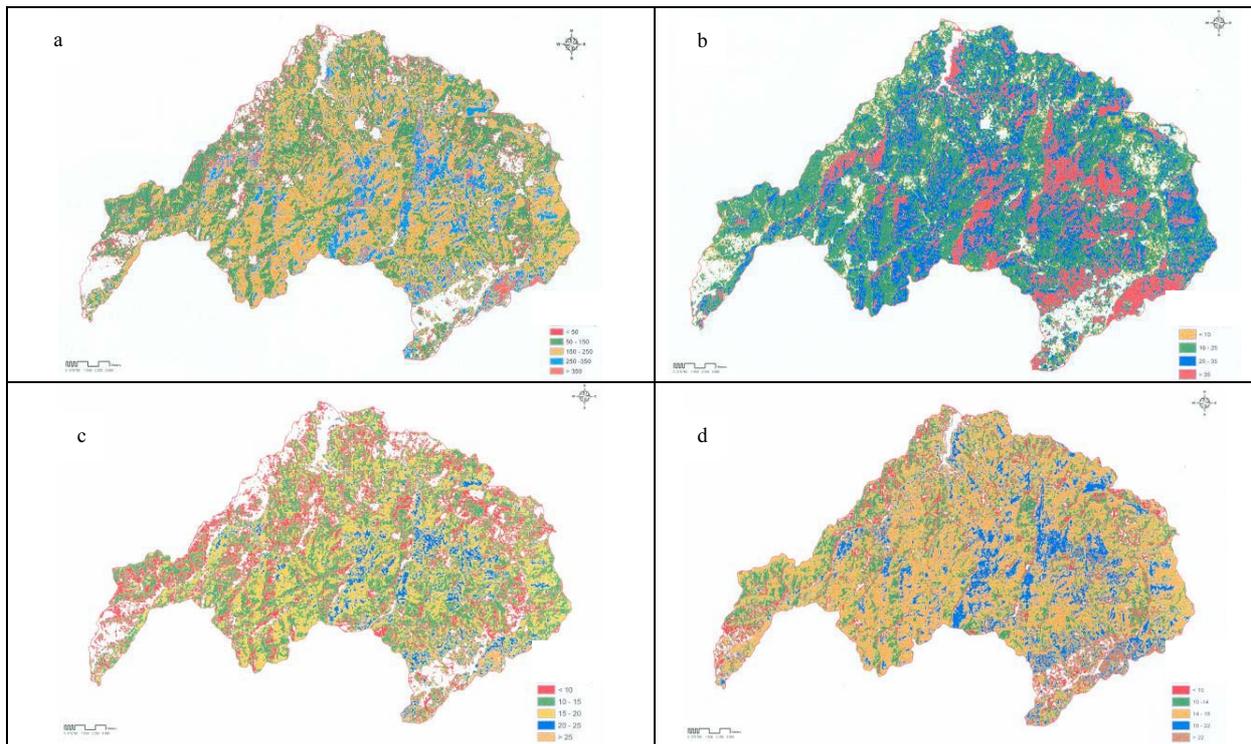


Figure 2. Average stand parameters distribution derived from spectral based models (a: stand volume, b: basal area, c: stand diameters, d: stand heights)

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Literature Cited

- Crist, E.P. and Cicone, R.C., 1984. Application of Tasseled Cap concept to simulated Thematic Mapper data. *Photogramm. Eng. and Remote Sensing*, 50, 343–352.
- Erdas, 1998., *Erdas Field Guide 8.6*, Erdas Inc. Atlanta USA.
- Huete, A.R. 1998. A soil adjusted vegetation index (SAVI). *Remote Sensing Environment*, 29, 295–309.
- Inan, M., 2004. Remote sensing data for determining forest resources. Ph.D. diss., Istanbul University, Istanbul.
- Jordan, C.F., 1969. Derivation of leaf area index from quality of light on the forest floor. *Ecology*, 50, 663–666.
- Jackson, D.R., Huete, A.R., 1991. Interpreting vegetation indices. *Preventive Veterinary Medicine*, 11, 185–200.
- Kalipsiz A., *Orman Hasılatı Bilgisi*, 1988, İ.Ü. Orman Fakültesi Yayınları, İstanbul, 975-404-074-5
- Kaufman, T.J., and Tanre, D., 1992. Atmospherically resistant vegetation index (ARVI) for EOS-MODIS. *IEEE Transactions on Geoscience and Remote Sensing*, 30, 261–270.
- Kauth, R.J. and Thomas G.S., 1976. a Tasseled Cap-a graphic description of the spectral-temporal development of agricultural crops as seen by Landsat. In *Proceeding of the symposium on Machine Processing of Remotely Sensed Data*, Purdue University, WL,IN, pp 41–51.
- Lawrence, L.R., Ripple, W.J., Comparisons among Vegetation indices and bandwise regression in highly disturbed, heterogeneous landscape: Mount St. Helens, Washington. *Remote Sensing Environment*. 64, 91–102.
- Nelson, R., Swift, R., Krabill, W., 1988. Using airborne lasers to estimate forest canopy and stand characteristics. *Journal of Forestry*, 86, 31–3
- Oza, M. P., Srivastava, V. K., Pariswad, B. S., Setty, K. R. V., 1989. Relationship between Landsat MSS and forest tree parameters. *International Journal of Remote Sensing*, 10, 1813–1819
- Peterson, D. L., Westman, W. E., Stephenson, N. J., Ambrosia, V. G., Brass, J. A., Spanner, M. A., 1986. Analysis of forest structure using Thematic Mapper Simulator data. *IEEE Transactions on Geoscience and Remote Sensing*, 24, 113–121.
- Ripple, W. J., Wang, S., Isaacson, D. L., PAIRRE, D. P., 1991. A preliminary comparison of Landsat TM and SPOT-1 HRV multispectral data for estimating coniferous forest volume. *International Journal of Remote Sensing*, 12, 1971–1991
- Qi, J., Chehbouin, A., Huete, A.R., Kerr, Y.H. and SOROOSHIAN, S., 1994. A modified soil adjusted vegetation index. *Remote Sensing Environment*, 48, 119–126.
- Spurr, S. H., 1960. *Photogrammetry and photo interpretation with a section on application to forestry*. The Ronald Press Company
- Tucker, C.J., 1979. Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing Environment*. 8, 127–150
- Roy, P. S., Ravan, S. A., 1996. Biomass estimation using satellite remote sensing data an investigation on possible approaches for natural forest. *Journal of Bioscience*, 21, 535–561
- Yener, H., Koc, A., 2006., Monitoring changes in forest and other land use forms in Istanbul. *Journal of Environmental Biology*, 27(1), 77–83.

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24/7 FOREST HARVESTING: IMPLICATIONS FOR PRODUCTION PLANNING

Glen Murphy, Michael Vanderberg

Abstract: Extending the amount of time allotted to the harvesting process (e.g., working longer periods within shifts, or adding shifts) is a practice that has become more common in forest operations over the past decade in order to meet the growing demand for increased production efficiency and overall monetary returns. However, there are many factors that must be considered when analyzing the effectiveness of extending the amount of time in which harvesting operations are active if the overall goal is maximizing production efficiency for an increased profit margin.

Using the best information available in the literature related to the forest industry as well as other industries, a model was constructed that allowed the evaluation of the economic impacts of altering shift lengths and total number of hours worked per year for ground-based mechanized harvesting and cable harvesting operations. The model takes into consideration the effects of these on both human-related performance and equipment performance. Production impacts, equipment impacts (e.g. depreciation, interest costs, and maintenance costs), value recovery impacts, and accident impacts are modeled. Sensitivity analysis was carried out to determine the relative importance of some of the key variables.

The research provides insight into how extending the working annual hours of logging operations is likely to affect overall production economics. It also highlights deficiencies in knowledge related to this area and where further research needs to be undertaken.

Key words: value recovery, forest harvesting, extended shift.

Introduction

The forest products industry, as a whole, has been constantly striving to improve the performance of the wood supply system in order to compete in the ever-changing global wood products marketplace. Although the productivity of timber harvesting operations is many times not considered to be the limiting factor of a particular wood supply system, inefficiencies in the production process can affect both harvesting and fiber procurement costs (Greene et al. 2004).

Extending the amount of time allotted to the harvesting process (e.g., operating hours) is a practice that has become more common in forest operations over the past decade in order to meet the growing demand for increased production efficiency and overall monetary returns (Nicholls 2003). However, there are many factors that must be considered when analyzing the effectiveness of extending the amount of time in which harvesting operations are active if the overall goal is maximizing production efficiency for an increased profit margin. The trend towards mechanization in forest operations requires the use of expensive equipment and machinery. In some countries, such as Australia (Nicholls et al. 2004), Sweden (Anders-

son 1999), Brazil (Izlar 2007), and Chile (Cordero et al. 2006), extending yearly operating hours is being used as a means of spreading equipment fixed costs.

Specifically, from a production planning and control perspective, extending the amount of time allotted to the harvesting process may have implications when utilizing current harvest production models. The first general area of concern in an extended working hour setting could be mechanical availability and utilization of the harvesting equipment and machinery. Implications from the increased demand on equipment and machinery could arise in a multiple-shift forest harvesting environment, which could also affect the production efficiency as well as the potential overall profit.

The second general area of concern is employee performance. Whereas equipment has a more static nature to specifications, capabilities, and limitations; the human employee could be considered to be much more variable and dependent on other hidden factors, making the prediction of individual or collective human employee performance potentially more complex. Implications from the increased physical, mental, and emotional demands placed on human em-

ployees associated with extended working hours could be related to productivity, safety (as human safety-related accidents often lead to a less productive forest harvesting operation due to lost time as well as the potential for a reduced workforce), and value recovery.

In order to quantify the effects of an extended operating hour work environment on forest harvesting productivity, a new model has been developed. The 24/7 Forest Harvesting model takes a broad approach to productivity analysis, and has been constructed to evaluate the economics of production from the perspective of a forest owner purchasing the services of a harvesting contractor and selling logs.

Model Structure

The 24/7 Forest Harvesting model determines total net revenue from three types of harvesting operations (shovel, ground skidding, and cable yarding systems) based on productivity, hourly costs of equipment and labor, and net value recovery calculations. Hourly costs depend on equipment depreciation, interest, taxes, insurance, and repair and maintenance costs, as well as labor factors, such as overtime wages and fringe benefits. The effects of extended working hours (night shifts and extended shifts) are determined by the predicted impact on productivity, potential accident rate, and potential operator error rate affecting value recovery.

The human factor model calculations are based on a variety of literature pertaining to forest harvesting, construction, manufacturing, medicine, and other shift-based operations. The night shift effect was based on five related publications (Nicholls et al. 2004, Maxwell 1982, Terlesk and Walker 1982, Vernon 1940, LaJeunesse 1999). An average drop in productivity due to night shift was found to be approximately 10%. This was increased to 12.5% to reflect higher production losses reported in the few studies of forest operations (Nicholls et al. 2004, Maxwell 1982, Terlesk and Walker 1982).

The effect of extended work hours on production was also modeled on five related publications (Hanna et al. 2005, Veasey 2002, Tyson 1997, Vernon 1940, and Atack et al. 2000). The loss of production due to extended work hours follows the following criteria: if the shift length is greater than 9 hours (i.e., 10, 11, 12 hours), then production loss is affected at a rate of 6% per hour (e.g., production for a 10 hour shift is decreased by 6%, whereas production for an 11 hour shift is decreased by 12%). Also, if the shift duration

schedule is greater than 25 weeks, then the production is reduced by another 1%.

The effect of night shift on human cognitive performance relating to value-based decision making was modeled on four related publications (Folkard and Lombardi 2004, Sibergleit and Kronick 2004, Veasey 2002, Freidman et al. 1971). The value loss multiplier represents an average relative increase in value loss of 30% for night shift compared to day shift operations.

The effect of extended working hours on accident rates is modeled after four related publications (WorkSafe BC 2007, Folkard and Lombardi 2006, Parker et al. 2003, Vernon 1940). The model accounts for these effects in several calculations. The base number of lost time accidents are set at 16 per 100 man-years for cable operations and 7 per 100 man-years for ground-based operations (WorkSafe BC 2007, Parker et al. 2003). The night shift accident rate is increased by 30% (Folkard and Lombardi 2006), and if the shift length is greater than 8 hours the accident rate is increased by another 3.5%, whereas if the shift length is greater than 10 hours the accident rate is increased by another 7% (Folkard and Lombardi 2006, Vernon 1940).

Overall, the 24/7 Forest Harvesting model takes both equipment and human factors into account when predicting net revenue from the three major types of harvesting operations. Net revenue prediction is determined also by accounting for extended operating hours, whether hours are extended by daily shift length, shift duration, work week length, or any combination of the three. The effect of night shift, relative to day shift, is also accounted for in the model.

Model Demonstrations

The effects of extended operating hours on the productivity of forest harvesting operations can be shown in several model demonstrations. Simulations were run for all harvesting systems (shovel, ground-skidding, cable yarding) under two forest stand conditions. Stand 1 (78 ac, 43.3 mbf/ac, 120 tpa, \$15200/ac, 90% value recovery), in terms of tree size, was the larger of the two stands (~340 bf per tree or 2.7 m³ per tree). Stand 2 (35 ac, 36.6 mbf/ac, 220 tpa, \$5700/ac, 95% value recovery) had smaller trees (~160 bf per tree or 1.2 m³ per tree). Average yarding distance for the three systems was held at 300, 450, and 600 feet for shovel operations, ground-skidding operations, and cable yarding operations, respectively.

Ten shift configurations were investigated and compared to a Base shift (one 9-hour daytime shift) in terms of change in net revenue. The ten shift configurations were as follows: single shifts of 10, 11, and 12 hours (S10, S11, S12); double shifts of 9, 10, 11, and 12 hours (D9, D10, D11, D12); a triple 9 hour shift (T9); a single 11 hour shift over 4 days (4S11); and a 9 hour nighttime shift (Night). Each shift includes a 1 hour break (i.e. a 9 hour shift equates to 8 working hours, etc.). All shifts revolve around a 5 weekday work schedule, with the exception of 4S11, which only includes 4 weekdays. The combination of shift configurations, harvesting systems, and stand characteristics yielded 66 simulations including the 6 baseline scenarios.

Results

The model simulation results will be discussed by harvesting system and stand characteristics. Results for the shovel harvesting operations consistently showed the lowest losses in net revenue due to extended work hours, whereas the results for the cable yarding operations consistently showed the highest losses in net revenue. Results for ground-skidding operations were consistently closer in magnitude to shovel operations, as opposed to cable yarding operations.

In the large tree stand, the highest amount of net revenue loss was found to occur during the D12 shift configuration for all three harvesting systems (18, 13, and 10% loss for cable, ground-skidding, and shovel operations, respectively). In the small tree stand, the highest amount of net revenue loss was also found to occur during the D12 shift configuration for all three harvesting systems (178, 88, and 74% loss for cable, ground-skidding, and shovel operations, respectively). The D9 shift configuration led to slight increases in net revenue for the large tree stand (~1%), as well as the small tree stand (3 – 7%), depending on the harvesting system. The T9 shift configuration led to slight decreases in net revenue for the large tree stand (1 – 3%). For the small tree stand, the T9 shift led to a decrease in net revenue in the cable yarding system (26%). The T9 shift configuration had little effect on net revenue for the ground-skidding harvesting system in the small stand, and increased net revenue for the shovel harvesting system (2%).

All of the other shift configurations (S10, S11, S12, D10, D11, 4S11, and Night) reflected losses in net revenue for all harvesting systems. The net revenue loss increased as the shift length, in hours, increased for the same type of shift (S or D). Comparisons between harvesting systems, stand characteristics, and shift configurations can be seen in Table 1 and Figures 1 and 2.

Table 1. – Predicted percent change (+/-) in net revenue due to extended working hours for three harvesting systems in two stand conditions.

Shift Type	Large Tree Stand			Small Tree Stand		
	Cable Yarding	Ground Skidding	Shovel	Cable Yarding	Ground Skidding	Shovel
Base	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
S10	-3.1%	-2.4%	-1.8%	-33.1%	-18.2%	-15.8%
S11	-6.7%	-4.8%	-3.6%	-70.8%	-37.1%	-32.1%
S12	-10.7%	-7.6%	-5.7%	-109.9%	-58.6%	-50.5%
D9	0.6%	0.8%	0.8%	2.7%	6.9%	7.5%
D10	-9.1%	-6.7%	-5.2%	-79.7%	-37.6%	-30.6%
D11	-13.6%	-9.8%	-7.5%	-128.1%	-61.7%	-51.3%
D12	-18.2%	-13.3%	-10.1%	-177.8%	-88.9%	-74.5%
T9	-3.0%	-1.2%	-0.9%	-25.6%	-0.5%	2.2%
4S11	-4.3%	-3.9%	-2.9%	-45.9%	-29.9%	-25.7%
Night	-12.4%	-9.6%	-8.0%	-85.2%	-46.1%	-39.3%

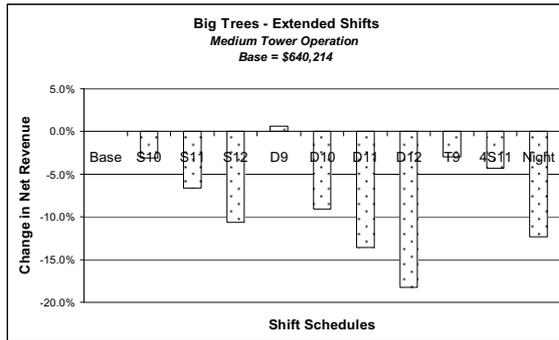


Figure 1. – Change in net revenue for a cable yarding harvesting system operating in large tree stand conditions.

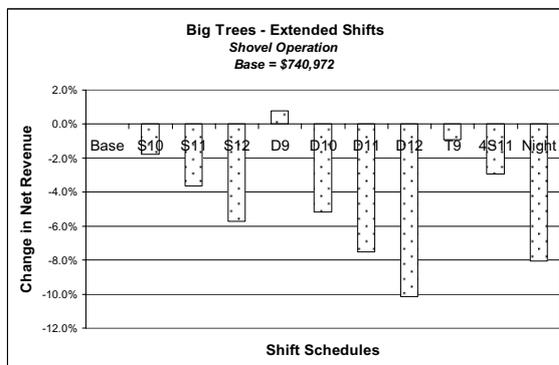


Figure 2. – Change in net revenue for a shovel harvesting system operating in large tree stand conditions.

Discussion

Upon preliminary exploration of three harvesting systems operating in two stand conditions, it appears that extended working hours can potentially affect the amount of net revenue generated by an operation. The 24/7 Forest Harvesting model predicts negative impacts to net revenue in all but one (D9) of the ten simulation scenarios, when compared to the baseline shift configuration of a single 9 hour shift with a one hour break. However, for small tree stand conditions, the T9 shift configuration did show an increase in net revenue for the shovel harvesting system, while the ground-skidding system remained unchanged compared to the baseline shift configuration. The T9 shift configuration is affected by nighttime factors, whereas the D9 shift is not.

The net revenues from the large tree stand conditions were less affected by extended working hours when

compared to the small tree stand conditions. The cable yarding harvesting system was consistently the most affected of the three systems in terms of net revenue loss due to extended working hours, which could be due to the increased accident rate found for cable systems. The shovel harvesting system was consistently the least affected of the three systems in terms of net revenue loss due to extended working hours, and ground-skidding systems appeared to be more closely related to shovel systems than cable yarding systems. Again, this could be partly due to the lower accident rate found for ground-based (shovel and ground-skidding) harvesting systems.

The simulation scenarios point towards an increasing negative effect (with the exception of D9, which has a positive effect) on net revenue as both shift length and number of shifts per day increase. The effect is relative to the baseline shift of 9 daytime hours with one 1-hour break. This finding includes the 4S11 daytime shift, or the “four 10’s” shift, which potentially shows that extended working days, rather than hours per week, may also have a negative effect on net revenue.

The 24/7 Forest Harvesting model shows, through simulation, that the extended hour operating environment can have overall negative effects on net revenues from forest harvesting operations. Even though hourly cost rates are reduced, productivity is, for the most part, negatively impacted on a potential human occupational level. Value recovery is also negatively impacted by the extended operating environment, and may also be potentially related to human cognitive and decision-making abilities.

Concluding Remarks

The 24/7 Forest Harvesting model is preliminary in nature, and is partially reliant on values found in related occupational literature pertaining to extended operating environments. Results should be interpreted with the former in mind. However, the conceptual framework of the model appears to be sound and encompassing. More research must be conducted in order to validate the 24/7 Forest Harvesting model. With validation there may also be potential for the incorporation of optimal shift scheduling and extension of the model to include other harvesting systems. The benefits of the model may be felt on both a productivity and value recovery level, as well as influence the well-being of human operators.

Literature Cited

- Andersson, W. 1999. Follow up of the logging industry project "Development of work environment and production" (in Swedish), Rapport 1999:2, Arbetskyddsstyrelsen, Solna, Sweden. 30p.
- Atack, J., F. Bateman, and R.A. Margo. 2000. Productivity in manufacturing and the length of the working day: evidence from the 1880 Census of Manufacturers. Department of Economics, Vanderbilt University. Working Paper No. 317, 12pp.
- Cordero, R., O. Mardones, and M. Marticorena. 2006. Evaluation of forestry machinery performance in harvesting operations using GPS technology. International Precision Forestry Symposium, Stellenbosch University, Stellenbosch, South Africa. March 2006. 12 pp.
- Folkard, S. and D.A. Lombardi. 2004. Modelling the impact of the components of long work hours on injuries and accidents. Extended abstract from "Long working hours, safety, and health: towards a national research agenda." University of Maryland, Baltimore, Maryland.
- Folkard, S. and D.A. Lombardi. 2006. Modeling the impact of the components of long work hours on injuries and "accidents". *American Journal of Industrial Medicine* 49(11): 953-963.
- Freidman, R., J. Bigger, and D. Kornfield. 1971. The intern and sleep loss. *Northern England Journal of Medicine* 285: 201-203.
- Greene, D.W., J.H. Mayo, C.F. deHoop, and A.F. Egan. 2004. Causes and costs of unused logging production capacity in the southern United States and Maine. *Forest Products Journal* 54(5): 29-37.
- Hanna, A.S., C.S. Taylor, and K.T. Sullivan. 2005. Impact of extended overtime on construction labor productivity. *Journal of Construction Engineering and Management* 131(6): 734-739.
- Izlar, R. 2007. Personal communication. Director, Center for Forestry Business, University of Georgia, Athens, GA.
- LaJeunesse, R. 1999. Toward an efficiency week – correlation between shorter workweek and higher productivity. *Challenge* Jan/Feb.
- Maxwell, D. 1982. A production analysis of the night shift in a forest operation. B. Sc. Thesis. University of New Brunswick. 42pp.
- Nicholls, A. 2003. Fact Sheet: Round the clock timber harvesting impacts productivity and profitability. Forest & Wood Products Research & Development Corporation, PO Box 69, World Trade Centre, Melbourne, Vic 8005.
- Nicholls, A., L. Bren, and N. Humphreys. 2004. Harvester productivity and operator fatigue: working extended hours. *International Journal of Forest Engineering* 15(2): 57-65.
- Parker, R., L. Ashby, and T. Evanson. 2003. Analysis of lost time and minor injuries - 2002 logging (accident reporting scheme statistics). Center for Human Factors and Ergonomics, New Zealand. Report 4(1): 12pp.
- Sibergleit, R. and S. Kronick. 2004. Effect of shift work on performance in the emergency department: relationship between time of day and emergency department quality makers. *Academic Emergency Medicine* 11(5): 483.
- Terlesk, C.J., and K. Walker. 1982. A highly mechanised harvesting system in New Zealand. *New Zealand Journal of Forestry Science* 12(2): 199-213.
- Tyson, J. 1997. Using ergonomics to improve health and well-being and the bottom line. *Health and Safety Resource* Sept/Oct.
- Veasy, S., R. Rosen, B. Barzansky, I. Rosen, and J. Owens. 2002. Sleep loss and fatigue in residency training: a reappraisal. *The Journal of the American Medical Association* 288(9): 1116-1124.
- Vernon, H.M. 1940. The health and efficiency of munition workers. Oxford University Press. London. 138pp.
- WorkSafe BC. 2007. Statistics for Forestry (2001-2005). <http://www2.worksafebc.com/Portals/Forestry/Statistics.asp> (assessed 28 February 2007).

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THINNING OPERATIONS IN JAPAN: DESCRIPTION AND MODELING

Edwin Miyata, Francis Greulich, Kazuhiro Aruga, Koki Inoue

Abstract: Thinning operations on planted forests are needed for the maintenance and improvement of their multifunctional role for society. The Japanese government has made a substantial commitment to thinning operations by subsidizing what is currently, in most circumstances, an uneconomic activity. There is great interest in improving the economic efficiency of the thinning process so that government subsidies can be reduced or eliminated. This paper examines the problem from a systems perspective and presents some initial thoughts on optimizing one possible thinning system design.

Key words: Non-linear optimization, thinning, hot deck swing, full tree processing, cost minimization, carbon sink.

Introduction

Japan comprises more than 3,000 small islands and the four main islands are Hokkaido, Honshu, Shikoku, and Kyushu. The total land area of Japan is approximately 38 million hectares (ha) and islands stretch nearly 3,000 kilometer (km) from north to south. About three quarters of the total land area is mountainous (Forest Agency 2001 and 2003). Most of the mountainous areas are steep, difficult to access sites. There are about 25 million ha of forestland in Japan and it covers about 67% of the total Japanese land area. Of the total forestland, plantations cover about 10 million hectares and natural forests and others make up 15 million hectares. Area of forests of 45 years or younger, which need thinning or other treatment, make up about 80% of the total planted forests. The growing stock of the forests is about 3.9 billion cubic meters (m³) (Forest Agency 2002 and 2005).

The forests provide not only logs, lumber, pulp, and other wood products, but in addition, well managed forests also play important roles in various multiple eco-functions such as soil stabilization (prevention of landslides), in the conservation of soil resources and biodiversity, and expands opportunities for outdoor recreation and aesthetic enjoyment. Trees and vegetation on forestlands also remove carbon dioxide from the air (active carbon sink) and release oxygen (Fujimori 2001). Trees and vegetation also assist in protecting water quality and providing fish and wildlife habitat (Washington 1997 and Forestry Agency 2005). Forests have a significant role in maintenance and improvement of their multifunctional roles through its forestry operations (Forestry Agency 2004).

“It is stipulated in the Kyoto Protocol Target Achievement Plan (Cabinet Decision of April 2005) that 3.9 percent out of the 6 percent of Japan's emission reduction commitment should be achieved through forest carbon-sinks” (Forestry Agency 2005). Thinning with the proper timing and tree selection have impacts on present and future timber supply by providing wood volume at present and increasing value of the final crop. Also thinning operations revitalize the remaining trees which in turn increases the future absorption of carbon dioxide from the air and increases the release of oxygen. On the basis of this concept, in fiscal year 2005 the Forestry Agency began executing a 3-year program (300,000 ha per year) for the Promotion of Thinning Plan, which aims to promote regular thinning and the utilization of thinned wood products (Forestry Agency 2005). One of the reasons for sluggish forestry practices in Japan is the declining profitability of forestry. Cost reduction or improvement of profitability of forestry operations through promotion of intensive forestry management, better thinning machine systems and methods are essential (Forestry Agency 2001, 2004 and 2005). This paper examines the problem from a systems perspective and presents some initial thoughts on optimizing one possible thinning system design.

General System Theory

The process begins with an awareness of a disequilibrium, difficulties, and necessities that must be integrated and considered to translate these issues into a rationale for allocating limited money and resources to improve the forestry operations. This rationale is stated as “issues statements” which lead directly to defining a problem. The purpose of this definition is to identify the underlying problem that the analysis will address. It combines the stated symptoms of dis-

equilibrium into one precise definition of the problem (Iverson 1985).

Today's logging equipment ranges from chain saws to multifunctional high performance machine which can fell, delimb, buck, and haul products to the landing. Of these existing machines and operational systems we have to determine which are technically sound, economically efficient, and environmentally acceptable under the changing working and environmental conditions. The problem, therefore, is defined as how to evaluate alternatives and select the best machine and systems for the specific forestry activity. Although there may be different approaches, this paper presents one possible avenue to the evaluation of alternatives and the selection of the optimum number of processors' site to minimize the production cost of thinning operations.

The Process of Evaluation

Proper planning of forest activities is essential to minimize negative environmental impacts. It is important to study the site-specific forest practice (activities) rules that are designed to protect ecosystems. The operational rules may vary with each prefecture in Japan. Precipitation in the form of rain or snow generally infiltrates into forest soils but much of it eventually drains or runs off following a course determined by the local topography. The runoff flows into creeks and streams which merge to form a river. The geographic area drained by a single river and its tributaries is called a watershed. When a logging site within a watershed area is harvested, the harvesting related activities such as road construction, logging, slash abatement, site preparation, planting and weed control impact not only the logging site but the entire watershed area. Watershed protection is the first line of defense in protecting water quality. Forestry related operational activities must be carefully planned to minimize potential impacts on water quality in the watershed. Thus, the spatial unit for forestry operational activities and planning should be at the watershed scale in most situations. Planning must include all activities which are necessary before, during, and after the harvest.

1) Develop background information: A detailed site description is a prerequisite to good planning. After a planning map is made, the site must be visited to assure accuracy of the data, including terrain condition, soil, and description of the site to identify what types of management and environmental protection requirements (watersheds analysis, riparian and wetland protection) that may be required for the specific site.

2) Measurement criteria: Based on the background information, measurement criteria must be developed to evaluate existing machine, systems, and methods available. Measurement criteria will revolve around cost, productivity, and environmental aspects. Costs include the production costs of each alternative. Productivity items include the productivity of each machine and a complete operational system requirements evaluation. Environmental criteria are evaluated, including soil erosion, soil compaction, and all environment protection requirements determined by the Japanese government.

The next step in general systems theory requires that a set of alternatives (courses of action) be generated. The analysis phase begins with the initial evaluation of the alternatives. A review of related research will yield the necessary information to perform a cost benefit analysis. Information on existing yarding techniques is gathered through a literature search, and alternatives are compared to the operational characteristics of ideal yarding machine and systems.

3) Evaluate alternatives: Many government, university, and industry investigators have studied and reported the performance of various equipment and systems under different operational conditions in Japan (Sakaguchi 1996). Some machines work well on gentle slopes and firm ground. Some other machines operate on over 20% slope, but expose more soil to erosion. The cable systems being used for yarding large, high-value timber in the Pacific Northwest of the United States are too large and expensive to use in Japan. An excellent data source for evaluation is the manufacturers' web sites. Information on existing equipment and systems is gathered through a literature search. Forestry Agencies and the Forest Product Research Institute have information on Japan. In addition, the Prefecture Forest Experiment Stations have information on local areas. All available alternatives are compared against the measurement criteria. Candidate alternatives are selected, and then a computer simulation and operations research techniques can be used to evaluate these alternatives to match a given set of activity sites. Reliable and accurate data is needed for computer analysis. If available data is insufficient or incomplete to evaluate candidate alternatives, we must either a) secure additional assistance from people most familiar with the machine and systems, b) negotiate with manufacturers, local loggers, and timber owners to conduct work measurement studies, or c) determine acceptable

assumptions for analysis. Data collection is an ongoing process. A data bank of the performance information for different activity conditions should be continuously accumulated and kept current for forestry machine and systems.

- 4) Selection: This is the point of decision. Based on the evaluation of all alternatives, the best machine and systems for this specific activity site will be selected. New concepts need to be developed if existing equipment and systems are not suitable for use in the area.
- 5) Implementation: In this final step, the decision is implemented and the results are monitored. If current systems and equipment are not up to the job, then modifications, improvements, or new concepts must be investigated. A general systems approach and the order of priority are presented in Figure 1.

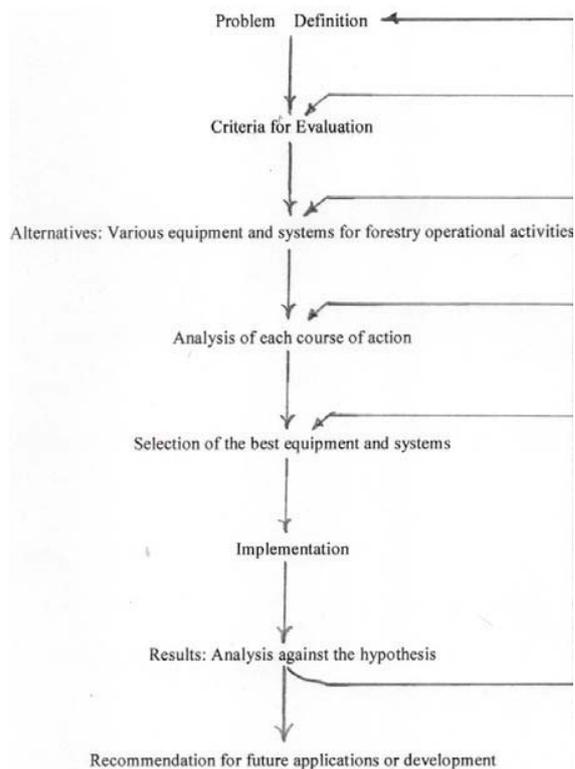


Figure 1: The Decision-Making Process

Literature Research

A search of the literature on the forestry operations that satisfies the measurement criteria can be conducted. Many pertinent publications have been studied within and outside Japan. In harvesting operations, trees are felled by a chain-saw, feller-buncher, or harvester. Narita (2003) and Hashira (2001) studied a chain-saw and high performance processor. Mitsudome (2005) reported the productivity of the skidder and the backhoe with a winch for yarding operations, and Goto (2002) used a swing yarder and a high performance processor. Yoshida et al. (2006) studied the productivity of yarding system for forest biomass with a tower yarder. Sawaguchi (1996) studied the characteristics of parameters for forest-road evaluation and reported valuable information on thinning operations of planted forests in Japan. Garner (1978) reported a contractor hauling system and Aruga et al. (2006) studied the reduction of skidding or yarding distance. Zabinsky et al. (1992) examined nonlinear programming optimization methods to reduce yarding costs. Peters (1978) and Greulich (2000) applied operations research techniques to reduce harvesting costs.

Model Development

Given the current heavy emphasis on thinning operations in Japanese forests it was decided to construct a model that might potentially serve as a guide to operations planning. Here we present some initial thoughts and results on that modeling effort. We acknowledge that these results are of a preliminary nature and would require additional work to be of any substantial assistance to managers of Japanese thinning operations.

We assume that a cable thinning operation is to be conducted on steep ground. Full tree yarding up-hill to a low-standard, single-lane, contour road is to be done. A hot-swing along the road to a processor where the full-tree will be delimbed, topped, and bucked, is planned. In this first pass at a model we assume that harvestable trees are uniformly distributed over the area to be thinned. Full trees are cable yarded up a series of parallel cable roads that are perpendicular to the truck road from which the yarder operates. The turns are continuously decked along the road centerline on that side of the yarder currently accessible to the swing machine. We also assume that logging trucks can access the processor site from either direction along the contour road and that they have equal hauling costs in both directions. The trucks will arrive at the processor from the side oppo-

site the ongoing yarding operation, but we assume that there is sufficient space for the yarder to bypass the processor when necessary as it works up the road.

The objective is to yard, swing, process, and haul the total volume from the site at minimum cost. The decision variables are the number of processor sites to establish along the road as well as the location of these sites. We assume that the relevant costs for this initial model are: the cost of moving and setting up a processor site and the cost of swinging trees from the yarder location to the processor. The processor cost is a lump sum amount per move and the swing cost is a linear function of the distance from the yarder to the processor. All other costs are assumed to be insignificant or irrelevant to this initial problem statement. We also assume for this development that the road is a long tangent section with little or no grade.

Given a decision to have "n" processor sites along the road our immediate objective is to locate those sites so as to minimize the expected total cost of swinging the material to the processor. Since the swing cost is a linear function of the distance travelled we may write the objective function quite simply as the minimization of the expected one-way distance of the swing:

$$\text{Min}_{L_i, i=1, n} E\{s\} = \frac{1}{A} \sum_{i=1}^n \left[\int_{M_{i-1}}^{L_i} (L_i - x)h(x)dx + \int_{L_i}^{M_i} (x - L_i)h(x)dx \right] \quad (1)$$

where

$$A = \int_a^b h(x)dx \quad (2)$$

is the horizontal area between the road tangent, which is the near boundary of the thinned area, and the outer thinning boundary. The horizontal distance measured perpendicularly from the road centerline to the outer thinning boundary is denoted $h(x)$. The thinned area starts at point a and ends at point b along the road. With the exception of the thinning unit start and end points along the road, M_i denotes the midpoint between processor location L_i and processor location L_{i+1} ; viz., $M_i = (L_i + L_{i+1})/2$, with $M_0 = a$, and $M_n = b$.

It would appear that analytic solutions can be found for only relatively simple cases. For example, if $h(x)$ is a constant distance from the road (a rectangular thinning unit) then the optimal spacing is quite intuitive and easily confirmed by the calculus. For a triangular thinning unit where, for example $h(a)=0$ and $h(b)$ is some positive distance, the optimal spacing is not intuitively obvious but analytic solutions can also be obtained fairly readily. (These cases for low values of n (e.g., 1 or 2) and some variations

from the current assumptions are good student exercises in the application of the calculus.)

Figure 2 illustrates an example where the external yarding boundary of the thinning unit has been free-hand plotted as a smooth curve on a logging plan. We approximate this curve with a series of straight line segments as illustrated in Figure 3. The coordinates (in meters) of this approximating string of line segments, starting at point a and ending at point b, are given in Table 1.

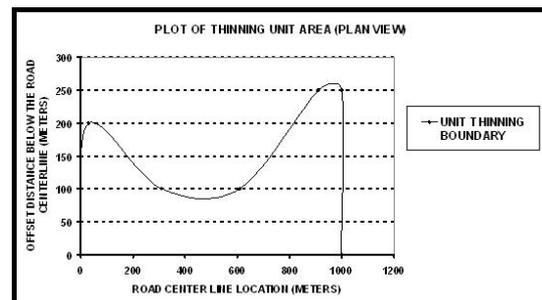


Figure 2. A hypothetical thinning unit shown in plan view as recorded and plotted on the harvesting plan. The horizontal axis represents the centerline of a 1 kilometer tangent section of road forming one boundary of the unit.

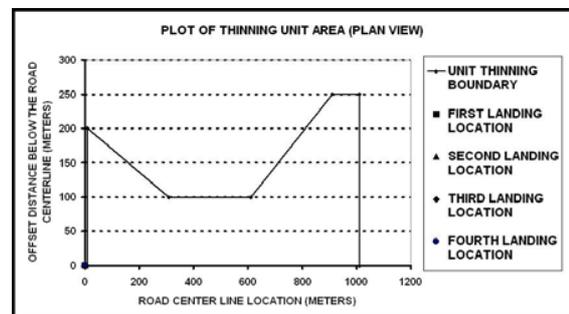


Figure 3. The same thinning unit as shown in Fig. 2 as approximated by a series of linked straight line segments in preparation for mathematical modeling.

Table 1. Coordinates for line segment approximation to the thinning unit boundary.

j	0	1	2	3	4	5	6
x_j	a = 10.0	10.1	310.0	610.0	910.0	1010.0	b = 1010.1
$h(x_j)$	0.0	200.0	100.0	100.0	250.0	250.0	0.0

Perhaps the easiest solution is achieved by numerical optimization using the Solver add-in for the MS Excel spreadsheet program. A spreadsheet based optimization program is easily written. When run for this problem results for up to 4 processor sites are found; optimal site coordinates are given in Table 2.

Table 2. Optimal processor site coordinate along the road tangent and the associated mean swing distance for 1 to 4 sites.

n	L_1^*	L_2^*	L_3^*	L_4^*	$E\{s\}$
1	622				283.6
2	207	830			118.8
3	146	535	879		80.7
4	123	417	718	919	60.2

These optimal processor locations, L_i^* , are given in meters measured from the origin of the coordinate system, 10 meters to the left of point a. Figure 4 shows the optimal processor sites if it is decided to have a total of 4 sites along the road. Some caution is needed in running this problem. The problem, as stated, has a non-convex objective function and suboptimal solutions may be encountered. A good choice for the starting points of the optimization algorithm (the initial L_i values) should result in at least a near-optimal, if not the optimal, solution in most cases. Restarting the algorithm with a variety of initial point combinations is also advisable. It is also to be noted that the objective function is quite flat near the optimal point and the algorithm is providing solutions, L_i^* , within about ± 3 meters. This variation is a function of not only the algorithmic procedure itself but also the numerical estimates provided by the spreadsheet formulation of the problem; e.g., the size of Δx used to approximate the differential dx . A flat objective function near the optimal is encouraging when encountered since it provides flexibility in the actual siting decision with little subsequent departure from the optimal cost minimum.

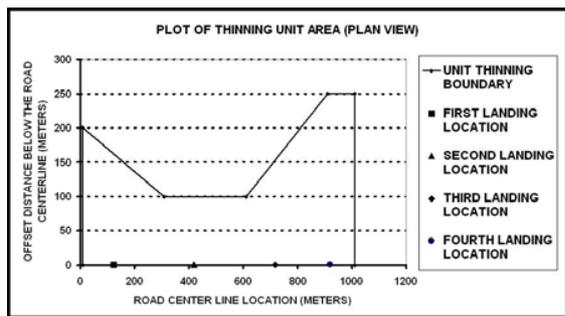


Figure 4. The optimal processor siting locations as determined by the numerical optimization model when it has been decided that exactly 4 processor sites will be employed for the unit.

With these results now in hand it is possible to examine the total cost relationship as the number of processor sites is varied between 1 and n (Figure 5). In this illustrative example n has been set equal to 4 and the optimal number of processor moves is 2. The optimal number of processor moves will depend on

the size and configuration of the thinning unit as well as the relative costs of the two activities. At a minimum, one processor siting location is obviously required, but the optimal number may be quite large in some cases. In this latter situation the computational effort to determine optimal processor siting may be found excessive.

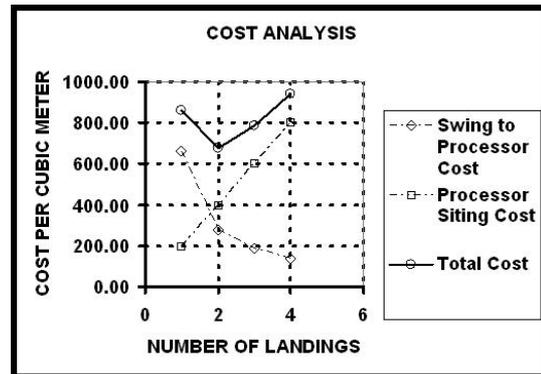


Figure 5. The individual and total aggregated costs for swinging and processing trees for the specified thinning unit. In the absence of actual harvesting cost data arbitrary costs have been assigned to the swing and processing operations.

Some interesting variations of the problem are possible, for example: 1. conditioning the hauling cost on which side is accessed by the truck, 2. restricting logging truck access to only one side, 3. placing the road on a grade and conditioning the swing cost on the adverse or favorable grade, 4. making the swing cost a quadratic function of distance, and, 5. generalizing the turn distribution along the road centerline. This latter change is easily done. The use of a road tangent, the spatial description of the thinning unit, and the specification of a uniform distribution of thinned trees, were only done for clarity of presentation in this paper. It is the distribution of turns along the road centerline that is needed for the optimization process; how that distribution along the centerline is determined is a separate, and rather pedestrian, issue.

Concluding Statement

In order to meet their commitment to Kyoto Protocol targets, the Japanese government is emphasizing carbon sequestration through management activities on Japanese forests. Due to unfavorable economic conditions the active management of their forests has been at a very low level for many years. Many of the forested areas of Japan are in need of thinning operations. In order to encourage thinning the government is now subsidizing these operations.

Most of these forests are on steep ground of difficult access, and substantial costs are incurred during thinning. A systems approach to this issue suggests, among other things, that an effort should be made to identify the most efficient procedures in the use of equipment under different operational conditions. This paper presents some initial thoughts on improving the operational efficiency of cable thinning on steep terrain using pre-existing low-standard access roads with minimal environmental disturbance.

Literature Cited

- Annual Report on Trends of Forest and Forestry
Fiscal Year 2001, 2002,2003, 2004, and 2005.
Japanese and English version. Forestry Agency,
The Ministry of Agriculture, Forestry and
Fisheries of Japan
<http://www.rinya.maff.go.jp/new/hakusyo.html>
- Aruga, Kazuhiro, Toshiaki Tasaka, Takuyuki
Yoshioka, Rin Sakurai, and Hiroshi Kobayashi.
2006. Long-term feasibility of timber and forest
biomass resources at an intermediate and
mountainous area (2)-Examining the optimum
scale of an energy plant. Journal of Japan Forest
Engineering Society. Vol. 21 December 2006
No.3. p185-192
- Fujimori, Takao. 2001. Ecological and Silvicultural
Strategies for Sustainable Forest Management.
Elsevier. Amsterdam. 398 p.
- Garner G.J. 1978. Study of a Contractor Hauling
System.. Forest Engineering Research Institute
of Canada. Technical Report No. TR-24 June.
24p.
- Goto, Makoto. 2002. Thinning production systems
with a swing yarder. Tokushima Pref. Forest
Exp. Stn., Tokushima 9p.
- Greulich, F.E. 2000. Calculation and use of
effective external boundary and related setting
parameters in cable yarding production
estimation. In Proceedings of: Seventh
Symposium on Systems Analysis in Forest
Resources, Traverse City, MI. May 28-31, 1997.
Published as USDA, FS, North Central Research
Station General Technical Report NC-205.
pp364-370.
- Hashira A. 2001. Felling, bucking and delimiting
with chain saws and processors. Kagoshima Pref.
Forest Exp. Stn., Kagoshima 899-5302 4p.
- Iverson, Scott C. 1985. Quantitative methods for
public administration in developing countries.
John Wiley & Sons. New York. New York.
167 p.
- Mitsudome, Y. 2005. Thinning logging system in
the small-scale forest stand. Productivity
comparison between skidder yarding and
backhoe equipped the winch function yarding.
Kyushu J. For., Res. No. 58 p42-45. Kagoshima
Pref. Forest Exp. Stn., Kagoshima 899-5302
- Narita, Tomoki . 2003. A trial of a high
performance processor for improving the
systems productivity and reducing the
production cost -Funyu Experiment Forest. A
graduation Thesis Utsunomiya University. 13p.
- Sawaguchi, Isao 1996. Studies on Forest-Road
Evaluation and Forest-Road Standards in
Mountain Forests(I) Characteristics of
Parameters for Forest-Road Evaluation. Bull.
For. & For. Prod. Res. I Productivity. No. 372.
1996. 110p
- Washington State Department of Natural Resources
(DNR). 1997. Forest Practices Illustrated.
Washington. 64 p.
- Yoshida, Chikashi, Masaki Jinkawa, Koji Kondo,
Yuki Imatomi, Masahiko Nakazawa, Asako
Tsuchiya, and Yozo Yamada. 2006.
Productivity of yarding system for forest
biomass by tower yarder. Journal of Japan Forest
Engineering Society. Vol. 21 December 2006
No.3. p211-217
- Zabinsky, Z.B., F.E. Greulich, and E.S. Miyata.
1992. A nonlinear programming approach to
skidder congestion. ASAE Transaction. St.
Joseph, MN. American Soc. of Agricultural
Engineers. Jan/Feb. Vol. 35 No. 1, pp 335-339.

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TWO SENSOR TECHNOLOGIES FOR IN-FOREST MEASUREMENT AND SORTING OF DOUGLAS-FIR LOGS BASED ON INTERNAL WOOD PROPERTIES

Glen Murphy, Dzhamal Amishev, Francisca Belart

Abstract: Forest products companies in the U.S. face vigorous competition from other wood producers around the world and other industries (steel, aluminum, plastics, composites). To be competitive, forest companies need to control costs, sort and allocate logs to the most appropriate markets, and recover more value at time of harvest. Interest in log sorting based on internal wood properties is increasing.

Wood properties, such as stiffness and density, are now being considered by log buyers. Assessing these properties in-forest and in real-time will be a challenge for log supply managers. The utility of two technologies were examined in Douglas-fir; near infrared (NIR) for measuring wood density, and acoustic velocity for measuring stiffness. Wood samples and measurements were collected from more than 1200 stems located at 23 sites around Oregon.

The research provides insight into how these technologies could be incorporated into the design of mechanized harvesters and processors to enhance bucking and sorting for optimal matching of wood properties to markets.

Key words: Douglas-fir, near infrared, acoustic velocity, wood density, wood stiffness

Introduction

Douglas-fir is a very important commercial timber species in many parts of the world. In the United States 7.3 percent (~ 14.3 million ha) of the country's 196 million ha of non-reserved timberland is presently occupied by Douglas-fir. In Canada the area stocked with Douglas-fir is slightly less than one-third (~ 4.5 million ha) of that in the United States. In Europe this species is highly significant in plantation forests, especially in France and Germany (330,000 and 134,000 ha, respectively). In the southern hemisphere it is also well represented; New Zealand, Chile and Australia being the countries with greatest presence of the species (Hermann and Lavender, 1999).

Timber resources in the Pacific Northwest have gradually shifted from unmanaged old growth to intensively managed young growth. As younger stands are harvested, wood quality is negatively affected in comparison to old growth wood because of the presence of a higher proportion of juvenile wood, which in turn affects properties such as strength and dimensional stability (Gartner 2005).

Douglas-fir timber must compete against timber produced from other tree species and, in some markets, against substitute materials such as steel, aluminum, plastics and concrete. Competition is making the wood market more complex and demanding (Acuna and Murphy, 2006a). For Douglas-fir, significant quality attributes for wood products include density, microfibril angle, fiber length, lignin content, ring width, knot size and distribution, grain angle, and coarseness, color, etc. (Gartner 2005). Optimally matching wood quality to markets can mean cutting logs for very specific end uses and classifying them into several categories or "sorts" to improve product uniformity, productivity and profitability along the seedling to customer supply chain. New sensor systems are being developed to help classify logs based on internal wood properties.

Internal wood properties

Specific gravity is considered to be the single most important physical property of wood. Most mechanical and physical properties of wood are closely correlated to specific gravity and density. These terms have distinct definitions although they refer to the same characteristic (Bowyer et al, 2003).

Wood density is a simple measure of the total amount of solid wood substance in a piece of wood (Jozsa *et al.* 1989).

It is possible to learn more about the nature of a wood sample by determining its specific gravity than by any other single measurement. Perhaps it is for this reason that density was the first wood property to be scientifically investigated (Bowyer *et al.* 2003). It is one of the most important physical characteristics for wood products because it is an excellent predictor of strength, stiffness, hardness and pulp yield (Megraw 1986, Haartveit and Flæte, 2006).

Stiffness is correlated to strength and is the most frequently used indicator of the ability of wood to support loads. Wood stiffness and strength have long been recognized as crucial product variables in both solid wood and pulp and paper processing (Eastin, 2005). Raw timber material is highly variable in these properties, dependent upon site, genetics, silviculture, and location within the tree and stand.

Near Infrared technology (NIR)

Relative to other spectroscopic techniques NIR has a number of advantages that make it an ideal tool for characterizing biomass. These advantages include minimal sample preparation, rapid acquisition times, and non-contact, non-destructive spectral acquisition (Kelley *et al.* 2004a). Some commercial spectrometers are also lightweight, easy to operate and economic.

Some recent applications of NIR on harvesters have been undertaken in agriculture in Europe (Dardenne and Femenias 1999), USA (von Rosenberg *et al.* 2000) and Australia (Taylor *et al.* 2006). Taylor *et al.* (2006) have reported the use of NIR as a protein sensor on grain harvesters. GIS have been attached to the NIR sensor in order to map crop nutrient deficiencies. The output from the NIR protein sensor showed strong spatial patterns that were consistent with what growers expects, observed yield variations and management decisions.

NIR has also been used to measure wood properties affecting a wide range of forest products. Many studies can be found in the literature on the prediction of physical (density, microfibril angle, tracheid length), mechanical (MOR, MOE), and chemical (glucose, lignin and extractives content) wood properties from NIR spectra for a range of softwood and hardwood species (Schimleck *et al.* 2002; Kelley *et al.* 2004b; Schimleck *et al.* 2004; Jones *et al.*

2005). Good correlations, R^2 values ranging from 0.79 to 0.96, have been reported. NIR measurements have been made on green and dry solid wood, green and dry auger shavings, and dry powdered wood. It has also been shown that mechanical properties could be predicted using a reduced spectral range (650 nm-1500 nm) with nearly as good predictive ability (Kelley *et al.* 2004b).

Acoustic technology

It is expensive to process logs or purchase timber stands that have low yield of product with the stiffness and strength levels desired. Nondestructive testing (NDT) and evaluation of wood products for stiffness and strength has been proven and commercialized for years (Wang *et al.*, 2004; Walker and Nakada, 1999). It is performed by measuring the velocity of an acoustic wave, originating from a hammer strike on the end of the specimen and is used as a direct indicator of the dynamic modulus of elasticity (MOE), a measure of the material's stiffness (Carter *et al.*, 2004). Hand-held tools using acoustic technology, such as the Director HM-200TM, for testing logs, and the Director ST-300TM, for testing standing trees, have been developed. Initial research trials indicate high correlation between yield of structural grades of lumber and acoustic velocity of logs processed as measured using acoustic techniques (Carter *et al.*, 2004; Wang *et al.*, 2002; Ross *et al.*, 1997). Segregation of logs based on tools that measure stiffness is already being used by some forest companies to improve the value of lumber recovery (Dickson *et al.*, 2004). Also, there is a very strong linear relationship between acoustic velocity measured in standing trees and that in logs (Wang *et al.*, 2004).

Methods

In summer 2003, 119 second growth Douglas-fir trees of similar age (45-60 years) were felled at 17 forest sites located in the Coast Range and the Cascade Range of northern Oregon. Approximately 7 trees were felled at each site and these were selected to cover the range of diameters present. After felling, disks approximately 100 mm thick were cut at regular intervals up each stem: at 0, 1.4, 5, 10, 20, and 30 above the base of the tree. The disks were labeled, placed in large bags, and stored in a cold room until they were ready to be used for the wood density determination. About 150 disks were used for NIR spectra measurements. Bark was removed from the edge of each disk. Each disk was then cut with a chain saw, of similar pitch to that used on

mechanized harvesters/processors, to provide saw chip samples. Specific gravity was obtained by weighing oven drying wood samples, and then determining their volume using the water displacement method (De Castro *et al.*, 1993). NIR spectra were collected under laboratory conditions from chips in a Petri dish which was slowly rotating on a turntable. Wavelengths ranged between 500 and 2500nm. Partial least squares analysis was used to develop calibration and validation models which related NIR spectra to specific gravity. More detailed information on this work can be found in Acuna and Murphy (2006b).

In summer 2006, six Roseburg Forest Products company (RFP) second growth Douglas-fir stands of similar age class (50 – 60 years) located in the Coastal (stands A, D, E and F) and Cascade (stands B and C) Ranges of southern Oregon, were harvested as part of two studies evaluating acoustic sensor systems and NIR sensor systems for in-forest measurement of wood properties. Two hundred trees from each stand were sampled totaling 1,200 trees and more than 3,500 logs. The logs cut from each stand were trucked to a veneer plant, peeled, dried and then graded with a Metriguard 2800 DME veneer tester. In-forest measurements included, but were not limited to tree length, merchantable length, diameter at breast height (DBH), biggest branch diameter at each 6 m segment of the tree, acoustic velocity measurement of the standing tree (using the ST300 tool), of the whole stem with and without the branches (using the HM200 tool), of each log made out of the stem. Approximately 100 mm thick disks were collected from a sub-sample (40 trees per stand) of the trees. These samples were taken at different heights from the tree, one from the base and one from the top of each log. Close to 800 disks were collected. The disks were labeled, placed in bags, and stored in a cold room. Green densities, as well as sapwood/heartwood ratios, were calculated for each disk for the acoustic study.

Three criteria were used to select the final 326 disks used for NIR study: (1) select approximately 350 disks total spread approximately evenly from each stand, (2) pick the highest and lowest one percentile of disks on the basis of the green density measurements obtained from the acoustics study, the rest could be randomly selected, (3) select only those disks that could be safely cut with a chainsaw while gathering NIR spectra. Bark was removed from the edge of each disk prior to cutting with the chainsaw.

Additional samples were taken from various locations in OSU's Dunn Forest in January 2007 so that comparisons could be made of NIR spectra when bark was left on the disks and when bark was removed prior to collection of chain saw chips. A total of 52 disks were collected for the bark-on/bark-off study. These disks were sampled from trees that had fallen over a few weeks earlier in a December 2006 storm. All 52 samples were cut in half and one half debarked. The number of samples then became 104, one half with bark on and the other with bark off.

NIR spectral measurements were gathered on the green chain saw chips ejected as the disks were being cut with 0.404 in. chainsaw chain (to simulate a harvester head). A DSquared Development Inc. ProSpectra spectrophotometer (with wavelengths ranging between 600 and 1100 nm) and software were used for data recording. Specific gravity was determined for each disk. Multivariate analysis of NIR spectra using partial least square (PLS) procedures will be performed with D-Squared Delight Beta chemometrics software. Spectra-based models will be developed to predict specific gravity.

Results

Near Infrared Sensor Technology

The results from the NIR study of disks gathered from 17 sites in northern Oregon have been presented by Acuna and Murphy (2006b). They indicated that useful calibrations for Douglas-fir specific gravity could be developed using NIR spectroscopy of chain saw chip samples and that green chain saw chip samples could be used as the basis for sorting logs into several density categories (Figures 1 and 2). They noted that further research was required before NIR technology could be cost effectively applied in "real-time" forest harvesting operations. Among other things research was required to determine whether small, faster, lighter and less expensive industrial-grade spectrophotometers (with a reduced spectral range) could be used to measure density from green chain saw chips ejected as each stem is cut into logs by mechanized harvesting equipment. The idea will be to attach a NIR lens into a harvester head and take measurements of chips sliding past the lens while the log is being cut. This would allow spectra to be gathered across the log diameter - from bark to pith to bark.

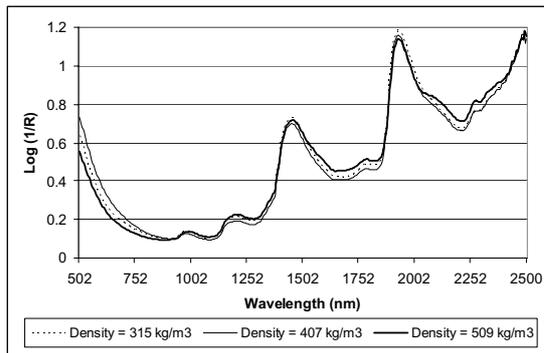


Figure 1. Variation in near infrared (NIR) spectra collected from green chain saw chip samples for different values of basic density.

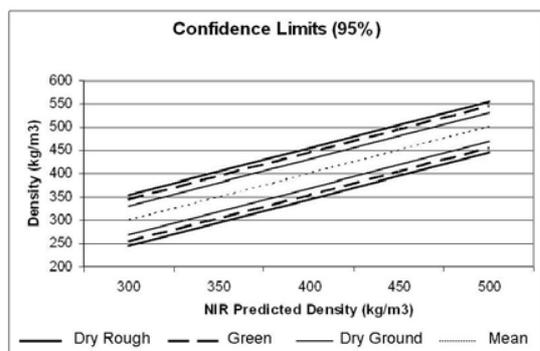


Figure 2. NIR prediction errors for different types of wood chips: dry ground, green rough and dry rough.

Data collection for the NIR study of disks obtained from the six sites in southern Oregon has been completed; spectra have been collected and specific gravities measured. At the time of writing this paper, however, no analyses have been undertaken. We expect the analyses to yield:

- A model that indicates whether NIR spectra in the 600 to 1100 nm range gathered from green chain saw chips can provide “good” correlations ($R^2 > 0.75$) with specific gravity of Douglas-fir logs.
- A model that indicates whether the presence of bark results in reduced ability to predict specific gravity – thereby changing the calibration procedures for the development of NIR based models.
- A model that indicates whether there are differences between stands – thereby changing the calibration procedures for the development of NIR based models.

Acoustic Sensor Technology

Preliminary statistical analyses have been carried out for the acoustic study. Not all stands yielded the same quantity and/or quality of veneer (Fig. 3). While the overall G1/G2 veneer grade recovery percentage for stands A, B, D and E was about the same (around 50%), the other two stands (C and F) were considerably lower (32 and 37%). This indicates that there is a need for preceding stand information in order to make informed management decisions.

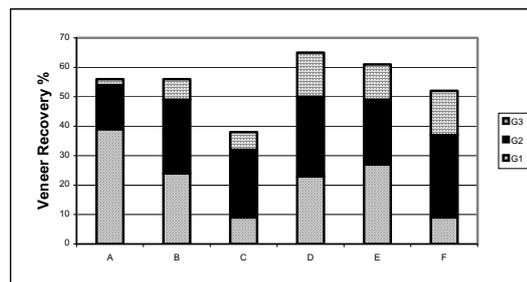


Figure 3. Veneer grades (G1, G2, and G3) recovery for the six trial stands from the OSU stiffness measurement study.

Analyses revealed that there was a quite strong relationship ($r^2 = 0.6$) between G1/G2 veneer recovery and average acoustic velocity for the logs measured in the six stands (Fig. 4). Average log velocities ranged between 11360 and 12930 ft per second (3440 to 3920 m per sec). Further analyses are required to determine possible causes for the “outlier” with medium velocity but low recovery.

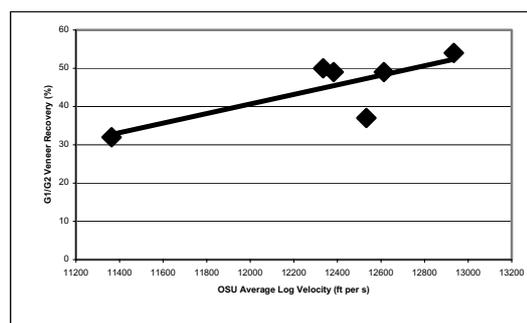


Figure 4. Relationship between G1/G2 veneer recovery and on-site average log acoustic velocity.

Differences in tree size are unlikely to account for the differences between stands. Investigation of the relationship between the acoustic velocity of the felled trees and tree DBH revealed that, overall, there

was no relationship or a weak negative trend (r^2 of 0.09) with increasing tree DBH.

The potential for sorting based on acoustic velocity is great. Individual log velocities ranged from 10350 to 15850 ft per second (3140 to 4800 m per sec).

If acoustic sensors are to be fitted to harvester/processor heads, the head itself should not confound the acoustic measurements. Investigating the relationship between HM200 acoustic velocity measurements on the ground and those in the grapples of a loader/harvester revealed that, overall, there is a very strong relationship with a correlation

coefficient r^2 of 0.86 (Fig. 5). The hold of the grapples, therefore, does not compromise the accuracy of the HM200 acoustic velocity readings despite the fact that, on average, acoustic velocity readings in the grapples of a loader/harvester are slightly higher (with a mean of 12325 ft/s) than those on the ground – 12263 ft/s. These comparisons are based on whole tree length (both with the limbs on and off) as well as individual log measurements. Although the grapples ranged in size and machine type (track mounted and rubber-tired truck mounted grapples, and track mounted Waratah processor head) the data from individual machines were combined for this analysis.

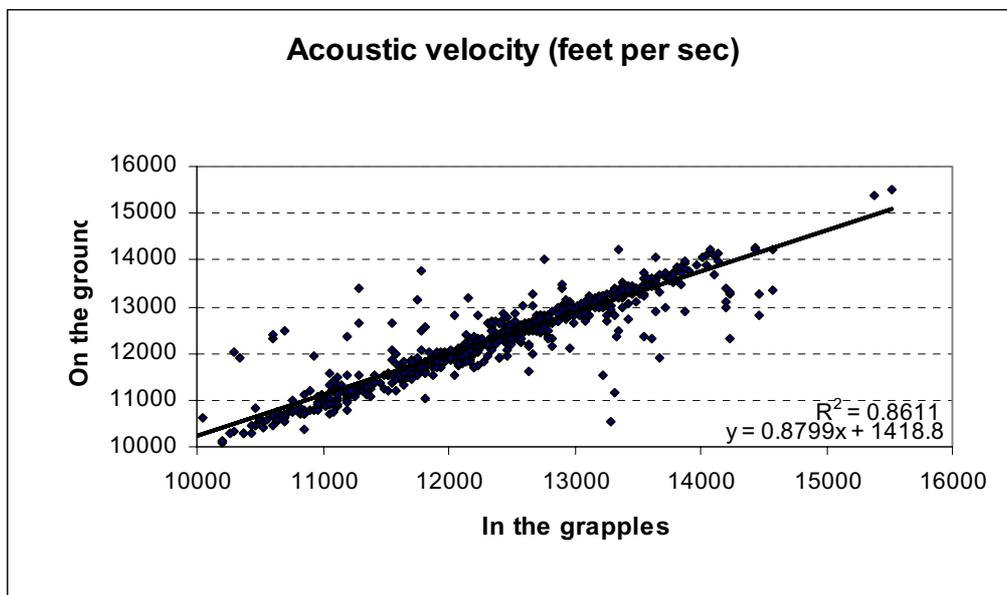


Figure 5. Relationship between acoustic velocity measurements ‘On the ground’ and ‘In the grapples’ of a loader/harvester for the six trial stands from the OSU acoustic stiffness study.

Discussion

It was confirmed under laboratory conditions that oven dry wood density can be predicted from measurements of green wood chips using Near Infrared (NIR) technology (Acuna and Murphy, 2006b) over wavelengths ranging between 500 and 2500 nm. Recently gathered data will reveal whether faster, smaller and lower cost NIR sensor systems can be effectively used in field conditions on a harvester/processor working in Douglas-fir forests. NIR sensors are already being used in agricultural settings to measure raw material properties of interest.

Segregation of logs based on acoustic tools that measure stiffness is already being used by some

forest companies to improve the value of lumber recovery (Dickson et al., 2004). Preliminary results from our acoustics trials show that sorting stands and sorting logs are likely to lead to improvements in recovery of higher value Douglas-fir veneer grades.

These two technologies (NIR and acoustics) are promising tools in the continuing attempts to improve value recovery from the forest stands and increase the competitive ability of the forest products industry. Our initial studies strive to address an array of questions related to the technical feasibility of using these sensor technologies in forest environments. Much more work, however, needs to be undertaken to examine the costs, benefits and economic viability of these technologies.

Literature Cited

- Acuna, M. A. and G. E. Murphy. 2006a. Geospatial and within tree variation of wood density and spiral grain in Douglas-fir. *Forest Products Journal* 56(4): 81-85.
- Acuna, M. A. and G. E. Murphy. 2006b. Use of near infrared spectroscopy and multivariate analysis to predict wood density of Douglas-fir from chain saw chips. *Forest Products Journal* 56(11/12): 67-72.
- Bowyer, J. L., Shmulsky, R. and J. G. Haygreen. 2003. *Forest Products and Wood Science: An Introduction*. Fourth edition. Iowa State University Press. 554 p.
- Carter, P., Briggs, D., Ross, R. J. and X. Wang. 2004. Acoustic Testing to Enhance Western Forest Values and Meet Customer Wood Quality Needs. In Harrington, C.H. and Schoenholtz, S., (eds.) *Productivity of Western Forests: A Forest Products Focus*. USDA Forest Service PNW Res. Sta. Gen. Tech. Rep. PNW-GTR-642. pp. 121-129.
- Dardenne, P., and N. Féménias. 1999. Diode array near infrared instrument to analyze fresh forages on a harvest machine. p. 121–124. In A. Davies and R. Giangiacomo (ed.) *Proc. of the 9th Int. Conf. on NIRS*. Verona, Italy. 13–18 Sept. 2003. NIR Publ., Chichester, UK.
- Dickson, R. L., Matheson, A. C., Joe, B., Ilic, J. and J. V. Owen. 2004. Acoustic segregation of *Pinus radiata* logs for sawmilling. *New Zealand Journal of Forestry Science*, Vol. 34 (2): 175-189.
- De Castro F., Williamson B. and R. Moraes de Jesus. 1993. Radial Variation in the Wood Specific Gravity of *Joannesia princeps*: The Roles of Age and Diameter. *Biotropica*, Vol. 25(2): 176-182.
- Eastin, I. 2005. Does lumber quality really matter to builders? In: Harrington, C.A., Schoenholtz, S.H., eds. *Productivity of Western Forests: A forest products focus*. USDA Forest Service PNW Res. Sta. Gen. Tech. Rep. PNW-GTR-642. pp. 131-139.
- Gartner, B. L. 2005. Assessing wood characteristics and wood quality in intensively managed plantations. *J. Forestry* 100(2):75-77.
- Haartveit, E. Y. and Flæte, P. O. 2006. Rapid prediction of basic wood properties by near infrared spectroscopy. *New Zealand Journal of Forestry Science* 36(2/3): 393-407.
- Hermann, R. K. and D. P. Lavender. 1999. Douglas-fir planted forests. *New Forests* 17: 53-70.
- Jones, P. D., Schimleck, L. R., Peter, G. F., Daniels, R. F. and A. Clark III. 2005. Nondestructive estimation of *Pinus taeda* L. wood properties for samples from a wide range of sites in Georgia. *Can. J. For. Res.* 35:85-92.
- Jozsa, L. A., Richards, J. and S. G. Johnson. 1989. Relative density. In *Second growth Douglas-fir: its management and conversion for value: a report of the Douglas-fir task force*. Edited by R.M. Kellogg. Forintek Canada Corp., Vancouver, B.C. pp. 5–22.
- Kelley, S. S., Rials, T. G., Snell, R., Groom, L. H. and A. Sluiter. 2004a. Use of near infrared spectroscopy to measure the chemical and mechanical properties of solid wood. *Wood Science Technology* Vol. 38:257-276.
- Kelley, S. S.; Rials, T. G.; Groom, L. H. and C. L. So. 2004b. Use of near infrared spectroscopy to predict the mechanical properties of six softwoods. *Holzforschung* 58(3):252-260.
- Megraw, R. A. 1986. Douglas-fir wood properties. In: *Douglas-fir stand management for the future*. C. Oliver, D. Hanley, and J. Johnson (eds.). *Inst. of Forest Res. Contrib. 55*. College of Forest Resources, University of Washington, Seattle, WA., pp. 81-96.
- Ross, R. J., McDonald, K. A., Green, D. W. and K.C. Schad. 1997. Relationship between log and lumber modulus of elasticity. *Forest Products Journal*, Vol. 47 (2): 89-92.
- Schimleck, L. R., Evans, R., Ilic, J. and A. C. Matheson. 2002. Estimation of wood stiffness of increment cores by near-infrared spectroscopy. *Can. J. For. Res.* 32(1):129-135.
- Schimleck, L. R., Jones, P. D.; Peter, G. F., Daniels, R. F. and A. Clark III. 2004. Nondestructive estimation of tracheid length from sections of radial wood strips by near infrared spectroscopy. *Holzforschung* 58:375-381.

- Taylor, J., Whelan, B., Thylén, L., Gilbertsson, M. and J. Hassall. 2005. Monitoring wheat protein content On-Harvester: Australian experiences. In Proceedings of the 5th European Conference on Precision Agriculture. Ed. J.V. Stafford, Wageningen Academic Publishers.
- von Rosenberg Jr., C. W., Abbate, A., Drake, J., and Mayes, D. 2000. A rugged near-infrared spectrometer for real-time measurement of grains during harvest. Spectroscopy 15(6):34-38.
- Walker, J. C. F. and R. Nakada. 1999. Understanding corewood in some softwoods: a selective review on stiffness and acoustics. International Forestry Review, Vol. 1(4): 251-259, 284-285.
- Wang, X., Ross, R. J. and J. A. Mattson. 2002. Nondestructive evaluation techniques for assessing modulus of elasticity and stiffness of small-diameter logs. Forest Products Journal, Vol. 52 (2): 79-85.
- Wang, X., Ross, R. J. and P. Carter. 2004. Assessment of standing tree quality – from baseline research to field equipment. In: Forest Products Society 2004 Annual Meeting – Technical Forum. Grand Rapids, Michigan, USA.

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A DESIGN CRITERION FOR GUYED BACKSPARS

C. Kevin Lyons

Abstract: Guyed backspars used in cable logging are complicated structural problems that include components with different strain rates (guylines, tree bole, tree roots) and that include geometrically nonlinear mechanics (P-delta effect). This paper first considers a rigid spar mounted on an elastic base and through this simplified model proposes a design criterion for a guyed backspar which estimates a maximum allowable rigging point displacement. The maximum allowable displacement is given as a function of dbh, rigging height, base stiffness, and the allowable stress for the wood. Preliminary analysis using a finite element model of a guyed backspar where the spar is a tapered elastic column mounted on a flexible base indicates the proposed design criterion may have merit; however, further analysis is required.

Key words: backspar, mechanics, design criterion

Introduction

Guyed backspars used in cable logging are complicated structural problems that include components with different strain rates (guylines, tree bole, tree roots) and that include geometrically nonlinear mechanics (P-delta effect). The guylines consist of cables with significant weight which results in the stiffness of the guylines being a function of both the sag in the cable and stretch of the cable. The guyline anchor locations depend on the availability of suitable stumps, which results in some guylines being longer than others and the stiffness of guylines is in part a function of the length.

Pyles (1987) noted that the base of a tree is flexible and can be modeled as a rotational spring. Pyles and Lyons (2001) modeled backspars without guylines with a finite element model (FEM) and used the allowable normal stress on a transverse cross section as a design limit. Pyles and Lyons (2001) noted since smaller trees are more flexible they displace farther before the allowable stress is produced somewhere in the bole. Saravi and Lyons (2004) used a solid element FEM to model guyed backspars. Saravi and Lyons (2004) found when the allowable stress was reached in the bole of the tree that guyed backspars could be dominated by either a bending load due to displacement of the top and deformation of the bole, or an axial load. When the guyed backspars were dominated by an axial load the allowable stress was reached first near the rigging point on the tree, and when bending dominated the allowable stress was reached first further down the tree.

Given the complicated interaction between the guyline anchor location, guyline pretension, stiffness of the tree base, and stiffness of the tree bole it is difficult to develop design guidance for guyed backspars that can be applied in the field. The results from Saravi and Lyons (2004) suggest under some conditions the backspar supports a portion of the horizontal load while for other conditions the horizontal load is supported by the guylines. When the backspar is supporting a portion of the horizontal load this load will cause a bending moment in the same direction as the vertical component acting over the displaced distance. The distance the spar displaces is in part a function of the stiffness of the guylines and can be reduced if the guyline pretension is increased. Given the effect of the vertical load acting over the displaced distance it is possible the restraining horizontal force of the guylines could exceed the applied horizontal force, producing a resultant horizontal load acting opposite to the direction of the applied load. Thus, a critical condition may exist where the resultant horizontal load switches from the direction of the applied load to the opposite direction. The objective of this paper is to propose a design criterion for a guyed backspar where the displacement of the rigging point on the backspar is limited to the distance where the resultant horizontal force acting on the rigging point is zero. This paper will first consider a rigid spar mounted on a flexible base and the results from this analysis will be compared to preliminary FEM results for an elastic spar.

Rigid Spar Problem

Though simplified models ignore components of a structural problem they can be used to focus the research in more complicated models. This section will consider a simplified model of a guyed back spar, where the backspar is considered a weightless cylinder with radius r supported at the base by a linear rotational spring (M_b) and subject to a constant load (T) (Figure 1). In addition to T , the resultant load from the guylines (J) will be applied at to the top of the spar, and this is assumed to act in the same plane as T .

$$\text{Let } M_b = b\theta \quad (2.1)$$

Here b is a spring constant. Since the spar is rigid δ is given by $\delta = h \sin(\theta)$ (2.2)

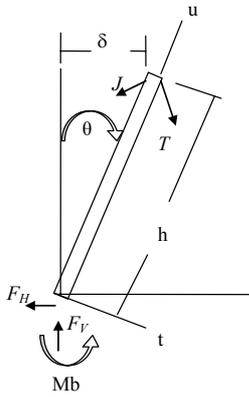


Figure 1. Rigid spar problem

Let γ and ϕ be the angles between the vertical and T and J respectively. The equilibrium equations (sum of forces in the t and u directions and the sum of moments about the base) for the problem defined by Figure 1 are

$$\begin{aligned} T \sin(\theta + \gamma) - J \sin(\phi - \theta) - F_H \cos(\theta) - F_V \sin(\theta) &= 0 \\ F_V \cos(\theta) - T \cos(\theta + \gamma) - J \cos(\phi - \theta) - F_H \sin(\theta) &= 0 \\ M_b + hJ \sin(\phi - \theta) - hT \sin(\theta + \gamma) &= 0 \end{aligned} \quad (2.3)$$

Substitute (2.1) into the third equation of (2.3), and use the trigonometric identities for the sum of two angles to rewrite this.

$$\begin{aligned} b\theta &= hT(\sin(\theta) \cos(\gamma) + \cos(\theta) \sin(\lambda)) \\ &\quad - hJ(\sin(\phi) \cos(\theta) - \cos(\phi) \sin(\theta)) \end{aligned} \quad (2.4)$$

Define the following components of J and T .

$$\begin{aligned} J_H &= J \sin(\phi), J_V = J \cos(\phi), T_H \\ &= T \sin(\gamma), T_V = T \cos(\gamma) \end{aligned} \quad (2.5)$$

Substitute (2.5) into (2.4)

$$\frac{b\theta}{h} = \sin(\theta)T_V + \cos(\theta)T_H - \cos(\theta)J_H + \sin(\theta)J_V \quad (2.6)$$

The magnitude of the horizontal component of the resultant load applied to the top of the backspar is given by $(T_H - J_H)$, solving for this in (2.6) results in the following.

$$(T_H - J_H) = \frac{\frac{b\theta}{h} - \sin(\theta)(T_V + J_V)}{\cos(\theta)} \quad (2.7)$$

Given the right hand side of (2.7) it is apparent that the resultant horizontal load acting on the top of the spar can be either positive or negative, that is, when considering Figure 1 it can act either in the direction of the applied load T or opposite to it. For small θ in radians let $\sin(\theta) = \theta = \delta / h$ and $\cos(\theta) = 1$ in (2.7).

$$(T_H - J_H) = \frac{\delta(b - h(T_V + J_V))}{h^2} \quad (2.8)$$

Three cases result from (2.8) if T is allowed to vary arbitrarily and δ is not equal to zero (Table 1); however, the goal of this paper is to develop a design criterion that places a limit on T . When the horizontal component of the resultant force applied to the top of the spar is in the direction of T the moment about the base created by the horizontal component has the same sign as that created by the vertical component. Thus, it is desirable to have the horizontal component of the resultant force applied to the top of the spar acting in the direction opposite to T . In the following section Case 2 from Table 1 will be considered when T is limited by a maximum allowable stress as suggested by Pyles and Lyons (2001).

Table 1. Cases considering the resultant horizontal force applied to the top of the spar.

Case #	Case	b
1	$T_H - J_H < 0$	$b < h(T_V + J_V)$
2	$T_H - J_H = 0$	$b = h(T_V + J_V)$
3	$T_H - J_H > 0$	$b > h(T_V + J_V)$

Allowable Stress Criterion for Rigid Spar

Pyles and Lyons (2001) suggested the allowable load applied to an unguayed backspar could be defined as the load that causes some portion of the backspar to experience the allowable compressive stress for the material (σ_a). Saravi and Lyons (2004) applied this criterion to guyed backspars. In the problem considered in Figure 1 the maximum stress in the backspar will occur on the distal fiber at the base and the compressive stress will be a function of the axial load and moment. Let $F_u = F_H \cos(\theta) - F_V \sin(\theta)$, then given the first of (2.3) σ_a is defined as

$$\sigma_a = \frac{T \cos(\theta + \gamma) - J \cos(\phi - \theta)}{A} + \frac{rM_b}{I} \quad (3.1)$$

Here A is the area of the cross section and I is the moment of inertia. Substitute (2.1) into (3.1).

$$\sigma_a = \frac{T \cos(\theta + \gamma) - J \cos(\phi - \theta)}{A} + \frac{rb\theta}{I} \quad (3.2)$$

Considering Case 2 from Table 1, where

$$T_H - J_H = 0 \text{ and } J_V = \frac{b}{h} - T_V, \text{ then (3.2) can be}$$

written as follows when considering θ to be small.

$$\sigma_a = \frac{2T_c (\cos(\gamma) - \frac{\delta_c}{h} \sin(\gamma)) - \frac{b}{h} + \frac{rb\delta_c}{Ih}}{A} \quad (3.3)$$

Here the subscript c indicates these are the top displacement and T corresponding to the backspar scenario that satisfies Case 2.

Isolate T_c from (3.3).

$$T_c = \frac{\pi r^2 \sigma_a - \frac{4b\delta_c}{rh} + \frac{b}{h}}{2(\cos(\gamma) - \frac{\delta_c}{h} \sin(\gamma))} \quad (3.4)$$

All the variables on the right hand side of (3.4) except for δ_c are fixed for a particular problem. Since T is applied by a cable and a cable is assumed to only support tension, T can not be negative. For $0 \leq \gamma < \pi/4$ the denominator of (3.4) will always be positive; therefore, the numerator of (3.4) provides a limiting condition above which Case 2 in Table 1 can not exist.

$$\delta_c \leq \frac{rh}{4b} \left(\pi r^2 \sigma_a + \frac{b}{h} \right) \quad (3.5)$$

As previously stated it is preferable to have the horizontal component of the resultant force acting in the direction opposite to T , which is Case 1 from Table 1. Taking the equality in (3.5) a criterion for the maximum allowable displacement is

$$\delta_c = \frac{rh}{4b} \left(\pi r^2 \sigma_a + \frac{b}{h} \right) \quad (3.6)$$

Table 2 provides typical values for the variables found in (3.6). Substituting the values from Table 2 into (3.6) the limiting displacement for this particular case is found to be $\delta_c = 0.127m$. It is interesting to note that this result is independent of γ .

Table 2. Parameter magnitudes for a typical backspar

Dimensional variable	Values considered
σ_a	1.103E07
h	15m
$r = dbh/200$	0.325m
$b = 23.665(ID_{1.5})^{3.65}$ (Pyles, 1987)	98.0E06Nm

Comments on an Elastic Spar

The results from Section 3 were for a rigid spar mounted on a flexible base. For an elastic spar displacement is also a function of bending of the spar. When the spar is allowed to bend the problem is complicated by the P-delta effect where the axial load produces a moment. Effectively for a given b the elastic spar is more flexible than the rigid spar and this will affect δ_c . Consider (3.6), reducing the stiffness of the spar (i.e. reducing b) while holding r fixed increases δ_c .

In this section a FEM developed by Saravi and Lyons (2004) will be used to consider an elastic spar

mounted on a flexible base that is restrained by guylines with significant self weight. Four backspar scenarios will be considered 1) $dbh = 65\text{cm}$ with low guyline pretension, 2) $dbh = 35\text{cm}$ with low guyline pretension, 3) $dbh = 65\text{cm}$ with high guyline pretension, and 4) $dbh = 35\text{cm}$ with high guyline pretension. The displacement of the neutral axis for the four backspar cases (Figure 2) indicates Cases 2, 3, and 4 have noticeable bending due to the axial load, and Table 3 indicates for these cases that the horizontal component of the resultant load applied to the top of the spar is acting opposite to the direction of T .

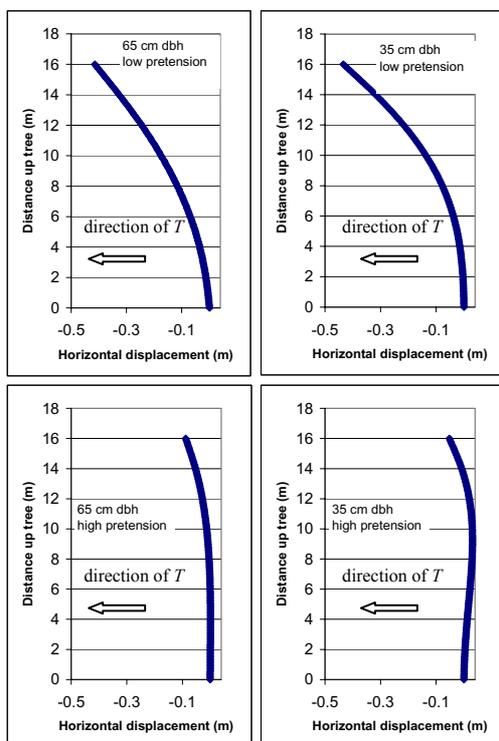


Figure 2. Neutral axis displacement for four backspar cases

Table 3. FEM results for backspar cases

	Case 1	Case 2	Case 3	Case 4
Tension (N) that results in σ_a	103,399	49,828	248,444	74,117
Top displacement (m)	0.41	0.43	0.09	0.05
Direction of horizontal load	same as T	opposite T	opposite T	opposite T

In the rigging cases considered in this section reducing the top displacement by increasing the guyline pretension increases the magnitude of T that a backspar can support when limited by σ_a .

However, the results of Section 2 suggest there could be an abrupt decrease in the allowable tension when the horizontal component of the resultant force applied to the top of the spar begins to act in the direction of T . Further analysis with the FEM will be required to determine if this phenomenon exists for the elastic spar.

In Section 3 the displacement when the horizontal component of the resultant force equals zero was calculated for a rigid spar mounted on a flexible base with $dbh = 65\text{cm}$, and this resulted in $\delta_c = 0.127\text{m}$.

Considering Figure 2 this estimate of δ_c seems low, which is consistent with the observation that decreasing the stiffness of the spar will increase δ_c because considering the backspar to be elastic reduces the stiffness of the spar for a given diameter.

Literature Cited

- Pyles Marvin R., 1987, *Structural properties of second-growth Douglas-fir logging spars*, Transactions of the ASAE, Vol. 30, No.1, pp. 65-69.
- Pyles Marvin R., Lyons C. Kevin, 2001, *Analysis of unguyed spar-trees*, International Journal of Forest Engineering, Vol. 12, No. 2, pp. 11-17.
- Saravi Albert, Lyons C. Kevin, 2004, *Finite element modeling of guyed backspars in cable logging*, Canadian Journal of Forest Research, Vol. 34, pp. 817-828.

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LIDAR-DERIVED TREE PARAMETERS FOR OPTIMAL CABLE LOGGING SYSTEM DESIGN

Akira Kato, Peter Schiess

Abstract: Tree location and parameters are considered fundamental information in designing logging operations. A small footprint Light Detection and Ranging (LIDAR) can provide microscale information for individual tree parameters because of high point density. Conventionally, tree parameters given by LIDAR data are estimated at the scale of inventory plots or circular sampling plots. The findings are then averaged to the whole units. However, LIDAR data can provide more microscale tree parameters such as individual tree height and tree crown diameter. In this research, we introduce an efficient method to obtain individual tree tops from a group of LIDAR points in a large area and identify tree location, which yields important information for setting skyline cableways. To achieve this, tree tops are found by the local maxima of stationary points on Digital Surface Models (DSMs). The tree tops derived from LIDAR are verified with stem locations collected in the field and displayed with Digital Terrain Models (DTMs) to show the location of trees sufficiently large to be used for skyline operation.

Key words: LIDAR, Skyline operation, Stationary Points, Tree tops.

Introduction

Airborne laser altimetry can produce maps of amazing detail and accuracy. For that reason forest engineers are beginning to use it for road location and skyline operation planning since topographic detail is likely of better quality than field-surveyed profiles (Krogstad and Schiess 2004, Schiess and Krogstad 2003). Previous research efforts have concentrated on utilizing LIDAR data for the purpose of deriving stand structure information. LIDAR technology has the promise of eventually supplanting terrestrial-based stand measurements such as forest inventory plots. Andersen and co-authors (2001) showed the promise of using LIDAR-derived stand parameters that can be used for silvicultural modeling and stand data prediction. However, a number of substantial issues still remain before LIDAR-derived stand data will replace terrestrially-derived information for that purpose.

Nevertheless, LIDAR-derived stand data do show promise in the context of operational planning. Cable harvesting and in particular cable thinning operations require tree dimensions of a certain minimum diameter. Required trees for intermediate supports and tree or stump diameter for anchoring skyline cables are a function of design payloads, terrain profile, corridor length and cable diameters. The forest engineer usually can vary or adjust most of the above design elements except for the dimensions of trees found on site. The typical design process starts

with an assessment of tree dimensions which are used to arrive at the design payload and also identifies the tree size diameters across the planning unit. The latter is an important design parameter in that it impacts design payloads depending on finding the appropriately sized stump or tail tree, or the availability of the necessary intermediate support trees. Typically this information has been derived statistically. Based on stand data derived from Forest Resources Inventory System (FRIS) plots, one could estimate the average spacing of a certain tree diameter based on the number of trees above a certain diameter class. A typical process that may be used by forest engineers is outlined below to demonstrate the approach:

“Using the Landscape Management software (LMS) in conjunction with the Forest Resource Inventory System (FRIS) data available in GIS, the number of trees per acre over 18 and 20 inches DBH was determined. These diameters were chosen based on cable yarders using 7/8 inch cable typical for thinning, which requires 15 inch DBH tailholds when rigged at 30 feet. For yarders in regeneration harvests, using 1 ¼ inch mainlines, trees over 18 inch DBH were chosen for tying off at a height of 30 feet. Due to lateral yarding capabilities, we assumed corridor spacing to be 100-150 feet. This would require as few as three trees per acre with 150 foot spacing.” (Schiess and Mouton, 2005)

This approach, although statistically correct, is not spatially explicit. Harvest setting design, however, requires spatially explicit data, including tree locations with height, diameter and type of species. The presence or absence of trees with the prerequisite parameters such as sufficiently large diameters has a significant impact on whether a harvest operation is environmentally and economically successful or not.

Previous LIDAR research has shown that LIDAR-derived stand parameters can be used for silvicultural modeling. One well-known modeling program is the Landscape Management System (LMS) (McCarter, 2001). LMS can visualize stand location and simulate the growth of stands from inventory data in the context of operational planning. Another visualization tool is the FUSION program (McGaughey et al. 2003) that enables the three-dimensional display of LIDAR points. These visualization tools are very powerful, but require significant pre-processing of data to conform to the program's input requirements.

In previous research efforts, LIDAR data was analyzed with the objective of deriving the height and coordinates of tree location. Height information could be used to derive tree diameters from region-specific algorithms. In order to obtain LIDAR points describing crown characteristics of a single tree, segmentation techniques have been utilized, including the K-means method (Morsdorf et al. 2004, Riaño et al. 2003, 2004) and watershed segmentation (Chen et al. 2006, Sollie 2003). A marker-controlled method was especially effective in improving the absolute accuracy of the result (Chen et al. 2006). The approach used by Andersen and co-authors was applied to a LIDAR data set to evaluate its operational application in a harvest planning project (Figure 1), (Schiess, 2005). A top-hat transformation of morphological operation (Sollie, 2002) on a binary image was used to identify tree tops. A circular filter was applied on the binary image to remove the noise on the binary image, which is given by the height of Digital Surface Models (DSMs) bigger than a certain threshold. They concluded that the size of the circular filter depends on the vertical structure of stands. Those efforts were not successful, since LIDAR-derived density estimates were not well correlated with data derived with the LMS model. The noted discrepancy could have been caused by the low LIDAR point density (3.5 pulses per square meter) and/or the necessary user input in setting the appropriate sizes and height threshold. Therefore, we took another approach to find tree tops using convexity of DSMs and higher point density data (6.5 pulses per square meter).

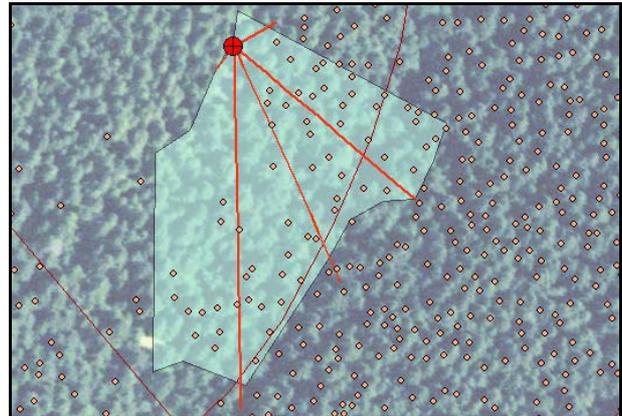


Figure 1: Harvest setting with many options for tail-hold trees derived from LIDAR data. Orange dots represent trees >15 in. DBH, red lines display yarding corridors. The harvest setting is shown as a lighter blue shading. Corridor locations and subsequent profile analysis are dictated by tree locations with appropriate diameters (Schiess and Mouton, 2005).

Improvements in the technology have facilitated more accurate methods for deriving stand structure statistics. Higher point densities for LIDAR coverage are now becoming available, with ground point densities up to 20 per square meter with current technology (Ackerman, 1999). Different approaches to processing algorithms have emerged as well, suggesting that the issues outlined above should be revisited. Therefore, we propose a new approach to obtain tree top location by using convexity of Digital Surface Models (DSMs). Such an approach allows algorithm-derived identification of tree tops rather than a user-dependent approach as reviewed above.

The objectives of our research are to:

1. Develop an efficient algorithm, independent of user input, to identify discrete tree tops, their corresponding ground location coordinates, and estimate tree height using LIDAR point data.
2. Use standard, off-the-shelf graphical software, (e.g. ArcGIS, ESRI, Inc.) to manipulate and display the results.

Data

Research Site

The research site is in the Mission Creek area, located in the Wenatchee National Forest in eastern Washington State. The main species are Douglas-fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*). Summers are dry and hot, and the natural

disturbance regime is characterized by frequent, low-intensity forest fires (Agee 1993).

Field Data

A total of 12 study units were established at the research site for the purpose of studies on fire and fire surrogates, including treatment plots of control, burn only, thin/burn, and thin only, with three replications per treatment (Agee et. al. 2001). Each plot measured 50 m x 50 m square. The stem locations of all the trees within the plots were measured using a differential GPS receiver (Trimble XR Pro, Santa Clara, California) and an Impulse laser rangefinder with a Mapstar compass (Lasertech, Inc., Englewood, Colorado) during the summers of 2003 and 2004 (Figure 2).

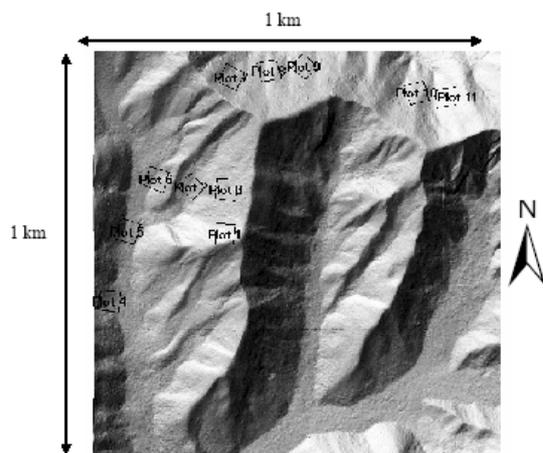


Figure 2. Plot location within a larger, 100 ha large area for which LIDAR point data exist. Stem locations are mapped for each plot.

Tree species and crown position (dominant, co-dominant, intermediate, and suppressed) were recorded for all trees > 5 cm diameter in the plots. The number of trees for each crown category (dominant – suppressed) is shown in Table 1.

Table 1. Number of trees by category for the various plots. Each tree was mapped with GPS and laser units to establish their respective coordinates.

Plot #	Treatment	Dominant	Co-Dominant	Intermediate	Suppressed	Total
Plot 1	*B	17	54	33	40	144
Plot 2	*B	11	27	26	26	90
Plot 3	*B	12	21	14	16	63
Plot 4	*B	13	22	34	36	105
Plot 5	*B	14	40	26	40	120
Plot 6	*B	14	52	38	49	153
Plot 7	*TB	17	12	15	53	97
Plot 8	*TB	13	22	30	67	132
Plot 9	*TB	11	30	22	53	116
Plot 10	*TB	15	23	36	55	129
Plot 11	*TB	9	23	43	70	145
Average		13	29	28	45	117

B: burned treatment plot, TB: thinned and treatment plot.

LIDAR Data

Small footprint LIDAR data were acquired by the Optec Airborne Laser Terrain Mapper (ALTM) 30/70 LIDAR system. The coordinates of the LIDAR points were projected in Universal Transverse Mercator (UTM) Zone 10 coordinate system in the NAD83 datum. The pulse rate of the flown LIDAR dataset was 70 kHz, with a mean density of 6.5 points m⁻². Table 2 shows the system settings of this sensor. The vendor-selected last returns were based on a proprietary filtering algorithm. The last returns were used to create a Digital Terrain Models (DTMs). The values on DTMs were subtracted from the ground elevation of all LIDAR points to create a Digital Canopy Height Model (DCHM) and remove any slope effect. The vendor provided text files that included all LIDAR returns. We then stored all LIDAR points in a binary file to increase processing speed.

Table 2. LIDAR sensor system settings

Date of survey	August 30th 2004
Laser sensor	Optec's ALTM 30/70
Flying height	1,000 m
Impulse frequency	70,000 Hz
Scan angle from nadir	25 degrees
Laser pulse density	6.5 pulses m ⁻²
Approximate Z accuracy	27 cm

Method

The human mind can form a mental image of a tree from un-organized, independent LIDAR points (Figure 3) by instinctively assigning points to particular trees. The methodology outlined below is designed to imitate this interpretive process.

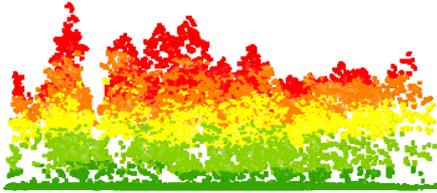


Figure 3. Raw LIDAR point distribution for a 50m x 50m plot. Colors represent elevations. The observer can identify ground level, tree shapes and tree tops. Except for the extremes (maximum heights) tree top identification can become difficult, even for the human observer.

Research discussed earlier (Andersen et al. 2001, Chen et al. 2006, Morsdorf et al. 2004, Riaño et al. 2003, 2004) showed some success with algorithms that identify individual trees and their parameters, but these approaches usually require specialized software. In our approach, we convert the discrete points to DSMs, which are created from local height maxima of LIDAR points within 1m by 1m cells. To smooth the surface, a 3 x 3 Gaussian filter (Hyypya et al. 2001) is convolved over the DCHM layer. The 3 x 3 Gaussian filter is given by:

1/16	1/8	1/16
1/8	1/4	1/8
1/16	1/8	1/16

Tree top location is defined by the local maximum of stationary points as defined by a second order Taylor's approximation and gradient of DSMs (Bloomenthal, 1997). A value of one is assigned to cells where a local maximum of stationary points exists, and a zero value is assigned to all others. In this way, all convex shapes of the DSM are identified.

Even though all convexity on the smoothed DCHM are identified successfully, small convexities in the DCHM may be misidentified as tree tops. Moreover, holes in the connected region of the binary image may also remain because of the complexity of the DCHM. To remove these small isolated pixels, closing and opening of the morphological operation

described by Sollie (2002) are conducted on the binary image.

Each region is labeled by connected component analysis (Shapiro, 2001) from the binary image after the morphological operation. From the labeled regions, LIDAR points are extracted and the maximum height among the points is recorded as the tree height for that individual tree.

Tree Top Identification

The local maxima of stationary points on DSMs is identified by using a second order Taylor's approximation and gradient of DSMs (Bloomenthal, 1997).

In the 1-dimensional case, the local maximum of function $f(x)$ is obtained by the following condition:

$$f'(x) = 0 \text{ and } f''(x) < 0 \quad (1)$$

In the 2-dimensional case, however, the bivariate function $f(x, y) = z$ has three types of stationary points: local maximum, local minimum, and saddle points. Stationary points are distinguished by second order Taylor's approximation and gradient of function f . The second order Taylor's approximation is:

$$\tilde{f}(x, y) = f(x_0, y_0) + (1/2)(x - x_0)^2 f_{xx} + (x - x_0)(y - y_0) f_{xy} + (1/2)(y - y_0)^2 f_{yy} \quad (2)$$

where (x, y) is an arbitrary point on the surface and (x_0, y_0) is a fixed point on a horizontal 2-dimensional plane sliced through the LIDAR derived surface.

The parameters in equation (2) are converted to polar coordinates:

$$(x - x_0) = r \sin \theta \quad (3)$$

$$(y - y_0) = r \cos \theta \quad (4)$$

where r is constant and θ is angle of polar coordinate.

Using equations (3) and (4), equation (2) is recalculated to obtain $\tan \theta$ as described below:

$$\tan \theta = \frac{-f_{xy} \pm \sqrt{f_{xy}^2 - f_{xx}f_{yy}}}{f_{xx}} \quad (5)$$

Therefore, local maxima are distinguished by the condition below:

$$f_{xy}^2 - f_{xx}f_{yy} < 0; f_{xx}, f_{yy} < 0 \quad (6)$$

The tree top derived from LIDAR points exists within the region of local maxima of stationary points. The maximum height of LIDAR points is set as the height of a tree top within the region.

Results

Digital Canopy Height Model (DCHM)

The above algorithms created the images of tree shapes as shown in Figure 4. The area processed covered about 100 hectares. The analytically-derived tree top locations (x/y coordinates) were then compared with the field-verified stem locations.

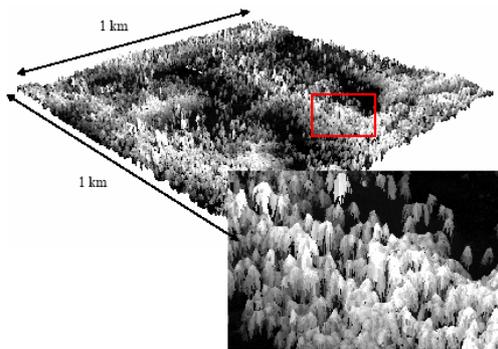


Figure 4. Digital Canopy Height Model (DCHM) covering a 100 ha area. The red box outlines a close-up view. The viewer can identify tree shapes and tree tops formed from the applied solid-surface DCHM.

Tree Top Identification

The tree tops were then identified from the DCHM. Tree heights were measured from the height maxima of LIDAR points extracted within the region of local maxima of stationary points of the DCHM (Figure 5).

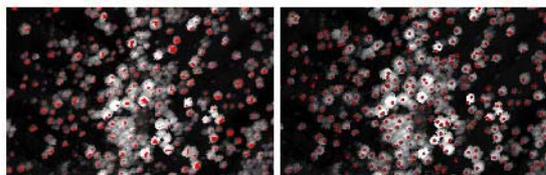


Figure 5. The region of local maxima of stationary points of the DCHM are shown as red clusters (left). The location of the maximum height of LIDAR points

are identified based on the region (clusters) and displayed on the right as red points. The elevation values from the DCHM are shown with in gray-scale, with black pixels implying ground level.

We can now extract the x and y coordinates for the red dots in Figure 5 and the z coordinates, or tree heights, is extracted from the DCHM. Standard GIS query methods can now be used to stratify tree locations by height (Figure 6). If desired, tree diameter can now be derived from appropriate, region-specific height-diameter equations (Husch et al. 2003). We have not measured actual tree heights in this research area. LIDAR-derived tree height is, however, highly correlated with field-measured tree height (Morsdorf et al. 2004).

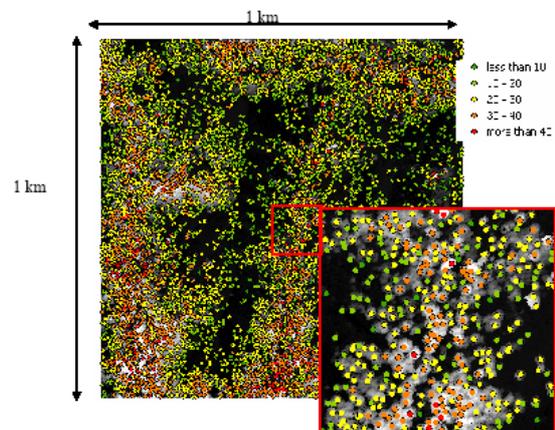


Figure 6. LIDAR-derived tree tops, color-coded by height laid over a DCHM. Tree heights (in meters) are extracted from the DCHM for each tree top. Standard GIS routines are then used to stratify (color-code) tree heights.

Verification of LIDAR-derived Tree Tops

The verification for the location of LIDAR-derived tree tops with ground data is shown in Table 3. The LIDAR-derived tree numbers are compared with the actual numbers of stems at each plot for each tree class. Dominant trees are identified with a success rate of 85%. For co-dominant trees, the success rate is 65% and then decreases to 51% and 47% for intermediate and suppressed trees respectively. However, this is not a limitation for the purposes of the method outlined in this paper, since intermediate and suppressed trees are not typically utilized as anchor points for cable logging systems (Schiess, 2005).

Table 3. Number of measured trees in each tree class for all plots. The number in parentheses indicates accuracy in percent between field-measured and LIDAR-derived tree locations.

Plot #	Treatment	Dominant	Co-Dominant	Intermediate	Suppressed	Total
Plot 1	*B	12(70)	33(61)	16(48)	18(45)	80(56)
Plot 2	*B	10(90)	20(74)	13(50)	11(42)	54(60)
Plot 3	*B	12(100)	14(66)	7(50)	6(37)	39(62)
Plot 4	*B	11(84)	12(54)	20(58)	16(44)	61(58)
Plot 5	*B	11(78)	24(60)	15(57)	19(47)	59(49)
Plot 6	*B	11(78)	27(51)	13(34)	19(38)	67(44)
Plot 7	*TB	13(76)	7(58)	3(20)	29(54)	52(54)
Plot 8	*TB	11(84)	14(63)	13(43)	29(43)	65(49)
Plot 9	*TB	9(81)	22(73)	9(40)	24(50)	63(54)
Plot 10	*TB	10(66)	17(73)	15(41)	20(36)	62(48)
Plot 11	*TB	7(77)	9(52)	16(42)	15(28)	47(40)
Total		117(85)	199(65)	140(51)	206(47)	649(45)

* B: burned treatment plot, TB: thinned and treatment plot

Conclusions

We have developed an efficient algorithm to accurately locate of tree tops. The method identified all convexities on the DCHM. In previous studies, height thresholds had to be set or established to derive binary images from DCHMs (Andersen et al. 2001). The height threshold, however, varies based on the vertical stand structure. In our approach, specification of the height threshold is no longer required.

The result shows that most of the dominant trees are identified. The intermediate and suppressed trees are not identified very well from LIDAR points, because the small footprint LIDAR returns tend to be reflected from a part of the canopy surface and not the entire canopy (Lefsky, 1999). However, for a number of forest operations planning we are primarily interested in dominant and possibly co-dominant trees. So this approach can provide a forest engineer with a tool to rapidly analyze large LIDAR data set. LIDAR data sets not only produce superb DEMs for road locations and cable load path analysis but provide additional information which has not yet been fully captured by forest engineers for harvest design purposes.

Acknowledgement

We thank the Precision Forestry Cooperative, University of Washington for providing LIDAR and field data and supporting our research. The mentioning of trade names does not constitute an endorsement.

Literature Cited

- Ackerman, F. 1999. Airbone laser scanning – present status and future expectations. *ISPRS Journal of Photogrammetry & Remote Sensing* 54: 64-67.
- Agee, J.K. 1993. Fire ecology of Pacific Northwest forests. Island Press. Covelo, CA.
- Agee, J.K., Edmonds, R.L., Gaines, W.L., Harrod, R.J., Hessburg, P.F., Lehmkuhl, J.F., and Zabowski, D. 2001. Fire and Fire Surrogates National Study Mission Creek Site Okanogan and Wenatchee National Forest, Mission Creek Study Plan, www.fs.fed.us/ffs/docs/studyplans2001/missionck.pdf
- Andersen, H.E., Reutebuch, S.E., Schreuder, G.F., 2001. Automated Individual Tree Measurement Through Morphological Analysis of a LIDAR-Based Canopy Surface Model. Proceedings from the first international Precision Forestry Symposium, Seattle WA: 11-22
- Bloomenthal, J., Bajaj, C., Blinn, J., Cani-Gauscuel, M., Rockwood, A., Wyvill, B., and Wyvill, G. 1997. Introduction to Implicit Surfaces. Morgan Kaufmann Publishers, Inc., San Francisco, CA.
- Chen, Q., Baldocchi, D., Gong, P., and Maggi, K. 2006. Isolating Individual Trees in a Savanna Woodland Using Small Footprint LIDAR Data. *Photogrammetric Engineering and Remote Sensing* 72 (8): 923-932.

- Holmgren, J. and Persson, Å. (2004). Identifying Species of Individual Trees Using Airborne Laser Scanner. *Remote Sensing of Environment* 90 (4): 415-423.
- Husch B., Beers, T. W., and Kershaw, J. A. (2003). *Forest Mensuration*. John Wiley & Sons, Inc. NJ.
- Hyyppä, J., Kelle, O., Lehtikoinen, M., and Inkinen, M. (2001). A Segmentation-Based Method to Retrieve Stem Volume Estimates from 3-D Tree Height Models Produced by Laser Scanners. *IEEE Transactions on Geoscience and Remote Sensing* 39 (5): 969-975.
- Krogstad, F. and Schiess, P. 2004. The Allure and Pitfalls of Using LIDAR Topography in Harvest and Road Design. Proceedings, Joint Conference of IUFRO 3.06 Forest Operations in Mountainous Conditions and the 12th International Mountain Logging Conference, Vancouver, B.C., Canada.
- Lefsky, M.A., Hardings, D., Cohen, W.B., Parker, G., and Shugart, H.H. (1999). Surface LIDAR Remote Sensing of Basal Area and Biomass in Deciduous Forests of Eastern Maryland, USA. *Remote Sensing of Environment* 67: 83-98.
- McCarter, J.B. 2001. Landscape management system (LMS): background, methods, and computer tools for integrating forest inventory, GIS, growth and yield, visualization and analysis for sustaining multiple forest objectives. Dissertation. University of Washington, Seattle WA.
- McGaughey, R.J., Carson, W.W., Reutebuch, S.E., and Andersen, H.E. (2004) Direct Measurement of Individual Tree Characteristics from LIDAR data. ASPRS Annual Conference Proceedings.
- Morsdorf, F., Meier, E., Koetz, B., Itten, K. I., Dobbertin M., and Allgower, B. (2004). LIDAR-based Geometric Reconstruction of Boreal Type Forest Stands at Single Tree Level for Forest and Wildland Fire Management. *Remote Sensing of Environment* 92 (3) : 353-362.
- Riaño, D., Meier, E., Allgöer, B., Chuvieco, E., and Ustin, S.L. (2003). Modeling airborne laser scanning data for the spatial generation of critical forest parameters in fire behavior modeling, *Remote Sensing of Environment* 86 (2): 177-186.
- Riaño, D., Chuvieco, E., Condis, S., González-Matesanz, J., and Ustin, S.L. (2004). Generation of Crown Bulk Density for *Pinus Sylvestris* from LIDAR. *Remote Sensing of Environment* 92(3): 345-352.
- Schiess, P and Krogstad, F. 2003. LIDAR-Based Topographic Maps Improve Agreement Between Office-Designed and Field-Verified Road Locations. Proceedings of the 26th Annual Meeting of the Council on Forest Engineering, Bar Harbor, Maine, USA: 7-10
- Schiess, P., 2005. The application of spatially explicit digital elevation and canopy surface data for harvest planning: Moving from coarse digital elevation models and stand averages to detailed ground and canopy surface models in the design of forest transportation systems. Proceedings, FORMEC 2005, INNOVATIONEN IN DER FORSTTECHNIK DURCH WISSENSCHAFTLICHE KOOPERATION. University of Ljubljana, Ljubljana, SLO, 26-29 Sept. 2005
- Schiess, P and A. Mouton, 2005. North Fork Mineral Creek Access and Transportation Strategy. Tech. Report, University of Washington, Seattle, WA
- Shapiro, L. G. and Stockman, G.. C. 2001. *Computer Vision*, Prentice Hall, Upper Saddle River, N.J.
- Sollie, P. 2003. *Morphological Image Analysis Principles and Applications*. Springer NY.

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SESSION A.3:

**WORKFORCE EXPERIENCES AND
DEVELOPMENTS**

BRITISH COLUMBIA FOREST INDUSTRY WORKFORCE REVIEW:2006 TO 2016

Bruce McMorland, Marv Clark

Abstract: Between October and December 2006, FERIC conducted surveys and interviews with forest licensees, and logging contractor principals and employees in British Columbia. The work was conducted in cooperation with the Logging Worker Training Needs Committee, comprised of members from regional loggers associations, forest industry employers and union representatives. The purpose was to compile information and ideas to help the Committee and industry implement initiatives to address human resource needs. The study resulted in a comprehensive report on labour workforce projections, skills requirements, training needs, training resources, training approaches and possibilities, recruitment needs, and retention practices for the forest sector.

Key words: Logger training, workforce projections, recruitment, retention.

Introduction

The Logging Worker Training Needs Committee (LWTNC) was established in the fall of 2006. The committee was comprised of members from the Truck Loggers Association, the North West Loggers Association, the Interior Logging Association, the Central Interior Logging Association, employers, the United Steelworkers, and the BC Forest Safety Council. The purpose was to compile information and ideas to help the Committee and industry implement initiatives to address human resource needs in the forest sector, particularly in woodlands operations, or harvesting phases. The committee set as one of its first tasks the identification of specific skills relevant to forest harvesting. A contract to conduct that assessment was awarded through a bid process to the Forest Engineering Research Institute of Canada (FERIC). Funding for the research was provided by the government of Canada and FERIC membership. This report documents the results of that research.

The project focused on six objectives.

- To describe and quantify labour and skills requirements for the current year (2006), 2011 and 2016 relative to anticipated provincial harvest volumes.
- To document the skills needed in the harvesting and forest management sector.
- To document training practices and resources available to meet skills development needs.
- To assess the potential for recruiting logging equipment operators and utilization of training resources by the industry over the next 5 years.

- To gauge the level of willingness on the part of industry and other potential users/funders to invest in training programs.
- To identify, in cooperation with the LWTNC recommendations and develop strategies for: priorities for action to address skill shortages training needs in the industry recruitment and retention

The project was accepted and undertaken as a needs assessment for logger training but as the project neared completion it became apparent that the work was also a needs assessment for loggers and equipment operators.

Study Procedures

Between October and December 2006, FERIC conducted two different surveys within the British Columbia forest industry. The first surveyed nine licensees, twenty-one contractors and 174 forest industry workers about recruitment, training, and worker retention. Licensees and contractors completed interviews with survey staff or returned surveys later, while worker survey forms (in postage prepaid envelopes to ensure anonymity) were distributed to all employees of cooperating contractors, and company logging crew employees of Western Forest Products and Island Timberlands. These two companies employ workforce directly while the others use contractor crews. Worker survey returns were weighted towards the Coastal Region. About 48% of the worker responses came from the Coast, 16% from the North Interior, and 34% from the South Interior.

The second survey was completed by 28 licensee respondents, representing about 30.1 million m³ (roughly 36%) of the provincial annual allowable cut for 2006 and it documented harvest systems and machines used in 2006. Using this base, a prediction model was built to estimate the number of logging workers stratified into nineteen job classifications.

Provincial Harvest Volumes

Estimates concerning the number and type of workers needed for a task (and their training needs) can be influenced by many factors but the underlying question that must always be addressed is, “How much work needs to be done?” With respect to the

forest and logging sectors, the amount of expected work is controlled by the volume available to harvest.

Table 1 contains information on billed products, issued as a supplement to the Ministry’s Annual Service Plan Report for 2005/2006 (BCMOFR (2006b)). These data show an annual billed volume exceeding 90.5 million m³ and represent the best estimates of the proportion of volume harvested from public and private provincial sources. FERIC utilized these numbers and distributions, combined with results from the survey of licensees, to calculate the number of harvesting operators in British Columbia.

Table 1. Annual volume of products billed in 2005/2006 by region and land status

	BC Crown all sources	Private, Federal, 1 st Nations	Province Total
Volume billed, m ³			
Coast forest region	17,896,279	6,533,662	24,429,940
Northern Interior forest region	32,817,060	1,994,802	34,811,862
Southern Interior forest region	29,584,230	1,717,856	31,302,085
Provincial total	80,297,569	10,246,230	90,543,888

Labour Force Employment

Table 2 shows estimates of the provincial labour force for all industries, and for the forestry and logging sector for the twelve year period ending in 2005 (BC Stats 2006).

Table 2. British Columbia Employment Statistics¹

Year	All industries	Forestry & logging with support activities
	(thousands of persons)	
1994	1,743.20	31.1
1995	1,785.60	36.1
1996	1,816.40	32.3
1997	1,860.50	32.2
1998	1,858.40	30.2
1999	1,894.40	30.0
2000	1,931.30	35.5
2001	1,921.60	24.7
2002	1,965.00	25.3
2003	2,014.70	27.7
2004	2,062.70	21.5
2005	2,130.50	21.6

¹ Source: Statistics Canada's Labour Force Survey, Revised January 25 and March 20, 2006
Prepared by BC Stats March 20, 2006

The data are shown graphically in Figure 1. Although the BC workforce increased by more than 20%, the logging and forestry workforce decreased by 9500 people (about 30%) from 1994 to 2005. The logging sector data could be interpreted in two ways. The sector could be described as being consistently in decline except for some occasional short-term in-

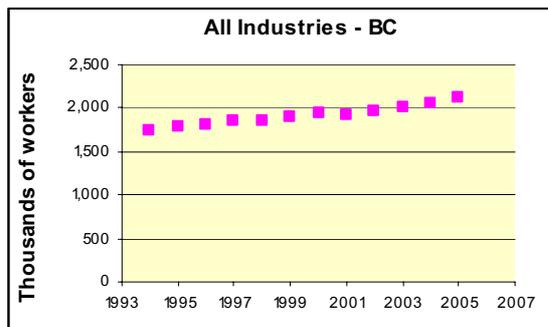


Figure 1. British Columbia workforce

In total, the logging and forestry workforce decreased by about 30% between 1994 and 2005 while provincial harvest volumes increased from about 75.3 million m³ to 90.5 million m³.

Operator Prediction Model – 2006 to 2016

Table 3 contains results from the Harvest Systems Survey for 2006 combined with predictions for 2011 and 2016. The 28 licensee responses accounted for about 33% of billed provincial volume in 2006. Proportionate rates were 24% in the Northern Interior, 45% in the South and 46% on the Coast. The tabulation represents an Operator Prediction Model developed by FERIC to estimate the number of logging machine operators. Survey responses were extrapolated to provincial totals based on the proportions of regional volumes.

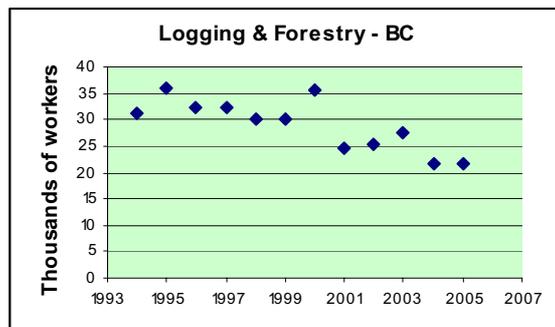
Because of space limitations, the detailed functions of the model are not shown here. Table 3 contains only the results of running the model with some realistic, but probably conservative, assumptions.

The model's calculation procedure is controlled by regional volume and modified by several parameters:

- Anticipated volume distribution by harvest phase.
- Operating days per year.
- Production rates (m³/shift) by machine type.

The regional billed volumes for 2005/2006 were divided into phases based on the reported survey distri-

creases; but it might also be described as being relatively static within two different ranges, one ending in 2000, and a second lower range commencing after 2000. Nonetheless, there has been a 30% reduction in persons employed in the BC forest and logging sector from 1994 to 2005.



butions (e.g. 83 % handfelled, 15% feller buncher, 2% harvesters).

In operation, the model calculates the required number of shifts per year to harvest each phase based on the shift productivity, and divides that by the available days per year to determine the number of operator shifts.

Estimates for operating days per year were averaged from licensee and contractor surveys, as well as from additional industry sources. For the Coast we generally assumed 235 operating days per year but reduced that to 165 days for hand fallers, 220 days for feller bunchers and 180 days for hand buckers and skidders, and increased it to 270 for helicopters. We also assumed that cable log loaders and cherry pickers were one machine that worked for 235 days. In the Interior, we generally used 190 days for the Southern Interior and 185 days for the Northern Interior.

Productivity estimates came from various sources including recent FERIC reports, information from staff files and projects, additional industry sources, and the surveys. The measure of 'shift productivity' is often considered a poor indicator of performance because it is influenced by many factors, but for calculating numbers of operators, it is actually a useful term. A 'shift' refers to an operating time frame for one individual. For the purposes of this work, FERIC used estimates for shift volumes that ought to be attainable, on average, during a 10-hour period.

Table 3. British Columbia Harvest Systems Projection – 2006 to 2016

Volume, million m ³	2006			2011			2016					
	Coast	North	South	Coast	North	South	Coast	North	South			
	# oper. / day	# oper. / day	# oper. / day	# oper. / day	Attri'n rate	New ops	# oper. / day	Attri'n rate	New ops	# oper. / day	Attri'n rate	New ops
	24,429	34,811	31,302	23,144	36,183	28,094	21,975	34,633	24,798			
Operation Type												
Felling Systems												
Hand Fallers	1137	28	188	822	15%	-145	34	11%	10	142	11%	-26
Feller-Bunchers	50	434	339	76	6%	29	440	7%	36	299	5%	-23
Harvesters	13	0	109	18	5%	6	0	8%	0	87	5%	-17
Total	1200	461	637	915		-110	475		46	528		-66
Yarding Systems												
Skidders	25	420	397	58	8%	35	447	8%	61	300	10%	-58
R.T. Forwarders	0	144	58	4	6%	4	122	6%	-13	117	6%	62
Excavator. Forwarders	93	5	3	123	6%	36	20	5%	15	37	6%	34
Cable Yarders	221	26	85	117	12%	-78	16	10%	-8	62	8%	-16
Helicopters	16	0	6	10	6%	-5	10	4%	10	16	4%	10
Cherry-pick	37	0	0	46	5%	11	0		0	0		0
Total	392	595	549	358		2	615		65	532		33
Processing Systems												
Hand buck	128	4	29	55	10%	-60	5	8%	1	21	6%	-6
Delimb or Process	86	691	618	159	6%	78	681	6%	31	512	6%	-69
Delimb / bark / chip	0	0	0	10	3%	10	34	5%	34	25	8%	25
Total	214	695	647	223		27	719		66	558		-51
Loading Systems												
Cable Loaders	76	0	0	32	10%	-36	0	10%	0	0	12%	0
Hydraulic Loaders	143	342	262	158	6%	24	356	6%	34	242	6%	-4
F.E. Loaders	10	0	52	6	6%	-3	0	6%	0	37	6%	-12
Total	228	342	314	196		-15	356		34	279		-16
Trucking Systems												
Long Log	478	864	769	427	13%	11	797	13%	45	635	13%	-34
Short Log	194	488	403	184	6%	1	507	6%	48	361	6%	-17
Picker Trucks	24	45	53	23	6%	0	78	6%	36	47	6%	-2
Chip vans	0	0	0	10	0%	10	41	0%	41	31	0%	31
Total	696	1,397	1,224	643		22	1,423		170	1,075		-22
Regional totals	2730	3,491	3,371	2,336		-74	3,588		382	2,971		-122
Provincial total		9592			Total positions	187	8894		187	new		
					Total positions	247	8226		247	3,341		11
												37
												new
												2,549
												-221

The following example illustrates the model's basic operation. The model suggests that in 2006, about 23 feller buncher operators were working in Coastal Crown tenures. This assumes that 15% of the Crown volume was handled by feller bunchers which produced, on average, 550 m³ per shift. That level of performance required 4,957 operating shifts. When related to the operating season of 220 days, it equates to 23 feller-buncher operators working for a single shift each day for 220 days. On private land, the proportion of feller-buncher volume was 59%, resulting in an estimate of 27 operators.

In total, the model estimated about 50 feller-buncher operators in the Coastal region, 434 in the Northern Interior and 339 in the Southern Interior.

The distribution of trucks for different harvest systems was determined from in-house discussions at FERIC. Average load volumes were assumed to be 50 m³ on the Coast and 45 m³ in the Interior. Lesser volumes were allowed for self-load picker trucks. Trucks were calculated at three loads per day.

In 2006, there was an expected province-wide need for a total of 9,592 harvesting operators.

For subsequent periods, the model incorporates changes for regional volume as well as any alterations to volume distribution by phase, number of operating days or production rates, and recalculates the required number of operators. The next step is the application of a new factor to represent a measure of attrition, and the final calculation shows the net increase or loss of operators compared to the total at the end of the previous 5-year period.

The detailed workings are not shown, but the tabulation shows that in 2011, for the combined Coastal tenures, the model suggests a need for 29 additional feller-buncher operators and 145 fewer hand fallers, than in 2006. These changes result from less total harvest volume, differences in the amount of volume felled by each method, and attrition.

By 2016, there is an expected province-wide need for a total of 8,226 harvesting operators, an amount that is 668 less than required in 2011. However, attrition accounts for a loss that is greater than that difference, so there is actually a requirement for 37 "new" operator positions. The model estimates the number of full time operator positions, and does not address issues which may surround part-time or part-year scheduling.

The workforce numbers calculated by the model do not suggest that large numbers of new operator positions are needed in the province. The model examined 19 key industry job categories as a surrogate for forest industry employment levels. Employment levels are sensitive to annual harvest volume, annual operating days and phase productivity, before allowing an estimation for attrition loss. Using the assumptions shown in the model, there is a predicted decrease of 1366 net logging equipment operator positions (14% reduction) between 2006 and 2016.

The forest industry workforce has been declining in British Columbia since 1994. Applying the 14% reduction from the model to the 2005 provincial estimate of 21.6 thousand forestry workers suggests that, by 2016, there will be fewer than 19,000 workers classed as 'forestry and logging with support'.

Potentially this could mean that relatively small amounts of in-house or on-the-job training would suffice to adequately address the training needs of redistributed staff. This scenario pre-supposes a reasonably stable workforce whose employees have high levels of satisfaction with their job and their industry. Workers might leave a job (by promotion, for example) but would tend to stay in the industry. Instead, several factors influence forest industry workers' decisions to remain in or leave the industry.

Retirements/demographics

The graph in Figure 2 shows two trends.

- A large block of baby-boomer older employees is getting closer to retirement.
- Few young people (only 13%) under 30 years of age.



Figure 2. Employee age distributions – all regions

Attitudes and Opinions

Licenseses, contractors and employees were asked to explain whether they would recommend work in the forest industry to a relative or friend. The question was asked at the end of each survey after respondents had answered the other questions, i.e., spent time thinking about why the subject had some importance, particularly to them. The employee and contractor groups were very pessimistic about industry viability as a continued, long-term employer. Sixty percent of employees and 65% of contractors would not recommend their industry. Among the nine licenseses,

there were two clear “no’s” and a third probable. The remaining six licenseses said “yes, they would recommend the industry” but half of those responses were given on the expectation of capitalizing on anticipated labour shortages – they gave a positive slant to a gloomy situation.

Interest in the industry

Employee Question 4 asked employees why they had been interested in the industry. The question is reproduced below to show the style of phrasing used for most of the questionnaires.

EQ 4 What interested you about the logging industry? 171 responses - 3 did not identify their location

Choice of factors		Analysis rank
Family business	Attractive work environment Coincided with other seasonal work Potential for advancement Good wages	V = Very important Value 3
Friend or relative		S = Somewhat Value 2
Independence		L = Little importance Value 1
Only work available		N = Not a factor
Good benefits		

Figure 3 illustrates that *wages* was the primary motivator amongst responding operators for selecting the forest industry as an employer. The graph presents an ‘Importance Value’, which is a relative ranking measure showing how closely the average response value for an answer (factor) approached the maxi-

imum possible value. The ‘Importance Value’ ranking measure was used to illustrate responses to most survey questions. The maximum was usually 3 because most questions could be ranked for 4 possible answers (values of 0, 1, 2, 3). Answers or factors with an average value greater than the mid-point represent a majority feeling.

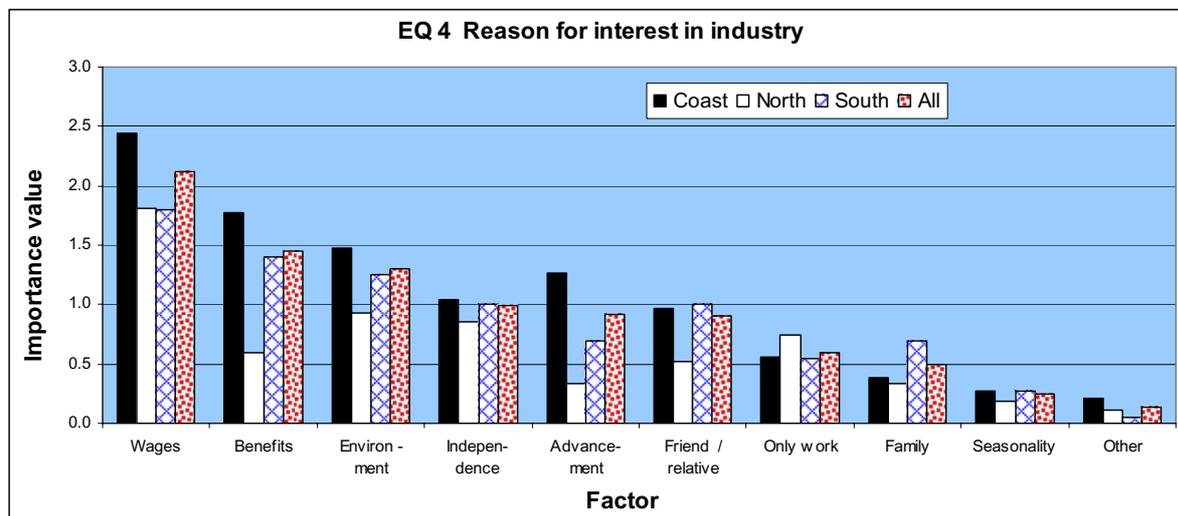


Figure 3. Reasons for interest in industry

Wages

Wages ranked as the highest-ranked answer for all questions related to choosing the industry, employer and job, and was also the most important consideration in selecting this job over other prospects (Figure 4) as well as in changing jobs (Figure 5). Hourly wages were reported between Cdn \$25 and \$32 per hour. Although high when compared to wages for many urban workers, those wages are not very high

compared to other sectors within and outside of British Columbia. The mining industry can equal these and oilpatch rates can exceed them. Forest workers are further influenced by annualized ‘losses’ because their work year is rarely more than 9 months and is frequently much less. Wage differentials that no longer favour forestry are one of the underlying dissatisfactions amongst forest workers.

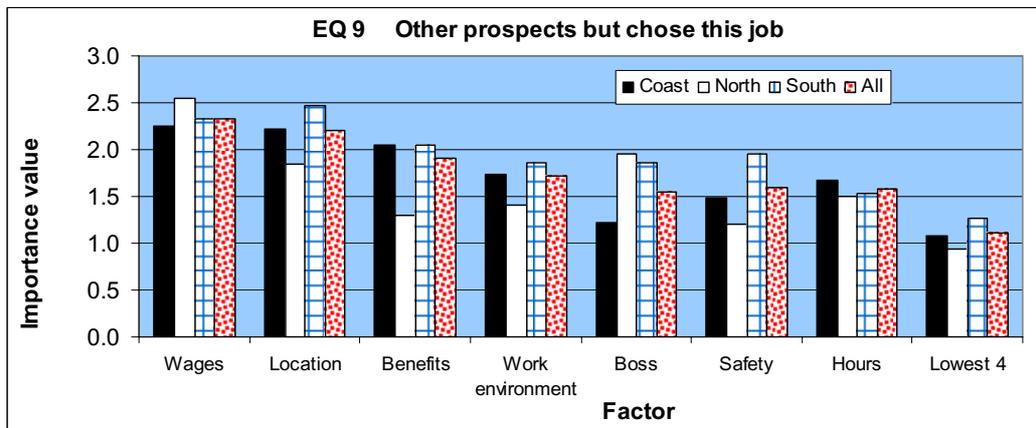


Figure 4. Choosing this job over other prospects

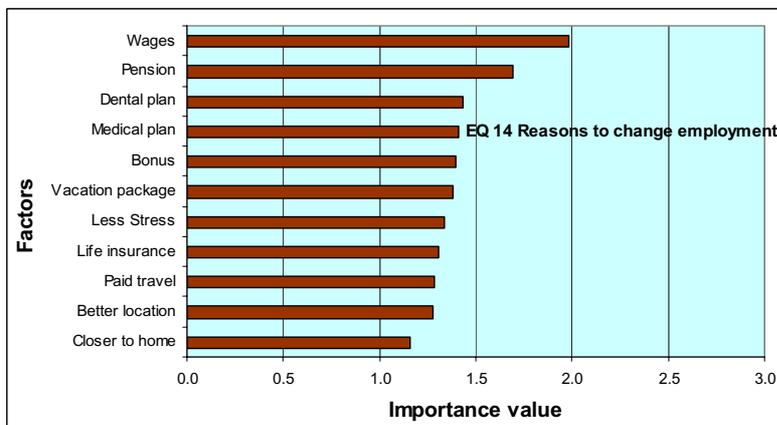


Figure 5. Primary reasons to change employment

Expansion

By 2011, about half of the twenty-one contractors surveyed expected to expand. One contractor recognized a need for skidder operators and another required drivers, while all remaining expansion plans needed operators in all phases. One contractor estimated a 40% increase in staffing. The others were unable to estimate numbers. Expansion estimates

over the 10-year period were less clear. Only five contractors seemed certain of expansion and expected to need a wide range of employees. Some believed they could find the required workers from within their geographic area's workforce.

Contractors were asked to explain whether they were currently experiencing a critical shortage of skilled

workers. About 40% of contractors surveyed indicated they had a shortage and about 70% expected the labour situation to worsen.

Recruitment

Employees ranked job security and better wages as the two most important factors of six topics they felt would help influence new recruits. In all three regions, contractors considered the most important

source of competition for workers was from other loggers, followed by the oil and gas industry. The most successful source for new workers was from other contractors or companies within the same region, but this was closely followed by the category of people looking for work. Generally schools and placement agencies were viewed as poor sources of acceptable workers. (Figure 6)

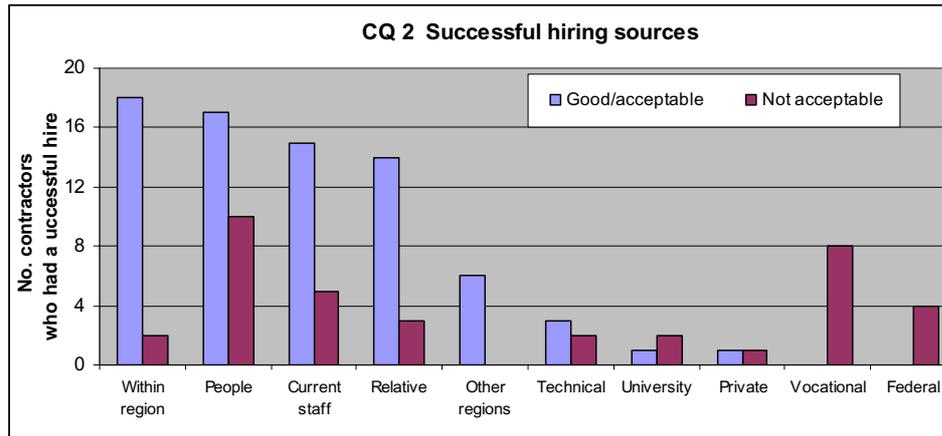


Figure 6. Successful hiring sources.

Retention

The ratio of departures to retirements (Table 4) was 16:1 in 2005 and 13:1 in 2006 amongst the contractors who were surveyed. Two contractors reported no departures during that period but all others experienced attrition. Of those surveyed, total attrition increased from 84 departures in 2005 to 112 in 2006. The totals are surprising and disturbing.

Table 4. Summary of employee departures - 21 contractors

	2005			2006		
	Retire	Quit	Total	Retire	Quit	total
	5	79	84	8	104	112
No. of contractors reporting attrition	18			19		
No. of contractors with no attrition	3			2		

Acquiring skills

The employees surveyed reported that the technical skills for operator jobs have primarily been learned on the job from another operator (86 responses) or from their boss (41 responses). These were followed closely by operators who felt they learned by watching experienced workers (36 responses) or learned in isolation by themselves (34 responses). Training courses accounted for 33 responses, about half of which were from mechanics or truck drivers.

Contractors were asked how they implemented training. About half the contractors conducted in-house training, about 25% did not train or did not respond, and the remainder had interest in a trainer or formal program.

Required skills

Employees surveyed believed it was important to work safely as part of a team without needing close supervision. To do this, they needed good hand-eye coordination, mechanical training and reading skills

(Figure 7). Contractors replied to this questions on the basis of new hires as well as for long-term employees. Contractors surveyed generally appear to have hired new employees who are strong in social skills (*ability to read, maturity, and work with others*) and relatively weak in the technical skills (*interpret maps/plans, mechanical skills, and experience*). This is in line with contractor assertions that they prefer to do on-the-job training. With respect to long-term employees, responses are shown in the chart in Figure 8, which shows a frequency count of comments or criteria related to each aptitude group. The contractors in this survey appear to believe that over the long-term, non-technical skills and aptitudes probably have a higher importance to an employer than the technical aspects of an occupation.

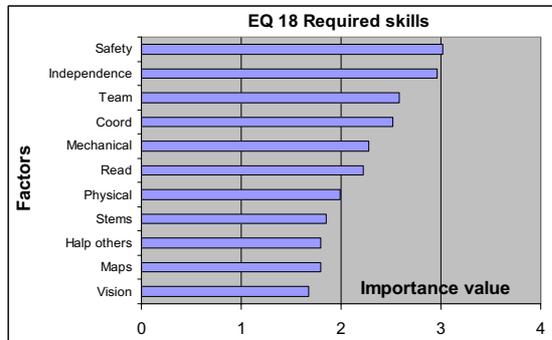


Figure 7. Required skills – employee perspective

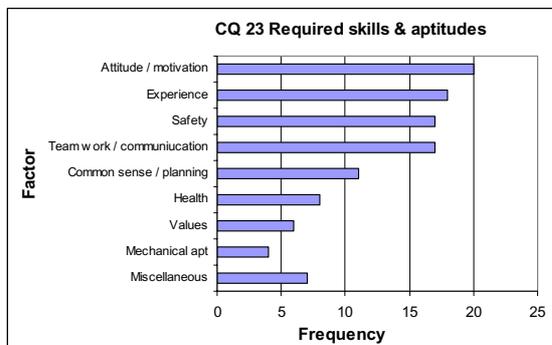


Figure 8. Desirable skills and aptitudes for safe, productive work

Conclusions

The British Columbia forest industry experienced a labour force reduction over the past decade (1994 to 2005) of approximately 30%. Work force projections made in this study suggest that this declining trend will continue through the next decade (2005 to 2016) but at a lower rate of 14%.

Although the predicted decline in logging equipment operator positions for the British Columbia forest sector should generate a surplus of skilled workers, the reality is that the sector will experience a labour deficit if changes are not implemented. Three factors contribute to this outcome.

1. **Workforce demographics.** A large segment of the work force (60%) is beyond the age of 50 and considering retirement. Also, as the number of available positions declined substantially over the last decade, very few young workers have either entered, or been retained in, the work force.
2. **Workforce retention.** The skilled workers currently involved in the sector see a combination of high uncertainty for sustainable employment, an undesirable social life style (i.e., long work hours, remote work sites, hazardous environments, harsh weather conditions), and a relatively modest compensation package (wages and benefits), and weigh these against a strong demand for their skills elsewhere. The outcome of this comparison causes many skilled workers to change sectors.
3. **Workforce recruitment.** Young people entering the workforce today seldom consider a career in the forest sector because the public image of the work appears in conflict with environmental ideals, work locations are often remote requiring them to change life styles or cultures, and work schedules are frequently seasonal and somewhat erratic. As a consequence, new workers only enter the sector in desperation, or to improve their qualifications for other sectors.

Recommendations

The old guard was drawn by wages. Perhaps the new wave will follow because of global warming and joy-sticks. Unconventional sources and solutions need to be examined.

Recommendations have been organized around three concepts of a Recovery Strategy loosely based on the basic-building-block-concepts of the primary school “three R’s.”

1 Reduce → Reduce Retirements and Resignations.

- Make compensation and benefits packages¹ for contractors and employees competitive with similar work in other industries.

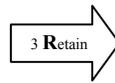
¹ These should include pension, medical and dental insurance, and daily travel allowances.

- Initiate discussions between licensees and contractors regarding plans, needs and expectations.
- Continue to improve the safety record.
- Reduce or eliminate shutdown periods, or schedule employee vacations during them.
- Retain workers past the age of 65 by offering creative job sharing arrangements.



Recruit and Retrain to
Replace departed workers.

- Incorporate resolve motion control in new equipment. Resolve motion control cost was approximately \$60,000 in the 1990s and is now probably in the range of \$12,000 per unit.
- Target forest communities for future employment.
- The construction industry designs ergonomic machines that have shorter learning curves for workers of all backgrounds and ages. Can these designs and concepts be transferred into forestry?
- Consider joint licensee-contractor presentations at large area high schools.
- Make conscious attempts to improve working relationships between licensees and contractors, aimed at reducing disputes and improving “image” at home and in communities.
- Change the work culture of the forest industry to attract unconventional labour sources, such as women and First Nations. Foreign nationals could possibly be retained on an indenturement program to ensure a minimum work period.
- Encourage pre-employment testing with simulators to both promote employment opportunities and identify exceptional candidates.
- Encourage student attendance at training programs by government subsidy (apprenticeship?).
- Explore work/job sharing.
- Resurrect hiring hall placement agencies that will improve worker access to longer seasons and employer access to skilled workers.



Retain by Reinforcing the positives.

- Take advantage of the global warming green movement for greenhouse gasses to further the benefits of working in the forest industry.
- In conjunction with industry trade and professional associations, fund, prepare and distribute information sessions in high schools. Demonstrate with simulators.
- Reinforce independence, outdoors, RENEWABLE (contrast against oilpatch).
- Encourage contractor cooperatives that can market harvesting services to multiple forest land holders and thereby extend equipment utilization and work seasons for employees.

Literature Cited

BCMOFR 2006b. “Detailed Statistical Tables for 2005/06 Table 9.2” website BC Ministry of Forests and Range,
http://www.for.gov.bc.ca/hfd/pubs/docs/mr/annual/ar_2005-06/tables/

BC Stats 2006. “Detailed Industry, BC: NAICS” website BC Stats
<http://www.bcstats.gov.bc.ca/data/dd/handout/naicsa mn.pdf>

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WORLD CLASS SAFETY PERFORMANCE IN A PACIFIC NORTHWEST FOREST OPERATION

Mike McDowell

Abstract: In 1993, Weyerhaeuser Company Timberlands Senior Vice-President Charles Bingham directed the entire division of the company to make a paradigm shift away from the belief that work-related disabling injuries and deaths were inevitable risks of doing business. Using basic business improvement processes, managers at all levels of the division began moving towards the goal of an injury-free workplace. By implementing key policies and procedures, the business has reduced the total Recordable Incident Rate to approximately 1.0 for company and contract workers who are growing and planting seedlings, building and maintaining roads, harvesting timber, and hauling logs to market.

Key words: Committed leadership, facts and data, reliable processes, employee driven, basics done well, risk management

Introduction

In 1993, Weyerhaeuser Company Timberlands Senior Vice-President Charles Bingham directed the entire division of the company to make a paradigm shift away from the belief that work-related disabling injuries and deaths were inevitable risks of doing business. Using basic business improvement processes, managers at all levels of the division began moving towards the goal of an injury-free workplace. This presentation reviews how the basic principles of 1) committed leadership, 2) employee ownership of safety, 3) basics done well, 4) focus on the critical few improvement opportunities, and 5) risk management enabled Western Timberlands to make continuous improvements in safety performance since the inception of the project. By implementing key policies and procedures, the business has reduced the total Recordable Incident Rate to approximately 1.0 for company and contract workers who are growing and planting seedlings, building and maintaining roads, harvesting timber, and hauling logs to market.

Committed Leadership

- The most important element in a successful safety program!
- The other principles cannot succeed without leadership commitment
- Makes safety a core value of the organization
 - All incidents are preventable
 - The commitment to safety focuses on the human being
 - Safety is a performance measure for line management

- All members of the organization are personally accountable for safety
- Safety is a condition of employment

- Exhibits key safety behaviors
 - Ensures all members of the organization understand their roles and responsibilities
 - Reinforces the organization's safety culture through a personal presence in the workplace
 - Never walks past a safety violation
 - Ensures that the organization's safety processes align with improvement goals
 - Serves as an excellent role model, exhibiting the highest standards of safety behavior at all times
 - Keeps the entire organization informed of progress on safety action plans with extensive use of facts and data
 - Ensures that a proactive safety measurement system is in use

Employee Ownership of Safety

- Successful safety programs derive their energy from the "grass roots"
 - Human nature drives us to care about our personal safety and the safety of the people around us
 - Committed leaders making safety a core value of the organization reinforces beliefs amongst the workforce that safety is "the right thing to do"
 - Employees take personal responsibility for their health and safety

- The minute-by-minute decisions that make or break an organization are made by the people doing the work
 - No organization, no matter the size, can provide enough supervisors and managers to do all the thinking
 - Committed leaders provide the training, coaching, monitoring, clear expectations, accountability processes, and physical resources
 - Empowered employees manage unsafe behavior (source of most injury risk) out of the job site
 - In a mature safety culture, all employees develop the courage to intervene, on the spot, in a caring way to prevent injuries
- The people doing the work have the most to gain from an effective safety program
 - Employees know what works for them to create genuine involvement
 - Committed leaders tailor the processes to fit the size and needs of the grass-roots units
 - Employees working with an effective program internalize safety as a way of life, which allows them to put more energy into production planning and implementation
- Responsibility, accountability, and authority for safety are as clearly and fully aligned as for production
 - All employees understand and exercise their roles and responsibilities
 - All employees are held accountable for failures and recognized for successes
 - Safety attitudes and results are used by the organization in hiring, promotion, and salary action processes
 - In the context of employee ownership of safety, practically everyone on the crew is in some kind of leadership role and management delegates the appropriate amount of authority
- Trend analysis
- Identification of potential risks
- Cascading key learnings throughout the organization
- Communicating corrective action progress
- Incident Investigation is a highly structured process:
 - Includes near-misses, property damage, hazard observations (conditions and behaviors) as well as injury incidents
 - Reveals all pertinent facts and data of the incident
 - Determines basic and root causes
 - Develops a corrective action plan that, if properly implemented, will eliminate the cause of the incident
 - Used as a tool to “make some lemonade out of the lemons”
- Committed Leaders develop and implement Reliable Processes
 - Many of the same processes used in production settings
 - Training
 - Inspections
 - Preventive Maintenance
 - Job Hazard Analysis
 - Hazard Prevention and Control
 - The only way to manage “upset” conditions
 - Consistent use of reliable processes ensures systems are under control
- The organization fully understands and performs to all regulatory standards

Focus on the “Critical Few” Improvement Opportunities

- Committed leaders use “basics” to identify which units in the organization are not performing to established safety expectations
 - Units under scrutiny develop corrective action plans to be approved by leadership
 - Leaders conduct aggressive reviews of progress against plans
 - Units held accountable for outcome of action plans
- Committed leaders use “basics” to identify, throughout the organization, typical “upset conditions” and unsafe behaviors that pose the highest risk for injury
 - Units throughout the organization develop corrective action plans to address the conditions and behaviors under scrutiny and incorporate into safety plans

Basics Done Well

- Committed leaders implement and maintain Effective Management Systems
 - Continuous Improvement processes:
 - Assess the management and control of the safety risks which exist in the workplace
 - develop and implement action plans to control these risks
 - Measure progress against the plans
 - Facts and Data are used extensively to provide objective, accurate, and consistent information for:

- Leaders develop safety improvement measures and hold entire organization accountable for outcomes

Risk Management

- Leaders ensure that the organization has a system in place to analyze, assess, and control risk
- Key elements in the system include:
 - Tools to identify the biggest opportunities and the greatest potential losses
 - The primary goals of the system are to 1) control losses and 2) eliminate incidents
 - The system does not attempt to eliminate risks, but to manage them
- The system operates under some common-sense assumptions
 - Limited resources don't allow everything to be done at once
 - Some risk management issues are more important than others
 - The organization will take on the most important issues first

Conclusion

- World-class safety performance is not “rocket science”
- Organizations can become world-class safety performers only when safety is internalized as a personal issue by the leaders of the organization
- Committed leadership requires energy, stamina, and a process by which the leaders constantly remind themselves of what is at stake

- Leadership commitment to an incident-free workplace grows through the use of continuous improvement processes
- The organization must increase the scope of “leadership” from the traditional list of VP's and managers to include anyone (first-line supervisor, crew leader, contract administrator, etc.) who is managing another person's activities
- If the leadership of the organization is committed to world-class safety performance, the other elements necessary to achieve that goal will fall into place
- In an incident-free workplace, the people doing the work are combining the resources provided to them, with their own personal belief in success, to make the right choices every day

Literature Cited

This presentation contains material paraphrased from “Weyerhaeuser- Safe From the Start: Our Approach to Safety” and “Weyerhaeuser Company Springfield Forest Area Team 2007 Safety Plan” and cannot be reproduced without written consent from Weyerhaeuser Company.

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DANGER TREE MANAGEMENT ON NATIONAL FOREST LAND IN OREGON AND WASHINGTON

Richard Toupin, Gregory M. Filip

Abstract: Danger trees in the workplace kill people. The workplace includes forest roads and jobsites where people work in the forest.

A field guide with a five step process has been developed for classifying danger trees, and determining how to respond to them (Toupin & Barger, 2005). The Pacific Northwest Region of the US Forest Service (FS) has developed a policy for danger tree management along roads. The FS has also implemented a training program to qualify employees to identify danger trees.

The process does not apply to developed recreation sites.

Key words: Danger trees, potential failure zones, qualified person.

Introduction

Between November 2002 and June 2006, twelve accidents involving danger trees on logging sites, resulting in either fatalities or injuries, were reported to the Oregon Occupational Safety and Health Division (OR-OSHA). These accidents included failed tops, snags, limbs, and adjacent trees (Struck by Report, 2006).

Danger trees are also a problem along roads. During the winter of 2005/2006, an Oregon Department of Transportation (ODOT) snow plow was struck by a tree on Highway 20. An injury accident during 2004 was the result of a vehicle running into a downed tree on the Mt. Hood National Forest. A US Forest Service vehicle was struck by a tree during August 2005.

Danger trees can be found at other jobsites such as tree planting areas, along trails, and in places where people congregate while working.

To respond to the ongoing danger tree issue, the FS developed a danger tree management strategy.

Danger tree management consists of four parts: a danger tree identification process, a policy about how to identify danger trees along roads, and determine what to do with them, a training program to train the qualified person about how to identify danger trees, and action.

Discussion

Danger Tree Identification Process

There are five steps in the danger tree identification process. The steps are independent of each other.

1. Determine the type of work activity.
2. Identify tree defects and determine the tree's potential to fail.
3. Determine the potential failure zones.
4. Determine if the tree poses a danger to workers.
5. Determine what action to take if the tree is a danger to workers.

Step 1 - Determine the type of work activity

Three categories contain all work activities: (1) traffic on roads, (2) jobs that do not impact the tree, such as walking, or conducting non-motorized tasks without tree contact, and (3) motorized activities near the tree, or any activity with tree contact.

Traffic on roads

Due to the many miles of roads that exist, it was necessary to develop a method to prioritize roads for evaluation. Consideration of exposure level and traffic frequency provided a way to prioritize the workload.

There are three types of exposure. Intermittent exposure includes traffic driving by a defective tree. Short duration exposure includes people stopping next to a tree for a short time; less than 15 minutes.

Long duration exposure includes people exposed to defective trees for longer periods.

Roads that have a higher traffic frequency expose more people to a defective tree than roads with a lower traffic frequency. The longer the exposure, and the higher the traffic frequency, the more likely it is for a worker to be hit by a tree failure.

Non-motorized, non-tree contact

This category consists of activities that involve walking near trees without touching them. They are also non-motorized. Examples include tree planting, inventory (any type), surveying, walking to a jobsite along a trail, or through the forest, and designating timber.

The idea behind this work activity is that trees are less likely to fail if they are not contacted, and workers are more likely to recognize tree dangers, and avoid them, if they are not focused on operating vehicles or machines.

Motorized, tree contact

This category consists of motorized activities, or jobs that cause tree contact. Examples include road construction, logging, timber falling, tree climbing, site

preparation, trail construction, and helicopter operations.

The idea behind this work activity is that tree failure may be induced by vibration due to machine operation, air movement in the case of a helicopter, or tree contact by a machine, log, or line. Also workers are less likely to recognize tree dangers, and avoid them, if they are focused on operating vehicles or machines.

Step 2 - Identify tree defects and determine the tree's potential to fail

Failure potential is a function of tree condition. There are three types of failure potential; low, likely, and imminent. A tree may have an imminent potential to fail, if it is so defective or rotten, it would take little effort to make it fail. A tree with a likely failure potential will fail, but it will take more effort to make it fail.

An understanding of forest pathology and entomology was used to develop the condition indicators listed on Table 1 (Toupin & Barger, 2005). These condition indicators were designed to be used to classify failure potential.

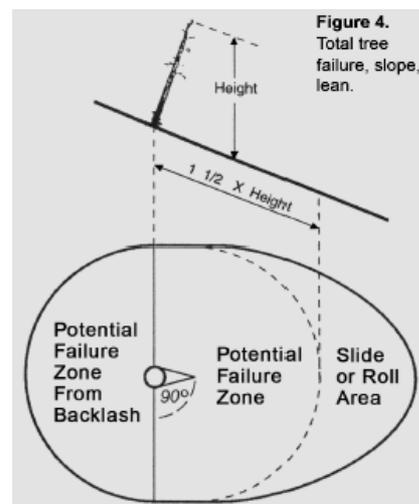
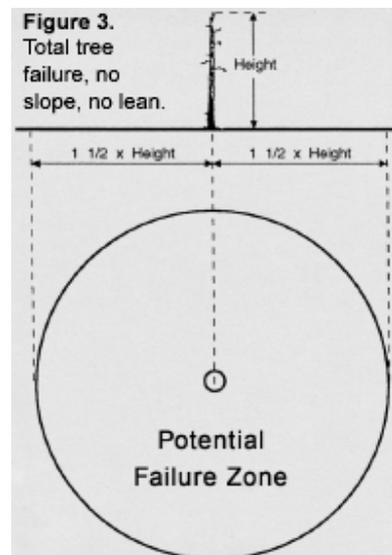
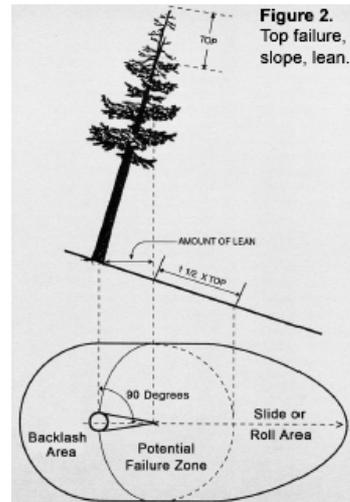
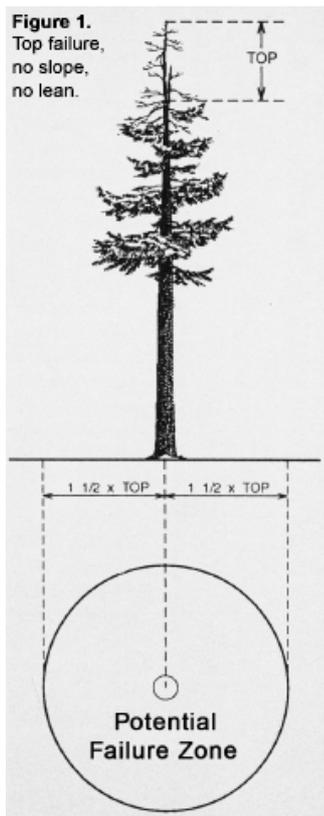
Table 1: Failure Potential Condition Indicators

Imminent	Likely
Root sprung.	Root diseased, but still alive.
Recent lean.	Old lean that has not corrected itself.
Missing bole wood due to fire or damage.	Some undermined or severed roots.
Significant heart or sap rot.	Some heart, butt, or sap rot.
Loose bark.	Cracks or structural defect associated with some decay.
Dwarf mistletoe bole swellings if they have decay extending to an area more than half the bole diameter.	Dead tops with some heart or sap rot.
Fungus cankers on the bole when the canker width is more than half the bole diameter.	Dwarf mistletoe bole swellings if they have decay extending to an area less than half the bole diameter.
Dead tops with significant sap rot.	Fungus cankers on the bole when the canker width is less than half the bole diameter.
Hung up tops, limbs, or hung up trees.	Forked tops and crotches associated with decay, cracks, splits, or callus ridges. Pitch or resin is not always associated with likely failure potential. Pitch is often a sign in a healthy tree when it is defending itself against pathogen or insect attack.
Dead trees that are not sound.	Dead trees that are still sound.
Fire damaged or killed trees that are not sound.	Fire damaged or killed trees that are still sound.
Trees with multiple defects.	Hardwoods with sap rot approaching half their diameter.

The identification process was designed to be used by qualified people. A qualified person does not need to be a forest pathologist. However, there are situations that are more complex than those normally encountered. For example, large pines standing along roads are valued by many people, for many reasons. Many of these large pine trees have significant fire scars, and dead tops. What is their failure potential? It may be low, likely, or imminent. This is an example of when it may be necessary to obtain the counsel of a forest pathologist so that failure potential is not overstated, resulting in the unnecessary removal of large pine trees.

Step 3 - Determine the potential failure zones

Potential failure zones are defined as areas within reach of any part of a failed tree. The top, limb, or bark may fail, or the entire tree may fail. The tree may be on a slope, or on level ground. It may either be vertical, or it may have a lean. The zone is defined as a distance equal to one and a half times the height of the part that may fail. Figures 1 through 4 illustrate the failure zones for a variety of situations.



Step 4 - Determine if the tree poses a danger to workers

This step was designed to help the qualified person consider the implications of the first three steps. Here is the thought process.

First, the qualified person needs to determine whether or not the activity is likely to cause tree failure. Second, the tree's failure potential is considered. If it is imminently about to fail, and people will be within the failure zone, it is a danger tree, regardless of the work activity. If the tree is likely about to fail, and people are in its failure zone, it may or may not be a danger tree. If the exposure or traffic frequency is low, in the case of a road, or the activity won't cause the tree to fail, it may not be a danger tree. If the tree has a likely failure potential, and the failure zone covers an area where people will congregate, then the tree may be a danger tree.

The qualified person must consider the work activity, failure potential, and failure zone, and then make a judgment about whether or not the tree is dangerous.

Step 5 - Determine what action to take if the tree is a danger to workers

If the qualified person determines the tree is a danger tree, workers can not be exposed to the danger. The tree must be removed, or work arranged so workers are not exposed to the danger.

Qualified person

When faced with danger trees, the employer needs people qualified to identify them through the use of a consistent process. The FS believes people must be trained and qualified to identify danger trees. A qualified person is a person who has knowledge, training, and experience in identifying danger trees, their potential failure zones, and measures to eliminate them.

Policy

What roads and job sites should be evaluated for danger trees? If danger trees are identified, what should be done with them? These are important questions that need to be defined by the land owner.

The FS has recognized the danger tree problem along roads, and developed a policy to deal with it. The policy specifies a method for ranking roads for dan-

ger tree evaluation and treatment. It specifies that qualified people should be conducting the danger tree evaluation. The policy also states what must be done with danger trees along roads.

Results

The FS is utilizing the field guide for danger tree identification, as part of its strategy for managing danger trees along its road system (Toupin & Barger, 2005, Forest Service Manual).

A training program has been developed and implemented to train and qualify FS employees. The training is a two day session complete with testing. Instructors include pathologists, biologists, engineers, and a logging engineer. During 2006, 371 people were trained and qualified. Roads are being examined throughout the Pacific Northwest Region of the Forest Service. Danger trees are being removed.

Literature Cited

Toupin, R, and M. Barger. 2005. Field Guide for Danger Tree Identification and Response. USDA Forest Service. Pacific Northwest Region. R6-NR-FP-PR-03-05. 56p.

Struck By Report. Logging Accidents Reported to OR-OSHA 10/01/02 – 09/30/06. 2006.

Forest Service Manual. Pacific Northwest Region. R6/PNW Supplement No.: 7730-2005-1. 7733 Safety Provisions on National System Roads. 2005.

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SYNTHETIC ROPE REDUCES WORKLOADS IN LOGGING

John J. Garland, Stephen J. Pilkerton

Abstract: The workload in difficult logging tasks can be reduced by replacing heavy steel wire rope with strong but light synthetic rope. Results from a series of research projects funded by Oregon Occupational Safety and Health Worksite Redesign Grants are presented. Various heart rate measures on standardized tasks show improvements for student workers studied. Time and other efficiency measures are also reported. Ergonomic results are significant for the aging logging workforce. High use of steel wire rope in skyline operations offers great potential for replacement and workload reductions for workers.

Key words: Synthetic rope, skyline logging, workloads, ergonomic, harvesting, heart rates

Introduction*

Timber harvesting starts the production cycle for forest products and has been characterized as difficult, dangerous and dirty (Garland 2005). In the United States, logging is among the top three most dangerous jobs nearly every year, and when all factors are considered, logging is likely the most dangerous job (US Department of Health & Human Services 1999).

Part of the exertion is due to the nature of the workplace and the tasks performed. On many logging sites, slopes are 30-100% (~17 to 45 degrees) in steepness. The terrain is covered with cut trees and logging slash so workers are literally walking on wood (trees, logs, limbs, and underbrush). Workers actually climb trees to attach rigging to support cables used in operations (Figure 1). Weather and climate demands also increase workloads at temperatures to 45 Celsius with relative humidity of nearly 100% or sub-zero temperatures in snow and ice conditions (Vik 2004).

In many countries, logging workers are aging as a proportion of the logging workforce. Garland (2005) showed Oregon's pre-1991 logging workforce had less than a quarter of workers over 45 years, but now, that percentage of older workers exceeds 45%.

Logging Tasks

The tools and equipment for logging tasks are typically "heavy metal" to withstand the rigors of the work environment. Steel wire rope (SWR) is used universally in thousands of miles annually for logging but it is heavy, stiff and produces "jaggers"

(broken wires that cause lacerations and painful puncture wounds). The mass per meter of length for the 10-35 mm diameter steel wire ropes used are typically 0.39-5.22 kg. A summary of selected logging jobs, tasks, and the ergonomic consequences are briefly described so readers can see what logging workers encounter (Table 1).



Figure 1. Typical climbing task to rig trees for cable harvesting operations

* Mention of trade names does not constitute an endorsement by Oregon State University

Table 1. Selected logging jobs and tasks using steel wire rope (SWR) and ergonomic impacts.

JOB	ACTIVITY DESCRIPTION	TASK	ERGONOMIC IMPACT WITH SWR
Hooktender	Onsite supervisor, rigs yarding roads, and climbs and rigs trees	Carries guylines, blocks (pulleys), gear to anchor tree or support tree, carries and pulls/rigging line for next road ~323-1613 m	Multiple trips over slash on steep slopes, climbs trees (15-33 m high) Loads 27-45 kg Pulls 133-267 N force
Skidder Operator Setting Chokers	Drive vehicle, positions, pulls winch line and sets chokers, winches logs to machine, returns to landing	Pull winch line 24-40 m through slash & obstacles, uphill/downhill	With leg drive and arms pulls 267-356 N force, more than 40 times/day
Cable yarding crew	Pull line through carriage to logs to set chokers	Walk and pull line on slash covered slopes of 50-70% occasionally 100% with lines 10-19 mm diameter & distances 9-33 m	40-80 times daily pull lines with force 133-267 N

Prior Research

Oregon State University began research in 1999 on the use of synthetic rope to replace steel wire rope. Funding was provided by the Oregon Occupational Safety and Health Administration Worksite Redesign Grants whose objectives were to improve ergonomics of the workplace (Garland et al. 2004a, 2002, 2001). The direct motivation for the use of synthetic rope came from a Washington state logger who experimented with synthetic rope on his operation. Pilkerton et al. (2001) found Amsteel-Blue® synthetic rope (manufactured by Samson Rope Technologies of Ferndale, Washington) to meet the strength requirements for logging applications. Research progressed with the development of end connectors for synthetic rope (Hartter and Garland 2006, Hartter 2004). Field trials were conducted with static and running line applications (Leonard 2004, Leonard et al. 2003, Pilkerton et al. 2003, Garland et al. 2004b). We have reported on operational effectiveness for static lines in cable yarding (Leonard et al. 2003) and skidder winch lines (Pilkerton et al. 2004b, Pilkerton et al. 2003). There are even environmental benefits from using the lighter rope in forest operations (Garland and Pilkerton 2005, Pilkerton et al. 2004a).

There are a number of synthetic rope types available and suitable for logging applications; however, braided rope constructed of ultra-high molecular weight polyethylene (UHMWPE) fibers is effective in timber harvesting. It is lightweight, has a strength-to-weight ratio approximately eight times that of wire rope, floats, and is as strong as comparable wire rope of the same diameter up to 25 mm. Such UHMWPE braided ropes do not kink, corrode, nor absorb

chemicals or water (Samson Rope Technologies 2003). Our assessment of worker compensation claims in Oregon showed synthetic rope could possibly reduce accidents. In the period 2000-2004, Oregon logging disability claims totaled 2,365 claims (Oregon Department of Consumer & Business Services 2005). Thirty two percent of these claims came from Chokersetters, Rigging Slingers, and Hooktenders while 22.7% of claims were from workers who use wire rope daily. The logging sector had 41.9% of claims related to overexertion, slips and falls, and bodily reactions (9.4% from pulling, pushing, lifting, carrying and throwing objects).

Objectives and Methods

This paper reports on our designed studies to assess ergonomic benefits of replacing steel wire rope with synthetic rope from our experiments from 1999 to the present. We sought ways to measure differences if they did exist for the crew on tasks typically found on logging operations.

Workers

We assessed the employees of the Oregon State University Research Forests Student Logging Crew during summer work in 1999 and 2000. Characteristics of the crew are listed in Table 2. Workers self reported on their fitness level and the age is at the time the task was performed in 1999 or 2000. Workers were paid for their participation, consented to participating in the evaluations and were free not to participate, as in the climbing task. Conditions for the steel and synthetic rope trials were comparable but not exact.

Table 2. Worker characteristics in the study

Worker	Age	Height (cm)	Mass (kg)	Fitness	Gender
1	23	175	79	good	M
2	21	168	59	good	F
3	25	185	91	good	M
4	23	193	118	good	M
5	38	196	102	good	M
6	22	175	59	good	F
7	47	178	75	good	M
8	46	178	75	good	M
9	23	173	70	good	M
10	21	178	75	good	M
11	38	188	75	excellent	M
12	22	180	75	good	M
13	20	169	70	good	F

Tasks Studied

Standardized tasks using steel wire rope or synthetic rope were performed and data taken. The standardized tasks were designed to simulate activities encountered in both ground based skidding and steep slope cable yarding harvest processes including cable layout and rigging activities. The following activities were performed for heart rate monitoring and time measurement:

- 1) Drag Road – Both rope types (16 mm steel, 48.4 m segment, 50.4 kg; 16 mm synthetic, 48.4 m segment, 8.2 kg with steel thimbles) were pulled (extended) 98.6 m along a gravel surface road grade of 4 percent, downhill then uphill.
- 2) Drag Ridge - Both ropes were pulled 48.4 m along a native surface ridgeline of 25 percent slope, downhill then uphill.
- 3) Drag Steep - Both ropes were pulled 48.4 m along a native surface slope of 45 percent, downhill then uphill.
- 4) Carry Road - The rope segments were coiled and bailing wired for carrying, repeating the 98.6 m traverse along the road grade, down then up.
- 5) Carry Ridge - The coiled segments were carried on the ridge 48.4 m, down then up.
- 6) Carry Steep - The coiled segments were carried on the slope 48.4 m, down then up.

7) Climb - (Base activity for rigging comparison). Workers climbed a 46 cm diameter breast height, Douglas-fir tree to a height of 16.1 m.

8) Climb and Rig - The worker climbed then rigged the tree as an intermediate support tree with 2 fiber rigging straps, a 15 cm diameter steel block (total common rigging of ~16 kg), and either a 12.5 mm steel wire rope or a 16 mm synthetic rope guyline at a height of 16.1 m. Climbing and rigging involved the following elements:

Climb 16.1 m,
 Pull up strap and block,
 Rig strap and block,
 Pull up strap and shackle,
 Rig strap and shackle,
 Pull up guyline,
 Unhook guyline,
 Rig guyline.

Measurements

Heart Rate and Time Measures

Heart rate data and subjective evaluation data were collected to evaluate the physiological and other responses between using traditional steel wire rope and synthetic 12 strand braided rope in logging related tasks. Heart rate data were collected using the Polar Advantage® monitoring and recording system (Polar Electro Oy 1998). The Polar system consists of a monitoring strap worn around the chest and a wristwatch recording device. The chest strap senses the heart's electrical impulses and transmits them to the wristwatch device. The wristwatch device receives

the signals, displays continuous feedback, and stores heart rates at a selected interval. Heart rates (beats per minute, BPM) were recorded every five seconds. The time to complete each task element was compiled from the recorded heart rate – time relations created with data markers applied when subjects pushed a button on the wristwatch- style data logger. Data collected were downloaded to a computer with the Polar Interface System. Worker files were reviewed, graphed, and evaluated using the Polar Precision Performance 2.0 and Excel™ software.

Methods

We used a variety of methods to assess differences between the effects of using steel or synthetic ropes and offer some new perspectives on measurements for logging workers. Several heart rate measures were tested along with the time per task. Paired t-tests were used to assess differences. We also hypothesized that the pattern of significant differences could be important as we would expect to find no significant differences between tasks that were quite easy (eg, pulling a line on a flat road) or where steel wire rope provides added momentum to worker performance (eg, steel wire rope actually pushing workers down a steep slope). For the standardized tests, the sample size was generally 13 workers, but for one or two tasks, a worker missed the task and the sample size was reduced to 12.

Repeated Measures for Standard Tasks

We used each worker as his/her own control by performing the standard tasks including suitable rest periods. The sources of variation influencing logging tasks make it difficult to isolate differences of interest with small sample sizes. Our strategy was to remove as much extraneous variation and control these sources to the extent possible.

Maximum Heart Rate

For each of the standardized tasks, the maximum heart rate for each subject was recorded for either steel wire rope or synthetic rope. Results were analyzed with a paired two-tail t-test using the Excel™ spreadsheet statistical function.

Heart Rate Reserve

We used a variant of the Heart Rate reserve (HRR) described by Åstrand and Rodahl (1986, p.496) and Rodahl (1989) which states:

“One way of expressing the circulatory strain which a given work load imposes on a subject is to express the heart rate at the given work load as a percentage of the heart rate reserve of that particular individual (the heart rate reserve being the difference between maximal heart rate and resting heart rate):

$$\frac{\{(HR \text{ task} - HR \text{ rest}) / (HR \text{ max} - HR \text{ rest})\} \times 100\%}{= HR \text{ reserve} = HRR}$$

(page 70)”

We modified the formula for HRR by using the task’s weighted average HR as suggested by Rodahl (1989). Because our research was field-based and we could not establish workers’ maximal HR with laboratory apparatus like cycle ergometers, treadmills, step tests, etc., we used the rough approximation suggested by Åstrand and Rodahl (1986) as 220 minus age equaling the maximal heart rate. We did not adjust the formula for the age differences of two workers. Our value for resting HR (lowest observed value for each worker) is also somewhat skewed upwards by taking heart rates in the field. We believe logging workers use a portion of their HRR just being at the logging worksite with its uneven terrain and other environmental stimuli. For our comparison purposes to show the differences between steel and synthetic rope, we are comfortable with the modifications described above. We realize studies with better worker information, more samples, controlled environment, and so forth might better estimate absolute values for heart rate reserve.

Heart Rate Recovery Rate (HRRR)

Shetler et al. (2001) acknowledge the use of heart rate recovery after a specified time to reflect fitness of individuals but also use the recovery rate to predict mortality in male populations. Forjaz et al. (1998) document different exercise intensities produce different heart rates and recoveries in similar population of normotensive humans. The heart rate recovery rate is defined as the slope (rate of change) of the heart rate after task completion. Mathematically, the HRRR is the HR at end of task minus HR consistent with HR at task initiation with that difference divided by the elapsed time. Not all workers had heart rates that fully returned to pre-task levels; thus, we visually selected the heart rate slope interval. We report on what we think are differences in heart rate recovery rate related to task demands using steel or synthetic rope.

Time per Task

The stopwatch function of the heart rate measurement also provided a task time for each of the standardized tasks. Workers pressed a wrist-watch button to establish task times but were independently checked by a separate stopwatch to assure representation.

Climbing Task

Our efforts to ascertain differences with steel wire rope rigging versus synthetic rope were hampered using heart rate measures by what we term the “anxiety effect” of the climbing task. Not all of the student workers were comfortable climbing a tree with climbing spurs and a belt to a height of 16.1 m; so, our sample was reduced (n=5). Furthermore, we found that when workers started from a “standing rest” heart rate, by the time they were 2 m up the tree, heart rates jumped to a high level and remained there throughout the climbing task. For some inexplicable reasons, the average heart rates within a task were higher when climbing and rigging with synthetic rope in our sample. Figure 2 shows the heart rate traces for novice (inexperienced) and experienced climbers using steel and synthetic rigging. We might need a large sample of experienced climbers to more accurately assess the differences between synthetic rope and SWR rigging for the climbing task.

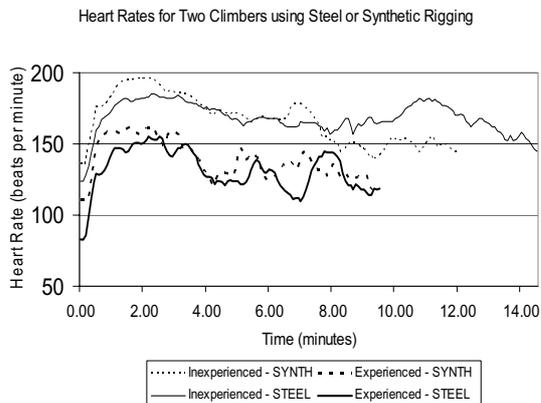


Figure 2. Climbing task for experienced and inexperienced climbers using steel or synthetic rigging

Results

We provide a number of measures and statistical results to show differences. Some tasks are relatively easy and we might not expect to see either time or heart rate differences.

Standardized Tasks

Table 3 shows the results for the measures of interest (time per task, maximum heart rate, heart rate reserve, heart rate recovery rate) for our suite of standardized tasks. Mean values are presented along with the significance level of the two-tailed paired t-test results. We selected a Po level of 0.05 for our significance of the test statistic. For the tasks where the steel wire rope has a tendency to push the worker downhill, we see a somewhat lower level of significance compared to uphill dragging or carrying tasks. Time differences are significant across all tasks as are the differences between mean maximum heart rates for the workers.

For the measures of the percent of heart rate reserve used on the task, the SWR only had 4 tasks below the 50% level while the synthetic rope had 8 tasks below. Rodahl (1989, p.196) suggests...”As a reasonable upper limit, in the case of prolonged work, a work load corresponding to 50 percent of the heart rate reserve may be acceptable, based on practical experience.”

Dragging and carrying lines uphill were the most exertive with steel wire rope reaching levels as high as 75 percent of the groups’ mean heart rate reserve. Dragging SWR uphill on a steep slope had individual workers reaching their maximal calculated heart rates and using up to 90 percent of their heart rate reserve.

When we examine the workers’ heart rate recovery rate, a pattern of differences emerges. For the moderately easy tasks, there are no significant differences between workers’ recovery rates suggesting to us, little difference between steel and synthetic rope. Also where SWR tends to “push” workers downhill, the difference is not significant. However, dragging the ropes on a slope or carrying ropes on a steep slope produce significant differences in heart rate recovery rates. We believe the differences are due to the exertion required for the standardized tasks from the differences in the demands for SWR or synthetic rope.

Table 3. Summary of Significance Two Tailed Paired t-Tests

TASK	STEEL TIME minutes	SYNTHETIC TIME minutes	Po	STEEL MAX HR	SYNTHETIC MAX HR	Po
drag road down	1.47	1.21	0.014	161	113	0.000
drag road up	2.41	1.26	0.002	175	141	0.000
carry road down	1.05	0.94	0.023	135	111	0.000
carry road up	1.27	0.96	0.004	133	117	0.000
drag ridge down	0.85	0.67	0.033	143	117	0.000
drag ridge up	4.16	0.9	0.000	180	154	0.000
carry ridge down	1.04	0.77	0.001	141	121	0.000
carry ridge up	1.27	0.85	0.003	169	149	0.000
drag steep down	0.99	0.72	0.016	144	129	0.012
drag steep up	5.09	1.34	0.000	177	164	0.000
carry steep down	1.35	0.93	0.001	147	130	0.002
carry steep up	1.89	1.12	0.003	177	160	0.000

SUMMARY OF SIGNIFICANCE TWO TAILED PAIRED t-TESTS

TASK	STEEL % HR RES	SYNTHETIC %HR RES	Po	STEEL HRRR BPM	SYNTHETIC HRRR BPM	Po
drag road down	59	30	0.000	27.4	23.9	0.339
drag road up	67	40	0.000	23.7	27.2	0.375
carry road down	44	25	0.000	27.4	27.5	0.494
carry road up	50	37	0.000	30.3	33.3	0.149
drag ridge down	45	31	0.001	20.3	19.3	0.369
drag ridge up	75	50	0.000	17.3	29.5	0.000
carry ridge down	46	31	0.000	24.6	34.6	0.064
carry ridge up	60	47	0.000	20.4	39.5	0.000
drag steep down	45	36	0.024	25.3	20.4	0.074
drag steep up	75	60	0.000	18.5	24.4	0.030
carry steep down	52	38	0.001	23.2	36.3	0.037
carry steep up	70	56	0.000	20.3	29.4	0.033

Climbing Task

As revealed above, for the climbing task itself with novice climbers, we were unable to demonstrate differences with rope type. However, as a practical matter, the task of rigging a tail tree or intermediate support tree (trees rigged with guylines and support lines plus the associated rigging) involves the standardized

carrying and dragging tasks where significant differences are evident from our research. In order to rig a tail tree with SWR a Hooktender would likely make at least two and perhaps three trips across difficult terrain carrying loads up to 30 kg. With synthetic rope and rigging, Hooktenders have been able to put all of the rigging in a backpack and just make one trip to the tail tree (Schlatter 2004). Once at the tail tree

the guylines and support lines must be dragged uphill and down as needed similar to our standardized tasks. Finally, the Hooktender must climb and rig the tree after some exertive tasks. Using the synthetic rope allows the climber to descend the tree by rappelling as opposed to the more strenuous method of climbing down the tree using spurs and climbing ropes.

Discussion

By a number of measures, there are differences in task times and ergonomic values with heart rates to demonstrate benefits of synthetic rope over steel wire rope for workers. Standard tasks similar to logging work activities were able to control environmental variation so rope differences could be shown by workers in paired t-tests. Time differences have significance for productivity and heart rate measures show lessened workloads. Maximal heart rate measures were useful except for the climbing task where high heart rates in the task itself may mask rope differences. Heart rate reserve differences are valid criteria; however, our modifications for the field research provide relative differences for rope material but not precise measures of individual heart rate reserve.

Heart rate recovery rate was a measure we examined to see differences between the task demands with synthetic or steel wire rope. Our measurement approach might be useful to others as the pattern of differences was predictable with the most exertive tasks showing the heart rate recovery rates were significantly different while less demanding tasks had about the same heart rate recovery rates for each worker.

Synthetic rope costs two to five times more than comparable steel wire ropes (Garland et al. 2004b). However, logging contractors have been willing to purchase synthetic ropes for the benefits to their workers and the efficiency gains. Efficiency gains provide pay back periods for the additional cost within one month of usage or sooner (Garland and Pilkerton 2005). As use of synthetic rope increases within the logging sector, prices may become more competitive. Authors are aware of at least two hundred logging firms in the Pacific Northwest currently using synthetic rope.

Much of the logging in developing countries relies on human effort and technologies using synthetic rope could lighten workloads. The materials for a complete harvest system based on new lightweight materials could benefit workers. Slips, falls, strains and sprains are the most common logging injuries and the

heavy materials used contribute to fatigue related injuries. Economic benefits of ergonomic gains always need documentation for logging managers and insurers.

Conclusion

Our research demonstrates ergonomic and efficiency gains from replacing steel wire rope with synthetic rope in logging applications. Workloads as measured by heart rates are reduced and task times are lowered as well. The lighter materials can eliminate some hazardous and exertive tasks such as extra trips needed to rig up cable harvesting operations. Anecdotal evidence by synthetic rope users confirms our designed experimental results in dramatic terms. Tree climbing tasks need further study for direct comparisons between the two materials. Other synthetic rope applications are underway in logging and merit further ergonomic research.

Literature Cited

- Astrand, P-O. and K. Rodahl. 1986. Textbook of Work Physiology: Physiological Bases of Exercise. McGraw-Hill. New York City, NY. 756 p.
- Forjaz, C.L.M., Y. Matsudaira, F.B. Rodrigues, N. Nunes, and C.E. Negrão. 1998. Post-exercise changes in blood pressure, heart rate and rate pressure product at different exercise intensities in normotensive humans. *Brazilian Journal of Medical and Biological Research*, 31:1247-1255.
- Garland, J. 2005. Who does the work in the forest? Connections between foresters and the forestry workforce. in *Proc. of Society of American Foresters Annual Meeting*, Oct. 18-22. Ft. Worth, TX.
- Garland, J. and S. Pilkerton. 2005. Use of Synthetic Rope as a Skidder Winchline for Designated Skid Trails. USDA Forest Service Gen. Tech. Rep. PSW-GTR-194. in *Proc. of Council On Forest Engineering. Annual Meeting*, July 11-14. Fortuna, CA.
- Garland, J., J. Session, S. Pilkerton, and B. Stringham. 2001. Synthetic Rope Used in Logging: Some Potentials. in *Proc. of Council on Forest Engineering Annual Conference Annual Meeting*, July 15-19. Snowshoe, WV.

- Garland, J., J. Sessions, S. Pilkerton, and B. Stringham. 2002. Using Synthetic Rope to Reduce Workloads in Logging. Final Report, Oregon Occupational Safety and Health Administration Worksite Redesign Grant Final Report. Salem, OR. 28 p.
- Garland, J., S. Pilkerton, and J. Hartter. 2004a. Running Lines and End Connectors for Synthetic Rope to Reduce Logging Workloads. Oregon Occupational Safety and Health Administration Worksite Redesign Grant Final Report. Salem, OR. 71 p.
- Garland, J., S. Pilkerton, and J. Leonard. 2004b. Field Testing of Synthetic Rope in Logging Applications to Reduce Workloads. Oregon Occupational Safety and Health Administration Worksite Redesign Grant Final Report. Salem, OR. 67 p.
- Hartter, J. 2004. Investigation of Synthetic Rope End Connections and Terminations in Timber Harvesting Applications. MS Thesis. Oregon State Univ. Corvallis, OR. 220 p.
- Hartter, J. and J. Garland. 2006. Synthetic Rope End Connections for Use in Timber Harvesting. *Int. J. For. Eng.* 17(1): 39-51.
- Leonard, J. 2004. Applications for Synthetic Rope in Logging. MF Paper. Oregon State Univ. Corvallis, OR. 90 p.
- Leonard, J., J. Garland, and S. Pilkerton. 2003. Evaluation of Synthetic Rope for Static Rigging Applications in Cable Logging. in Proc. of Council On Forest Engineering Annual Meeting, September 7-10. Bar Harbor, ME.
- Oregon Department of Consumer & Business Services. 2005. Occupational Safety and Health in Oregon's Forests: Logging and Forestry Services CY 2000-2004. Information Management Division, Research & Analysis Section. Available at www.cbs.state.or.us/imd/rasums/2998/o4web/04_2998.pdf Salem, OR. 90 p.
- Pilkerton, S., J. Garland, J. Sessions, and B. Stringham. 2001. Prospects for Using Synthetic Rope in Logging: First Look and Future Research. in Proc. of International Mountain Logging and 11th Pacific Northwest Skyline Symposium, December 10-12. Seattle, WA.
- Pilkerton, S., J. Garland, J. Leonard, and J. Sessions. 2003. Synthetic Rope Use in Logging Winching Applications. in Proc. of Council On Forest Engineering. Annual Meeting, September 7-10. Bar Harbor, ME.
- Pilkerton, S., J. Garland, and J. Hartter. 2004a. Applications of Synthetic Rope for Improved Ergonomic, Economic and Environmental Performance in Mountainous Logging. in Proc. of 2004 International Mountain Logging Conference June 13-16. Vancouver, BC, Canada.
- Pilkerton, S., J. Garland, and J. Hartter. 2004b. Comparison of Ergonomic Performance for a Skidder Operator Using Steel Wire and Synthetic Rope Winchline. in Proc. of Council on Forest Engineering Annual Meeting, April 27-30. Hot Springs, AR.
- Polar Electro Oy. 1998. Polar Precision Performance User's Guide: Software version 2.0 for Windows. Polar Electro Oy, Kempele, Finland. 147 p.
- Rodahl, K. 1989. *The Physiology of Work*. Taylor & Francis. Bristol, PA. 290 p.
- Samson Rope Technologies. 2003. Industrial Rope Catalog. Ferndale, WA. 59 p. www.samsonrope.com
- Schlatter, D. 2004. Personal Communication. 7 May 2004. Synthetic Rope Cooperator's Meeting. Oregon State University. Corvallis, OR.
- Shetler, K., R. Marcus, V.F. Froelicher, S. Vora, D. Kalisetti, M. Prakash, D. Do, and J. Myers. 2001. Heart Rate Recovery: Validation and Methodologic Issues. *Journal of the American College of Cardiology.* 38(7):1960-1967.
- US Department of Health and Human Services. 1999. Identifying High-Risk Small Business Industries. The Basis for Preventing Occupational Injury, Illness, and Fatality. NIOSH Special Hazard Review. Public Health Service, Centers for Disease Control and Prevention. National Institute for Occupational Safety and Health. 155 p.
- Vik, T. 2004. Ergonomic Research in the Nordic Countries Related to Work in the Forest. in Proc. of Council on Forest Engineering Annual Meeting, April 27-30. Hot Springs, AR. 11 p.

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SESSION B.3:

HARVESTING AND TRANSPORTATION MANAGEMENT AND ASSESSMENT

ESTIMATED COSTS FOR HARVESTING, COMMUNING, AND TRANSPORTING BEETLE-KILLED PINE IN THE QUESNEL/NAZKO AREA OF CENTRAL BRITISH COLUMBIA

A. J. MacDonald

Abstract: The Forest Engineering Research Institute of Canada (FERIC) estimated the costs of harvesting, comminuting, and transporting pine trees killed by the mountain pine beetle in the central Interior of British Columbia. Costs were based on computer models that used different harvesting systems depending on the proportion of fuelwood in the stand as estimated by a shelf-life model. The three situations examined were: the existing roadside harvesting system to harvest sawlogs and generate roadside residuals followed by a separate fuelwood chipping operation in stands with less than 50% fuelwood; a satellite sortyard system for stands containing 50-95% fuelwood; and on-site, full-tree chipping for stands with more than 95% fuelwood.

FERIC measured the volume of roadside harvesting residuals, and found that 14-55% of the original stand biomass remained at roadside after harvesting, depending on the sawlog utilization standards. A substantial volume of biomass was also dispersed across the cutblocks, however, it was mainly in pieces too small for harvesting, and was not considered to be a potential source of feedstock.

Key words: Mountain pine beetle, comminution, transportation, fuelwood, bioenergy, biomass, residues, cost

Introduction

The infestation of mountain pine beetle is having a significant effect on the lodgepole pine forests of interior British Columbia. Forest companies have increased their harvest of dead pine, but despite this increased harvesting activity, significant volumes of beetle-killed pine will remain unharvested and its commercial value may be lost. One option for salvaging more value from the dead pine is to harvest it for fuelwood.

FERIC was contracted by BC Ministry of Energy, Mines, and Petroleum Resources, the BC Ministry of Forests and Range, and BC Hydro in partnership with Forintek Canada Corp. to provide information for BC's forthcoming energy strategy about ways that forest biomass could be utilized for fuelwood. FERIC was asked to examine the harvesting, transporting, and comminuting of beetle-killed pine to a site where it could be used for power generation. The analysis was to include:

- A description of the appropriate harvesting and transportation systems for the dead pine trees;
- Estimated costs of harvesting and comminuting the beetle-killed pine from typical harvesting sites using the most appropriate harvesting system;

- Estimated costs for transporting the feedstock from the harvesting sites to the potential sites for power generation; and
- An example of applying the costs and volumes to a case study area. The corridor between Quesnel and Nazko, near the epicentre of the pine infestation, was selected as a case study area (Figure 1).

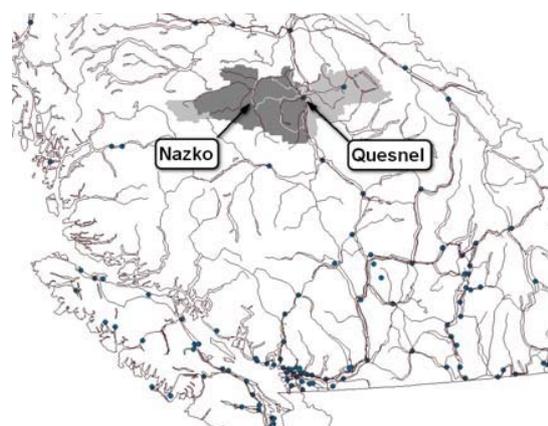


Figure 1. Quesnel TSA with case study area highlighted.

FERIC's analysis was for direct harvesting and transportation costs, and was to exclude:

- planning and administration costs;
- road development, maintenance, and deactivation; and
- reforestation.

Volume Measurements and Estimates

Potential fuelwood from the beetle-killed pine occurs in two classes: the residuals left after conventional harvesting operations, and dead standing trees from areas that are not harvested under current practices. Estimating the volumes in these two classes requires different approaches. The residual volume was further classified into two categories: the tops, butts, and limbs that were piled at roadside, and the small, broken, or overlooked pieces that were dispersed across the cutblock.

In July 2006, several cooperating companies operating within the case study area suggested cutblocks from their recent harvesting areas that would be appropriate to measure the residual volumes. Parts of the cutblocks that were visibly associated with specific residual piles were used.

Dispersed Volumes

The dispersed residuals were measured using the line intersect method (Sutherland 1986). Plots with two 20-meter perpendicular lines were established at random locations throughout the cutblock at a density of approximately one plot per hectare. Every sound piece of softwood residual with a minimum diameter of 1 cm and length of 60 cm was tallied. Volume was converted into its biomass weight equivalent using a conversion rate of 420 kg/m³.

Clearly such small pieces cannot be harvested economically, but they were measured in order to compare the total biomass between cutblocks. By collecting additional size measurements, FERIC calculated the dispersed biomass volume that met strict, but more economically feasible, utilization specifications of 15 cm diameter and 3 m length, and a more contemporary utilization specification: 20 cm diameter and 4 m length.

We found that the dispersed residuals comprise a significant volume, with an average volume of nearly 50 m³/ha or 20 oven dry tonnes per ha. However, most of that volume is from pieces that are much too small to be harvested economically; the dispersed

residual volumes that are larger than the strict utilization specifications ranged from 1 - 5 m³/ha. Furthermore, most of the volume that is over the strict utilization limit is also larger than operational utilization specifications, and may have been overlooked during skidding. FERIC concluded that the volume of dispersed residuals that actually represents potential for harvesting as biomass feedstock is very small, and therefore it was omitted from further analysis.

Roadside Residuals - Volumes

Top piles are left near the roadside (Figure 2) after the logs are processed mechanically, often by means of a dangle-head processor. Depending on the particular operation and the volume of residual material, the tops may take the form of continuous or discontinuous rectangular piles, or teepee-shaped discrete piles. The volume of the roadside residuals was estimated by measuring the dimensions of every roadside pile in each measurement area using logger and carpenter tapes. The bulk volumes of teepee piles were calculated using Hardy's (1996) paraboloid equation, while the volumes of linear piles were calculated as irregular solids. Each company implemented a different utilization specification in regard to small-diameter tops, and these differences manifested themselves in different amounts of roadside residual volumes. One company routinely harvested tops to a 5 cm (2 inch) diameter, while others used 10 cm or larger for their target top diameter.



Figure 2. Typical roadside residual pile with 10-cm top diameter target.

The bulk volume was converted into residual volume, expressed as ODT/ha, by multiplying the measured bulk volume of each pile by a bulk density factor, and dividing by the area of cutblock that contributed to the residual pile. A bulk density of 200 kg/m³ at 40%

moisture content, or 120 kg/m³ dry equivalent, was used for all piles. The cutblock areas were determined by GPS traverses of the areas that contributed to the specific residual piles.

Roadside residual volumes ranged from 22 ODt/ha to 145 ODt/ha, or about 14% to 55% of the original stand volume. FERIC observed that the company following the 5-cm top diameter utilization standard had among the lowest residual volume, while the company that targeted its top diameters at more than 10 cm had among the highest levels. The residual pieces with large diameter were usually affected by severe checking that made them unsuitable for sawlogs. This may have factored into the company's utilization standard.

Standing-Dead Volume Estimates

The primary objective for this project was to determine harvesting and transportation costs, both for the individual harvesting systems and the overall average from the case study area. However, the overall average is influenced by the harvesting system, which is partially determined by the proportion of fuelwood in the stand. Thus, it became necessary to examine the stand composition at various times in the future.

FERIC assumed that current roadside logging practices will continue for as long as the forest companies can extract sufficient value from the stands to cover operational costs, fixed development costs, and administrative costs, and to generate a profit. However, at some point, stands will deteriorate to a stage when conventional harvesting will not be undertaken. FERIC assumed that this point occurs when the stand comprises 50% fuelwood as determined by the shelf-life model described later. FERIC assumed that beyond 50% fuelwood content, the logs would be transported to a satellite yard where the sawlogs would be sorted out, and the remainder would be chipped. FERIC also assumed that beyond 95% fuelwood, no sawlogs would be harvested, and the entire stand would be chipped on-site.

The proportion of fuelwood in the stand was determined by the shelf-life of the dead pine. Using the principles described by Eng *et al* (2005), FERIC created shelf-life models in which the pine volume deteriorated from sawlogs to fuelwood to non-recoverable volume at a rate that depends on the biogeoclimatic zone and subzone. In principle, the pine trees in wet or warm subzones deteriorate faster than in dry or cool subzones.

Using the fuelwood volumes as generated by the shelf-life model and the definition of the stand types that are suitable for the various harvesting systems, the volumes of fuelwood and sawlogs that could be available from the case study area were calculated at 5, 10, 15, and 20 years past mortality (YPM). Based on the 95% fuelwood threshold, full-tree-chip stands do not exist at 5 years past mortality, but comprise a significant component of the volume beyond that point. By 20 years past mortality, the full-tree chipping stands comprise about 40% of the total volume.

Costs

Cost calculations were based on three harvesting systems. In the roadside residuals system, the tops and limbs are chipped directly into a semi-trailer chip van using a mobile chipper situated on the road. Costs for falling, skidding, and processing are excluded because they are borne by the primary logger. In the satellite system, trees are hauled to a satellite yard where they are separated into streams of sawlogs and fuelwood. Sawlogs are processed using a pull-through delimeter and saw, while fuelwood is chipped into B-train chip vans. Costs for falling, skidding, and loading are allocated to the fuelwood in proportion to its relative volume in the stand. In the full-tree chipping system, 100% of the stand volume, including incidental green trees, is chipped on-site into semi-trailer chip vans. All the direct costs, including falling and skidding are allocated to the fuelwood.

Costs were calculated using FERIC's standard costing methods which include the direct costs for these systems, but exclude the costs of road development, layout, administration, silviculture, and other overhead costs that occur during all timber-harvesting operations.

Roadside Residuals - Costs

The residual piles from conventional harvesting operations are situated 10-13 m from the centreline of the road and are distributed along its full length. These conditions imply that the comminution equipment must be able to move quickly between piles and be able to retrieve the residuals over a distance of about 15 m. Typical mobile comminution equipment of sufficient size to handle the roadside residuals would require significant moving and setup time, thus making it unsuitable for a highly-mobile operation. Furthermore, many of the roads had steep banks or deep ditches that would prevent most machines

from leaving the road. Accordingly, costs were based on using a mobile chipper that would remain on the road directly behind the chip van, and feed directly into a chip van (Figure 3). A separate hydraulic loader was used to move the residuals within reach of the chipper. A chipper was selected rather than a grinder for its ability to load the trucks from the end without using an auxiliary blower. Cost calculations were based on 13.7 m chip vans with a payload of 13 ODt of chips.



Figure 3. Track-mounted mobile chipper with integral grapple and straight-through processing path

A critical factor to minimize costs in this system is to maintain high utilization, thus requiring close coordination between the chipper and the trucks. With too few trucks, the chipper would be idle while waiting for trucks, and with too many trucks, they would incur additional costs while waiting to be loaded. Cost calculations were done for three levels of utilization, as determined by the dispersion of the roadside residuals (Table 1).

Table 1. Productivity and cost for chipping roadside residuals.

Roadside residual loading	Estimated Chipping Productivity (ODt/PMH)	Chipping Cost (\$/ODt)
Light	20	21.56
Medium	25	17.25
Heavy	30	14.38

Satellite Chipping

The satellite system was used when the sawlog content had declined to a point where the fixed costs made conventional harvesting uneconomic, but there was sufficient sawlog volume to make full-tree chipping unacceptable. FERIC assumed this point would occur when fuelwood exceeded 50% of the stand volume as determined by the shelf-life model. Trees would be hauled full-length to a central yard using off-highway trucks, thus one yard could service several harvesting sites. This system was the highest-cost alternative (Table 2) because of the number of times the trees must be handled even though the sorting, processing, and chipping phases could achieve some economies of scale. Two locations were examined for the sortyard: near the harvesting site (“remote satellite yard”) and near the power plant (“in-town satellite yard”). As an alternative to conventional delimiting practices, the sawlogs could be delimited and cut to length using a trailer loader with integral delimitter and topping saw, or a pull-through delimitter working in tandem with a conventional hydraulic loader.

Table 2. Summarized production costs through remote and in-town satellite yards (excluding haul costs).

Average tree size and stand type	Remote Satellite Yard		In-town Satellite Yard		Conventional Harvesting
	Chips (\$/ODt)	Logs (\$/m ³)	Chips (\$/ODt)	Logs (\$/m ³)	Logs (\$/m ³)
0.2 m ³ /tree					
Mixed stand	35-37	15-17	52-54	22-23	14
Pure pine	38-41	17-18	54-57	23-24	
0.3 m ³ /tree					
Mixed stand	29-30	13-14	42-43	18-19	11
Pure pine	31-33	14-15	44-47	19-20	
0.4 m ³ /tree					
Mixed stand	26-27	11-12	36-38	15-16	10
Pure pine	28-29	12-13	38-39	16-17	

Full-Tree Chipping

As the proportion of sawlog was reduced to nearly zero, a breakeven point developed where the cost to sort the sawlogs from the fuelwood exceeded any additional value gained. Beyond the breakeven point, stands should be harvested by full-tree chipping all of the volume in each cutblock. FERIC assumed the threshold level to be 95% or more fuelwood in the stand.

Costs for chipping were calculated using either an integrated loader/chipper as in the roadside residual scenario, or a separate chipper and loader (Figure 4). Costs were about the same for both systems. No sorting or log-manufacturing is required, so higher productivity is possible than for the roadside or satellite systems. Fuelwood must support the full costs of the falling and skidding because no sawlogs are produced from the system. Note also that costs exclude layout, road development, silviculture, and other overhead activities that would be borne by the sawlogs harvested from the other systems, so actual costs will be higher than reported. As with the satellite systems, costs depend on the tree size, and this system is applicable only to pure pine stands (Table 3).



Figure 4. Full tree chipper situated on a landing, and loading directly into chip van.

Table 3. Falling, skidding, chipping, and loading costs for full-tree chipping.

Average Tree Size (m ³ /tree)	Chips (\$/ODt)
0.2	27.11
0.3	23.49
0.4	20.91

Hauling

Haul costs were based on travel speeds for various road classes, and the distribution of road classes for various regions of the study area. Haul times includes allowances for loading, unloading, and delays. Costs were based on 13.0 and 21.5 ODt payloads respectively for semi-trailer and B-train trucks. Below a certain moisture content (typically about 50% moisture content, wet basis), chip vans are limited by volume rather than by weight, and once a truck is into the volume-limited condition, the payload expressed in terms of ODt is constant for all values of the moisture content. The average moisture content of the dead pine is assumed to be about 25%, therefore the loads are limited by volume.

Hauling costs for chips ranged between \$30-38/ODt¹ at 100 km one-way haul distance, depending on the type of truck (Figure 5).

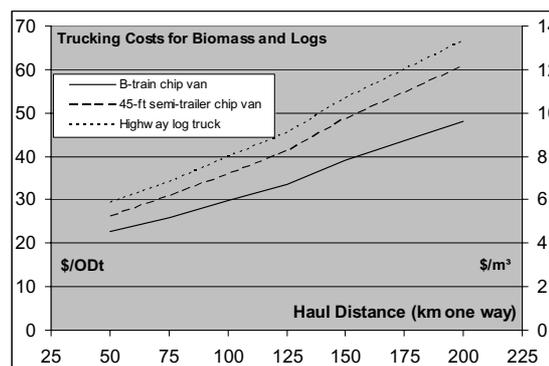


Figure 5. Estimated trucking costs for biomass and logs.

Comminution and Hauling Costs

The comminution and hauling costs were summed to estimate the total costs over typical haul distances (Figure 6). The cost for roadside residuals averaged about \$45-54/ODt for all processing and hauling, depending on the concentration of residuals at the roadside. Costs from pure pine stands with 0.3 m³ average tree size and processed through a remote satellite yard are estimated at \$63-65/ODt. Chip costs from full-tree chipping in pure pine stands with 0.3 m³ average tree size were \$53-56/ODt. As mentioned, these are direct costs only, and the costs for the latter two systems exclude the costs for layout, road development, silviculture, and other overheads that are borne by the conventional harvesting in the first system. These costs are estimated to add \$30-

¹ All costs are expressed as Canadian dollars.

41/ODt onto the direct costs of the satellite and full-tree chipping systems.

The costs for fuelwood depend on the average tree size, the stand type, the average haul distance as determined by the years past mortality, the satellite yard location, and the amount of sawlog in the stand. Changing the model parameters will change the relative costs of the different systems. Heavier roadside residual density will reduce the cost of the residuals, but will not affect the two satellite yard scenarios. For light residual density, the costs for roadside residual and full-tree chipping are almost identical. Conversely, running the model with a larger average tree size will reduce the cost for the two satellite systems and the full-tree chipping, but will not affect the cost of roadside residuals.

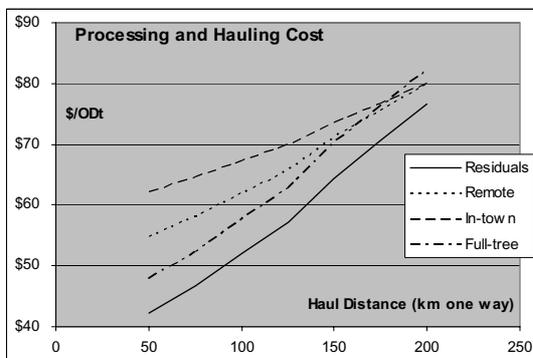


Figure 6. Processing and hauling costs under average conditions for four methods of producing biomass.

Discussion and Conclusions

This study considered two stand types that generate roadside residuals from harvesting sawlogs: mixed-species stands and pure pine stands up to 5 years past mortality. After 5 years past mortality, most of the volume of pure pine stands is forecast to degrade into fuelwood, and the sawlog content will decrease significantly. Without sufficient sawlog volume to justify the expense of layout, road development, silviculture, and other overhead costs, the licencees are unlikely to target these very-high-fuelwood stands for harvesting. FERIC assumed that stands containing more than 50% fuelwood will be avoided for harvesting sawlogs, and should no longer be considered as sources for roadside residuals.

The lowest-cost source for fuelwood is the roadside residuals generated by conventional harvesting operations, and it is the preferred system for as long

as the dead pine stands can support a conventional timber-harvesting industry. Once the stands degrade to a condition where insufficient sawlog volume exists to support the overhead costs, the licencees are unlikely to harvest from these very-high-fuelwood stands. FERIC assumed that stands containing more than 50% fuelwood will not be targeted when harvesting sawlogs, and should no longer be considered as sources for roadside residuals. A more appropriate system for such stands is to haul the logs using off-highway trucks to a satellite yard that would service several such harvesting operations. On-site full-tree chipping is the most appropriate system for stands which contain only a minor sawlog component.

Note that the direct cost does not provide a complete comparison between systems because the latter two systems omit some costs that are covered by the existing licencee in the roadside residual system (e.g., road development and silviculture), and are assumed to be provided for free to the biomass operation.

Based on FERIC's assumptions for shelf-life and harvest-system selection criteria, mixed stands will be a significant source of sawlogs and fuelwood using the roadside residuals system for most of the analysis time period. By 20 years past mortality the roadside residuals volume from mixed stands will be reduced significantly. The pure pine stands are impacted more quickly; roadside residuals from these stands are a significant source of fuelwood only until 5 YPM, after which point their volume is reduced to zero. At 10 YPM, the majority of volume from pure pine stands is suitable for satellite yard operations, but full-tree chipping comprises more volume at 15 and 20 YPM.

Depending on the utilization specifications for sawlogs, there was 22-145 ODt/ha of roadside residual, representing from about 15% to over 50% of the original stand biomass. There was an additional 8-30 ODt/ha of residuals dispersed across the cutblocks, but almost all of that volume was in pieces too small to be harvested with existing equipment. When compiled to more contemporary utilization standards, the dispersed residuals represented less than 2 ODt/ha, and were omitted from any further consideration.

This report is an abridged version of the original project report that is available on FERIC's website: www.feric.ca.

Literature Cited

- Eng, M., Fall, A., Hughes, J., Shore, T., Riel, B., Hall, P., Walton, A. 2005. Provincial-Level Projection of the Current Mountain Pine Beetle Outbreak: an Overview of the Model (BCMPB v2) and Results of Year 2 of the Project. Working Paper 2005-20. Natural Resources Canada, Canadian Forest Service, Victoria BC. 56 p.
- Hardy, C.C. 1996. Guidelines for estimating volume, biomass, and smoke production for pile slash. Gen. Tech. Rep. PNW-GTR-364. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, OR. 17 p.
- Sutherland, B.J. 1986. Standard assessment procedures for evaluating silvicultural equipment: a handbook. Ministry of Supply and Services Canada Catalogue No Fo42-92/1986E 96 p.

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PRODUCTION AND COST OF HARVESTING AND TRANSPORTING SMALL-DIAMETER TREES FOR ENERGY

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Abstract: Climbing fuel costs and scarcity of petroleum fuels have renewed interest in forest biomass for energy in the United States. The cost of harvesting, grinding, and transporting small-diameter trees often exceeds revenues due to high costs associated with harvesting and transportation and low market values for forest biomass. Productivity and cost were evaluated in a whole-tree harvesting system on four fuel reduction treatment units in Arizona. Thinning required removal of trees less than 5.0 inches in diameter at breast height (DBH). Harvest productivity for each machine in the system ranged from 4.89 to 39.60 green tons per productive machine hour (GT/PMH). Harvest system costs, including transportation, averaged \$46.91 per green ton. Hauling costs, highest over spur and unpaved roads, represented more than half the total cost. Close to market operation, reduced off-highway hauling, shortened skidding distance, and increased harvest tree size could significantly reduce cost. Without subsidies, breaking even or realizing profit would remain difficult.

Key words: Hog fuel, production rate, production cost.

Introduction

Dense, small-diameter stands of timber have been viewed as a major issue associated with fighting wild forest fires in the interior western United States (USDA Forest Service, 2001). In the last decade forest fires have increased in Arizona and New Mexico (Moir et al., 1997). The worst forest fire in Arizona to date, the Rodeo-Chediski fire in 2002, consumed 467,066 acres of forestland.

Dense, small-diameter stands generally require thinning from below to improve fire-tolerance (Graham et al., 2002; Healthy Forests, 2002). The amount of woody biomass resulting from increased thinning activities could be substantial. To ensure a thinning operation reduces fire risk for the residual stand, the operation must either remove sub-merchantable trees and logging slash completely through biomass harvesting or carefully burn the fuels using a prescribed fire (Han et al., 2002). Due to the heavy emissions of smoke and air pollutants from open burning of biomass residues, prescribed burning is increasingly limited as a tool for fuel reduction (Bolding, 2002; Morris, 1999). However, power generation creates an opportunity to use forest biomass (Sampson et al., 2001; Morris, 1999).

Use of forest biomass will become commonplace only when it becomes economically advantageous for users (GAO-05-373, 2005). Harvesting, processing, and transporting forest biomass stems of non-merchantable size are expensive when using conven-

tional harvesting system, due to decreased production (Han et al., 2002). How to lower the production cost has become the critical question in the feasibility of using forest biomass for energy. This study looked at the production and cost of harvesting, processing, and transporting small-diameter ponderosa pine trees less than or equal to 5.0 inches in diameter at breast height (DBH) for energy. The results of this study should improve our knowledge of cost reduction when harvesting small-diameter trees for energy.

Methods

Study site and harvesting system

The study sites were located in Springerville and Black Mesa, Arizona. The two sites were stocked with almost 100% ponderosa pine (*Pinus ponderosa*) trees. The ground slope of two sites ranged from 0% to 28%. Each site was laid out by GPS instruments, forming two 10-acre sub-units. Thirty systematic sampling plots were established throughout each unit to collect pre and postharvest stand inventory data. The silvicultural prescription required removal of all trees less than or equal to 5.0 inches in DBH.

A whole-tree system was used to harvest the trees. It included a three-wheel hot-saw feller-buncher (Valmet 603) that felled and bunched trees prior to skidding them using a rubber-tire grapple skidder (CAT 525B). Each unit had one main skid trail cut by the feller-buncher. The skidder would choose random skid trails from the main skid trail to bunched trees.

The main skid trail distance ranged from 700 feet to 1,400 feet, with an average of 1,025 feet. A log loader (Prentice RT-100) was used at the landing to feed the whole trees into a remote-controlled horizontal grinder (Bandit Beast 3680). The resulting processed hog fuel was loaded into a chip van (walking floor) directly through the grinder's conveyor. Chip vans that could be linked-up or disconnected from the truck were used for landing-to-market hauling. The hog fuel was sent to the Western Renewable Energy Co. in Eagar for site 1 and to the RENEGY LLC in Snowflake for site 2. The one-way transportation distance ranged from 29.5 to 36 miles.

Data collection and analysis

A preharvest cruise measured DBH, tree height, and tree count in each 0.02-acre sampling plot to estimate unit average DBH, tree height, and number of trees per acre. To allow collection of postharvest stand inventory data, plot centers were staked, numbered, and flagged; plot edges were painted; and two out-of-plot reference trees were flagged with angle and distance to the plot center. After harvesting, the same inventory measurements were recorded again.

Hourly machine costs measured in dollars per scheduled machine hour (\$/SMH) were estimated using a standard machine rate calculation (Miyata, 1980), summarized in Table 1. New machine prices, insurance, taxes, interest, lube cost, tire and chains cost, and repair and maintenance cost were obtained from the project contractor. The diesel consumption amount and the utilization rate (PMH/SMH) for each machine were calculated from actual operations. Diesel prices were determined from local market prices in effect during the study. Estimated economic life for all the machines was set at five years assuming 2000 scheduled machine hours per year. Salvage value was set at 20%. Overhead and profit were not included in the hourly machine cost.

To obtain machine production rate in terms of green tons per productive machine hour (GT/PMH), regression equations were developed for machine cycle time. A feller-buncher cycle started with a move to the tree, followed by multiple cuttings, and ended with the placement of the bunch on the ground. A skidder cycle consisted of traveling empty from the landing, positioning, grappling, traveling loaded to the landing, and unloading in sequence. A log loader cycle began when grappling the trees from the landing piles, then swinging to the grinder, in-feeding, and ended when swinging back to the pile. The grinder worked continuously until a chip van was fully loaded; therefore, the time for loading a chip

van was used as a grinder cycle. A hauling cycle started with the loading of the chip van, followed by traveling loaded to the energy plant, unloading, and traveling back empty to the landing. All the variables were identified prior to the start of operations. Time study data were examined for normality, outliers, and collinearity. The ordinary least squares regression in SHAZAM statistical analysis package was performed to develop these predictive equations. Average observed values for independent variables provided by the time study were used in the regression model to predict the cycle time.

In addition, the average tree weight was calculated using the formula (Jenkins et al., 2003):

$$BW = 2.2046 \cdot \text{Exp}(-0.4198 + 2.4349 \cdot \ln DBH)$$

where

BW = total above ground biomass weight, lb
DBH = tree diameter at breast height, inches
-0.4198 and 2.4349 are parameters for ponderosa pine trees.

Sensitivity analysis tested different variables in developed regression models while keeping all the other variables constant. The resulting value change in cycle time was then converted to a production cost change. Scatter plots showed how the production cost changed with the corresponding value change in the tested variables, which included one-way spur road distance, unpaved road distance, highway distance, and skidding distance.

Results

Thinning effects

Due to the removal of most small trees, stand characteristics changed dramatically with a decrease in stand density and increases in both average DBH and tree height (Table 2). In unit 1, 86% of the small trees were removed. This percentage for units 2, 3, and 4 was 95%, 98%, and 97%, respectively. The lower small tree removal rate in unit 1 was caused by the scattered distribution of the larger trees (DBH > 5.0 inches). Difficulties in maneuvering between trees caused the feller-buncher to occasionally forego cutting target trees to avoid damaging leave trees.

Some larger trees (DBH 5.1-7 inches) were removed during the operation (Figures 1, 2, 3, and 4). Errors in visual estimates might lead the operator to cut trees slightly larger than 5.0 inches in DBH. Sometimes a large tree was cut when it stood in the way and the operator could not identify a better route.

Table 1: Machine hourly cost (\$/SMH) information.

	Feller-buncher	Skidder	Loader	Grinder	Chip van
Year	2003	2002	N/A	2002	1989-1998
Manufacture	Valmet	CAT	Prentice	Bandit Beast	N/A
Model	603	525B	RT-100	3680	N/A
Number of machines	1	1	1	1	2
Initial price (\$)	140,000	240,000	180,000	260,000	400,000
Salvage value (%)	20	20	20	20	20
Economic life (yr)	5	5	5	5	5
Interest (%) ^a	8.51	8.51	8.51	8.51	8.51
Insurance (\$/yr)	900	1,800	1,800	3,000	2,800
Taxes (%)	0	0	0	0	0
Yearly SMH	2,000	2,000	2,000	2,000	2,000
Annual DEP	22,400	38,400	28,800	41,600	32,000
AAI	95,200	163,200	122,400	176,800	136,000
Interest (\$/yr)	8,472.8	13,708.8	11,383.2	12,818	11,832
Owning cost (\$/yr)	31,401.52	54,088.32	41,016.24	59,645.68	92,747.20
Owning cost (\$/SMH)	15.70	27.04	20.51	29.82	46.37
Fuel price (\$/gal)	2.9	2.9	2.9	2.9	3.2
Fuel use amount (gal)	294.9	165.5	80.2	519.9	977
Total productive time (min)	2,960	1,963	1,803	1,788	5,334
Fuel cost (\$/PMH)	17.33534	14.66989	7.739767	50.5943	35.1676
Lube amount (gal/SMH)	0.025	0.04	0.025	0.05	0.1
Lube price (\$/gal)	10	10	10	10	10
Lube cost (\$/SMH)	0.25	0.4	0.25	0.5	1
Tires / Chains (\$/SMH)	3.5	2.5	0.4	0	8
Repair / Maintenance (\$/SMH)	5	0.5	5	49	3
Filter / others (\$/SMH)	0.5	0.75	0.5	1	4
Operational cost (\$/PMH)	27.84	20.95	17.74	133.60	55.59
Overall utilization (%)	88.07	66.09	61.47	60.84	78.35
Operational cost (\$/SMH)	24.52	16.35	10.91	56.78	43.55
Labor (\$/SMH)	26.61	26.61	26.61	0	52.67 ^b
Total hourly cost (\$/SMH)	66.83	70.00	58.03	86.60	142.60
Total hourly cost (\$/PMH)	75.88	105.92	94.40	142.34	182.00

a: The interest rate applied here is the average value for all the machines interest rate.

b: In the first 6 days of operation, 1 highway truck driver (\$26.61/hr) and 1 onsite truck driver (\$19.41/hr) were hired. The total labor cost was \$46.02/SMH. In the last 2 days of operation, the second highway truck driver was hired. The total labor cost was \$72.63/SMH. Therefore, the average weighted labor cost during this study was: $46.02 \cdot (6/8) + 72.63 \cdot (2/8) = 52.67$ (\$/SMH). Labor includes benefits.

Table 2: Pre and Postharvest stand inventory information.

		DBH (inch)		Number of trees (per acre)		Tree Height (feet)	
		Mean	S.D.	Mean	S.D. ^a	Mean	S.D.
Unit 1	Preharvest	5.11	5.13	670	6.98	27.30	18.19
	Postharvest	8.72	6.38	264	3.41	41.17	25.43
	Difference	3.61	--	-406	--	13.87	--
Unit 2	Preharvest	5.41	4.06	678	8.76	26.50	21.87
	Postharvest	9.07	3.26	294	3.31	43.34	14.23
	Difference	3.66	--	-384	--	16.84	--
Unit 3	Preharvest	1.76	1.61	5,898	93.94	10.71	7.06
	Postharvest	5.70	4.76	225	4.42	20.50	19.64
	Difference	3.94	--	-5673	--	9.79	--
Unit 4	Preharvest	1.91	2.60	3,274	43.64	9.13	10.71
	Postharvest	7.84	6.15	252	3.63	29.25	24.63
	Difference	5.93	--	3,022	--	20.12	--

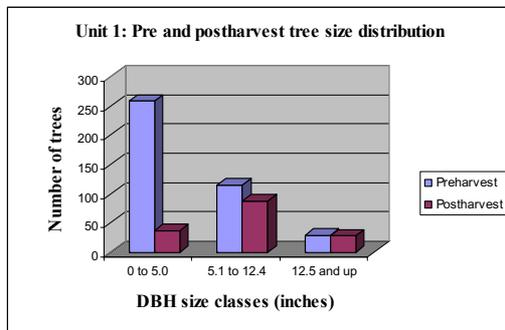


Figure 1: Unit 1 Pre and Postharvest tree size distribution.

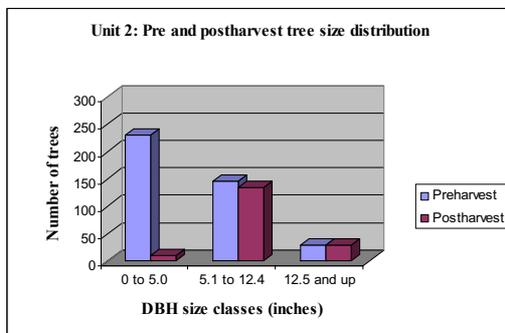


Figure 2: Unit 2 Pre and Postharvest tree size distribution.

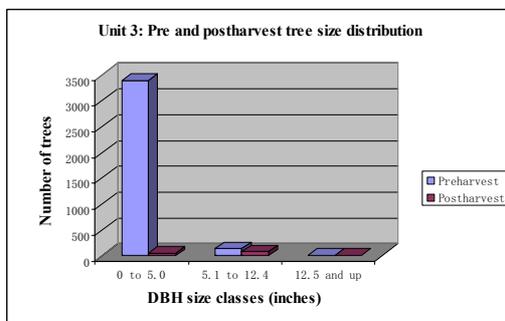


Figure 3: Unit 3 Pre and Postharvest tree size distribution.

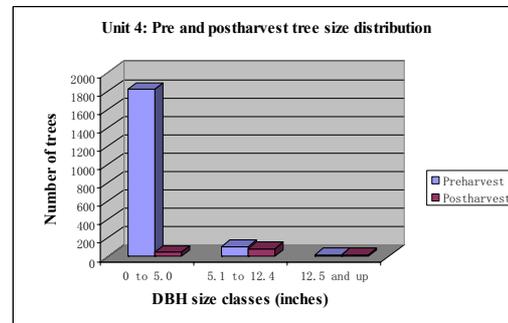


Figure 4: Unit 4 Pre and Postharvest tree size distribution.

Production rates

Machine cycle time predicted by regression equations is indispensable to calculate the harvesting production rate (Tables 3, 4, and 5). Regression equations developed from the time study have significant P-values for all the associated variables ($\alpha = 0.05$). The feller-buncher equation reflected that all the moving distances significantly affected the cycle time. It indicated a denser stand requiring shorter moving distances resulted shorter cycle time. The skidder regression function omitted DBH due to collinearity with number of stems per skidder cycle (NTS) and statistical insignificance to predict the skidding cycle time. The equation implied that a decrease in skidding distance would reduce cycle time. Provided a constant skidding distance, a shorter cycle time could be achieved by dragging more trees per cycle, which would require the feller-buncher to make larger bunches. Tree size and swing degrees positively impacted the loading cycle time, implying using a tree decking close to the grinder, requiring a small swing angle and loading small trees would decrease the cycle time. In the loader regression equation, both number of trees per loader cycle (NTL) and DBH were significant for loading cycle time prediction; therefore, they were kept in the equation despite the

collinearity. Total biomass weight processed by the grinder was the only factor influencing grinding cycle time. It generally takes longer for a grinder to process a larger tree, but tree size became insignificant for grinding trees less than 5.0 inches in DBH. For a relatively short period of time, moisture had no sig-

nificant effect on grinding cycle time. The transportation distance on various road types positively affected the hauling cycle time. Moreover, the coefficients in the model suggested that given the same distance, spur roads had the greatest effect on cycle time, while highway influence became minor.

Table 3: Delay-free cycle time equations for harvesting machines. All variables included in the equations have a significant P-value less than 0.05.

Machine	Average cycle time estimator (centi-min)	r ²	n
Feller-buncher	0.4203MTT + 7.1155NOC + 0.3431ITD + 0.4595MTB – 2.5276	0.8849	634
Skidder	0.1380TED + 0.5207 POSI – 0.4472 NTS + 0.1068TLD + 70.0000	0.9119	146
Loader	0.0703NTL + 0.3630DBH + 0.1589SID + 0.0999SBD + 7.5864	0.5154	1,077
Grinder	0.1338WT – 307.0800	0.7455	30
Chip van	0.1100WT + 262.6400HWY + 995.2400UPRD + 10078.0000SRD + 3149.6000	0.9596	29

MTT – move-to-tree distance (feet); NOC – number of cut actions per felling cycle; ITD – intermediate travel distance in a cutting cycle (feet); MTB – move-to-bunch distance (feet); TED – travel empty distance (feet); POSI – positioning distance (feet); NTS – number of trees per skidding cycle; TLD – travel loaded distance (feet); NTL – number of trees per loading cycle; DBH – tree diameter at breast height (inches); SID – swing-in degree; SBD – swing-back degree; WT – hog fuel weight per truck load cycle (lb); HWY – one-way highway distance (miles); UPRD – one-way unpaved road distance (miles); SRD – one-way spur road distance (miles).

Table 4: Summary of time study variables.

Machine	Variable	Max	Min	Mean
Feller-buncher	MTT (feet)	210	2	26.78
	NOC	25	1	7.03
	ITD (feet)	600	5	83.73
	MTB (feet)	250	0	22.75
Skidder	TED (feet)	1385	22	531.67
	POSI (feet)	200	10	47.73
	NTS	172	8	50.89
	TLD (feet)	1347	20	516.18
Loader	NTL	53	1	10.26
	DBH (inches)	8	1	2.92
	SID (degrees)	150	30	81.82
	SBD (degrees)	165	5	81.72
Grinder	WT (lb)	58060	22600	45011.33
Chip van	WT (lb)	58060	22600	45011.33
	HWY (miles)	36	8.5	27.07
	UPRD (miles)	13.5	0	2.34
	SRD (miles)	1.5	0	0.069

Table 5: Predicted delay-free cycle time (min) and production rate (GT/PMH).

Feller-buncher	Skidder		Loader		Grinder		Chip van			
	Cycle time	Prod. rate	Cycle time	Prod. rate	Cycle time	Prod. rate	Cycle time	Prod. rate	Cycle time	Prod. rate
Unit 1	1.12	12.00	3.00	10.11	0.31	39.60	69.05	23.42	308.82	4.89
Unit 2	1.03	14.36	2.70	16.52	0.33	20.09	60.00	23.42	236.60	5.57
Unit 3	0.52	7.36	1.56	21.59	0.29	17.67	55.03	23.67	159.34	7.97
Unit 4	1.02	9.91	1.54	33.37	0.32	24.08	55.87	23.65	150.62	9.13
Average	0.98	11.84	2.01	19.70	0.31	23.20	57.15	23.63	181.16	7.27

Information about the average biomass weight per cycle also is required to calculate the production rate. Because the number of cut trees per feller-buncher cycle (NTF) was difficult to observe, NTS was used to estimate the NTF, as field observation verified the feller-buncher generally needed two cycles to make a large bunch for the skidder. When regressing skidder cycle time, collinearity was detected between the NTS and the average DBH: $NTS = 106.87 - 18.253 \cdot DBH$, $r^2 = 0.48$. The average tree DBH for the observed feller-buncher cycles was 2.21 inches, which meant an average of 33 trees or 387 lb biomass were cut per cycle. Using the average DBH information, the biomass weight per cycle for the skidder and the loader were calculated to be 1,317 lb and 236 lb, respectively. Energy plant tickets showed the grinder and chip van cycle biomass weights ranged from 42,351 lb to 50,380 lb, averaging 43,898 lb.

Combining the predicted cycle time with the cycle biomass weight, production rates for all the machines were determined from 4.89 to 39.60 GT/PMH. Predicted productivity for all the machines by cutting units is presented in Table 5. The feller-buncher achieved the shortest cycle time in unit 3, but it had

the lowest production rate of 7.36 GT/PMH there due to the lowest cycle biomass weight of 128.75 lb. The same thing happened in the loading stage. The loader had the smallest swing-in degree (75.88°), swing-back degree (75.36°), and loading tree DBH (2.31 inches) in unit 3, which led to the shortest cycle time. However, because of the smallest DBH, the lowest cycle biomass weight of 170.34 lb resulted there, yielding the lowest production rate of 17.67 GT/PMH. To improve the production rate, for felling and loading, harvesting larger trees is more important than reducing the cycle time. The highest skidding production rate of 33.37 GT/PMH appeared at unit 4, which had an average skidding distance of 347 feet compared with 884 feet in unit 1, where the skidder had the lowest production rate. The grinder's production rates, averaging 23.50 GT/PMH, were quite uniform across the four units. The transportation achieved the highest production rate of 9.13 GT/PMH in unit 4, while significantly lower production rates appeared in units 1 and 2. Although units 1 and unit 2 enjoyed shorter highway distances to the energy plant, they had to cover 8 and 10.5 one-way miles of unpaved road plus 1.5 extra one-way miles of spur road in Unit 1 (Table 6).

Table 6: Road type, one-way distance, and average speed.

	Spur road (miles)	Unpaved road (miles)	Paved road (miles)	Highway (miles)	Total (miles)
Unit 1	1.5	8	2.5	17.5	29.5
Unit 2	0	10.5	1	22.5	34
Unit 3	0	0	0	35	35
Unit 4	0	0	0	36	36
Average speed (miles/hour)	2.67	13.83	14.40	44.14	--

Delays

Table 7 summarizes the delay types and associated delay time for all harvesting machines. Production time, delay time, and utilization rate for the equipment are presented in Table 8. Machine cooling due

to hot season operation, teeth replacement because of rocks, and diesel refueling created 38.4%, 18.1%, and 29.6% of the feller-buncher delay time, respectively. However, because the feller-buncher could work independently from other machines, it achieved the highest utilization rate in the system of 88.1%.

The skidder, loader, grinder, and chip van operated as a “hot” system, meaning one component of the system could be affected by the productivity of another component. Regression analysis showed the predicted cycle times for hauling and grinding were around 181 minutes and 57 minutes. This indicated that delays of “waiting on truck” existed. The shift-level data verified that waiting for truck caused the largest portion of the skidder, loader, and grinder delay. In units 1, 2, and most of the time in unit 3, only one highway truck driver was hired. More than one trailer was used in the system, which allowed the grinder to work when the truck driver was not present, yet hauling capacity was still not enough to match the production of other parts of the system. This was due to the long hauling cycle time com-

pared with the grinding cycle. Hiring a second highway truck driver in unit 4 reduced “waiting on truck” time significantly.

The skidder had the least “waiting on truck” delay in the hot system. Even when the loader and the grinder were shut down, the skidder could drag trees from the stand and deck them at the landings. The loader experienced 13 minutes more “waiting on truck” delay than did the grinder because the loader tended to start later when a chip van arrived. The chip van had the longest “waiting on truck” time. The truck driver tried to increase hauling capacity by working longer days than the rest of the crew, resulting in more “waiting on truck” time for loaded chip vans.

Table 7: Machine delay time summary.

		Operational delay	Mechanical delay	Personal and others	Total
Feller-buncher	Delay (min)	14	331	56	401
	% of total	3.49	82.54	13.97	100
Skidder	Delay (min)	881	117	9	1007
	% of total	87.48	11.62	9.00	100
Loader	Delay (min)	978	3	149	1130
	% of total	86.55	0.27	13.18	100
Grinder	Delay (min)	965	13	173	1151
	% of total	83.84	1.13	15.03	100
Chip van	Delay (min)	1237	25	212	1474
	% of total	93.08	1.70	5.22	100

Table 8: Production time, delay time, and utilization rates.

		Feller-buncher	Skidder	Loader	Grinder	Chip van
Unit 1	Production time (min)	418	331	342	332	604
	Delay time (min)	91	271	262	271	437
	Utilization rate (%)	82.1	55.0	56.6	55.1	58.0
Unit 2	Production time (min)	403	286	278	248	1237
	Delay time (min)	33	214	214	250	411
	Utilization rate (%)	92.4	57.2	56.5	49.8	75.1
Unit 3	Production time (min)	1489	1011	869	892	2470
	Delay time (min)	112	379	513	491	539
	Utilization rate (%)	93.0	72.7	62.9	64.5	82.1
Unit 4	Production time (min)	650	335	314	316	1023
	Delay time (min)	165	143	141	144	87
	Utilization rate (%)	79.8	70.1	69.0	68.7	92.2
Total	Production time (min)	2960	1963	1803	1788	5334
	Delay time (min)	401	1007	1130	1151	1474
	Utilization rate (%)	88.1	66.1	61.5	60.8	78.3

Production costs

The stump-to-market costs for each machine and their percentage in total are summarized in Table 9. The total production costs ranged from \$37.19/GT to \$78.23/GT. The overall production cost was \$46.91/GT. The transportation cost, which represented 53.36% of the total cost, was the largest component, suggesting the importance of operation close to the market. The skidder and the grinder remained at the same production cost level due to similar overall production rates and hourly machine costs. Although the feller-buncher had the lowest hourly machine cost, its production rate was the second lowest in the system, resulting in a production cost similar to those of the skidder and the grinder. The lowest production cost was attributed to the loader, which had the second lowest hourly machine cost and the second highest production rate in the system.

Table 10 summarizes the descriptive parameters of each forest unit and the associated hog fuel production cost. The production costs showed a positive relationship to the average DBH and a negative correlation with the number of trees per acre. The costs were also related positively to average skidding distance and negatively to one-way hauling distances. The hauling distance increase in this study was an integrated result of spur road and unpaved road distance decrease and highway distance increase. Due to the minor effect of highway distance compared with that of spur road and unpaved road distance, the total cost was decreased, even though the total hauling distance increased. The hauling cost accounted for over 50% of the total production cost. The effect of this major cost component overrode the effect of decreased DBH and lowered the total production cost with the decreasing DBH.

Table 9: Stump-to-market production cost and percentage in total.

	Feller-buncher		Skidder		Loader		Grinder		Chip van		Total	
	Cost (\$/GT)	% of total	Cost (\$/GT)	% of total	Cost (\$/GT)	% of total	Cost (\$/GT)	% of total	Cost (\$/GT)	% of total	Cost (\$/GT)	% of total
Unit 1	6.77	8.65	12.28	15.70	2.59	3.31	6.42	8.21	50.17	64.13	78.23	100
Unit 2	5.03	8.86	7.34	12.92	5.03	8.86	6.72	11.83	32.67	57.53	56.79	100
Unit 3	9.85	20.58	4.54	9.49	5.25	10.97	5.93	12.39	22.29	46.57	47.86	100
Unit 4	8.32	22.37	2.95	7.93	3.50	9.41	5.44	14.63	16.98	45.66	37.19	100
Overall	6.41	13.66	5.38	11.47	4.07	8.68	6.02	12.83	25.03	53.36	46.91	100

Table 10: Stand descriptive parameters and the associated cost of hog fuel production.

	Preharvest avg. stand DBH (inches)	Preharvest number of trees (per acre)	Avg. skidding distance (feet)	One-way hauling distance (miles)	Cost (\$/GT)
Unit 1	5.11	670	884	29.5	78.23
Unit 2	5.41	678	693	34	56.79
Unit 3	1.76	5898	370	35	47.86
Unit 4	1.91	3274	347	36	37.19
Overall	2.25	2630	574	33.63	46.91

Sensitivity analysis

The effect of hauling distance on total cost was determined by setting one-way distance to 5, 10, 15, and 20 miles for highway, unpaved road, and spur road, respectively. Although different road distances will change the truck diesel consumption, this effect was omitted here. The sensitivity test showed overall production cost changed at rates of \$0.18, \$0.69, and \$6.96 per green ton for each mile of highway, unpaved road, and spur road, respectively (Figure 5).

The greater influences of unpaved road and spur road indicated that reducing off-highway hauling should receive more attention to reduce the production cost.

The overall average skidding distance when traveling empty was 532 feet, the average travel loaded distance was 516 feet, and the total overall production cost was \$46.91/GT. Using these numbers as a base, costs were calculated for both skidding distance reductions and increases of 100 feet and 200 feet. The

sensitivity test showed given a 100 feet average skidding distance change, the overall production cost fluctuated by \$0.66/GT in the same direction as the change (Figure 6). The effect of a 100-foot skidding

distance on cost is nearly equivalent to the cost change of travel on 1 mile of unpaved road. Shortening the skidding distance should factor highly in the harvest planning work.

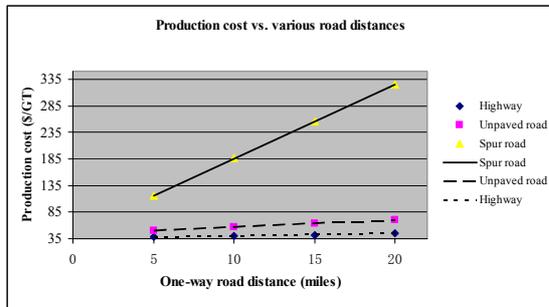


Figure 5: Sensitivity test – effect of various road distances on production cost.

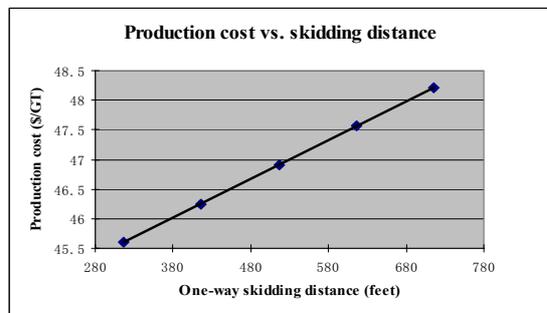


Figure 6: Sensitivity test – effect of average skidding distance on production cost.

Discussion

Both the time study and the regression analysis indicated that “waiting on truck” time caused an unbalanced system, which meant production rates and costs were not entirely comparable across the four units. Technically, many methods, such as using more trucks and choosing site closer to market can reduce the “waiting on truck” time. But these methods will change hourly machine costs and production rates. To keep the analysis simple, the hourly machine cost and production rate for all the machines were kept at the observed conditions.

Table 11 summarizes delay time and the associated utilization rate for an assumed balanced system by deleting the “waiting on truck” time. The balanced system cost is summarized in Table 12. The loading cost, 66.6% of the unbalanced condition, was reduced most significantly, due to the highest increase in its utilization rate. The overall production cost was reduced to \$37.45/GT, representing 79.8% of the overall production cost in the unbalanced condition.

Table 11: Delays and utilization rates without “waiting on truck” time.

		Feller-buncher	Skidder	Loader	Grinder	Chip van
Unit 1	Production time (min)	418	331	342	332	604
	Delay time (min)	91	89	91	107	107
	Utilization rate (%)	82.1	78.8	79.0	75.6	85.0
Unit 2	Production time (min)	403	286	278	248	1237
	Delay time (min)	33	0	0	4	25
	Utilization rate (%)	92.4	100	100	98.4	98.0
Unit 3	Production time (min)	1489	1011	869	892	2470
	Delay time (min)	112	8	13	19	18
	Utilization rate (%)	93.0	99.2	98.5	97.9	99.3
Unit 4	Production time (min)	650	335	314	316	1023
	Delay time (min)	165	29	48	56	87
	Utilization rate (%)	79.8	92.0	86.7	84.9	92.2
Total	Production time (min)	2960	1963	1803	1788	5334
	Delay time (min)	401	126	152	186	237
	Utilization rate (%)	88.1	94.0	92.2	90.6	95.7

Table 12: Stump-to-market production cost without “waiting on truck” time.

	Feller-buncher (\$/GT)	Skidder (\$/GT)	Loader (\$/GT)	Grinder (\$/GT)	Chip van (\$/GT)	Total (\$/GT)
Unit 1	6.77	8.79	1.85	4.89	34.31	56.61
Unit 2	5.03	4.24	2.89	3.76	26.12	42.04
Unit 3	9.85	3.27	3.33	3.74	18.02	38.21
Unit 4	8.32	2.28	2.78	4.32	16.94	34.64
Overall	6.41	3.78	2.71	4.05	20.50	37.45

Forest biomass piled at landings as residues of conventional logging can be used for energy. Processing forest biomass piled at landings avoids the costs for felling and skidding, but the loading, grinding, and hauling costs need be considered. In our study, if the felling and skidding costs were excluded, the remaining cost would be \$35.12/GT, or 74.9% of the observed cost. If the system was balanced and the felling and skidding costs were excluded, the loading, grinding, and transportation cost would be \$27.26/GT, or 58.11% of the observed cost for this study.

Given the average market hog fuel price of \$40 per bone dry ton, or \$20 per green ton, assuming 50% moisture in the hog fuel, it is not sufficient to break even the observed production cost of \$46.91/GT without any subsidies. The U.S. Congress authorized a \$20 per green ton subsidy for biomass in the 2005 Energy Bill. Given the availability of this subsidy, the average hog fuel price can be up to \$40 per green ton. At this price, if the machine system for this study is balanced, the biomass harvesting, processing, and transporting for energy will be economically feasible.

Conclusion

This study monitored a successful operation involving a mechanized fuel reduction thinning of small-diameter timber stands and the uses of forest biomass for energy. Under the conditions: target tree DBH \leq 5.0 inches, stand densities 670 to 5,898 trees per acre, skidding distances 347 to 884 feet, and one-way hauling distance of 29.5 to 36 miles, the production costs were found to range from \$37.19 to \$78.23/GT, averaging \$46.91/GT. Hourly productivity for different machines varied from 4.89 to 39.60 GT/PMH.

The transportation cost, averaging \$25.03/GT, represented more than 50% of the total cost. If the hauling distance is reduced, both a balanced system and lower cost will result. Maintaining an operation close to market is essential to make the forest biomass energy project cost-effective. For the same distance,

spur road had the strongest effect on transportation cost, followed by unpaved road, and highway. Reducing off-highway hauling should receive more attention. Shorter skidding distances decreased both the skidding cost and the total production cost. Well planned skidding placement is critical in harvest planning work. The low biomass weight per cycle in the feller-buncher and the loader operations overrode the effect of short cycle time and made their production costs very high. Harvesting larger trees should be considered. Grinding cost was quite uniform across four units since production and cost were independent of most site variables, and related only to the weight of processed hog fuel.

System balancing by reducing the operational delay greatly improved the production rate and lowered the cost. Should the operation process the biomass piled at the landing, the cost would be further reduced. The current market value of hog fuel products makes biomass harvesting difficult to break even and realize profit without any special subsidies.

Literature Cited

- Bolding, M.C. 2002. Forest fuel reduction and energywood production using a CTL / small chipper harvesting system. Master of Science Thesis. Auburn University, AL. 111p.
- GAO-05-373. 2005. Federal agencies are engaged in various efforts to promote the utilization of woody biomass, but significant obstacles to its use remain. United States Government Accountability Office. 17p.
- Graham, R.T., A. Harvey, T. Jain, and J. Tonn. 2002. The effects of thinning and similar stand treatments on forest fire behavior in western forests. USDA Forest Service, Pacific Northwest Research Station, Portland, OR. PNW-GTR-463. 27p.

Han, H.-S, J. Hinson, G. Jackson, R. Folk, H. Lee, L. Johnson, and T. Gorman. 2002. Economic feasibility of small wood harvesting and utilization on the Boise National Forest, Cascade, Idaho City, Emmett Ranger Districts: A report for Gem County Commissioners. University of Idaho, Forest Product Department, Moscow, ID. 62p.

Healthy Forests. 2002. An initiative for wildfire prevention and stronger communities. Accessed January 2, 2007 at http://www.whitehouse.gov/infocus/healthyforests/Healthy_Forests_v2.pdf. 22p.

Jenkins, J.C., D.C. Chojnacky, L.S. Heath, and R.A. Birdsey. 2003. National-scale biomass estimation for United States tree species. *Forest Science*. 49(1):12-35.

Miyata, E.S. 1980. Determining fixed and variable costs of logging equipment. USDA Forest Service General Technical Report NC-55. 16p.

Moir, W. H., B. Geils, M.A. Benoit, and D. Scurlock. 1997. Ecology of Southwestern Ponderosa Pine Forests. Pages 3-27 in Block, W. M. and D.M. Finch, tech. ed. Songbird ecology in southwestern ponderosa pine forests: a literature review. General Technical Report RM-GTR-292. Fort Collins, CO: USDA, Forest Service, Rocky Mountain Forest and Range Experiment Station. 152p.

Morris, G. 1999. The value of the benefits of U.S. biomass power. NREL/SR-570-27541.

Sampson, R.N., M.S. Smith, and S.B. Gann. 2001. Western forest health and bioenergy potential: A report to the Oregon Office of Energy. The Sampson Group, Inc., Alexandria, VA. 53p.

USDA Forest Service. 2001. Small-diameter timber on display at 2002 Winter Olympics. Forest Product Laboratory, Madison, Wisconsin. 2p.

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TRANSPORTATION PLANNING AND DECISION ANALYSIS TO DETERMINE LOW VOLUME ROAD STANDARDS, LONG TERM NEEDS, AND ENVIRONMENTAL RISKS AND TRADEOFFS

Elizabeth Dodson, Woodam Chung, Keith Mills, John Sessions

Abstract: Inventories of forest roads are used to manage road networks by chronicling existing road conditions and flagging areas that require attention. Tools are needed to integrate the environmental performance of forest roads, as captured in a road inventory, into the management of these roads. This study used a combination of a multi-criterion decision analysis tool (Analytic Hierarchy Process, or AHP) and a timber transportation model (NETWORK2000) to determine road standards to minimize both environmental and economic costs. This analysis technique is applied to the decision analysis for the transportation planning effort underway in the Wilson River forest road network in western Oregon, USA.

Key words: Road inventory, Analytic Hierarchy Process, Road management

Introduction

Forest management activities are normally planned over periods of decades or longer, since forests take many years to grow to maturity. To help plan its forest management activities, the Oregon legislature directed the Oregon Department of Forestry (ODF) to develop a model to balance timber harvesting with fish and wildlife habitat under different scenarios. Road construction and upgrading are activities considered in this modeling process. These roads access timber in locations where it will be removed from the forest based on terrain, timber volume, forest growth, and protecting fish and wildlife habitats. This process also considered recreational road uses.

This paper takes transportation planning to the next level. It combines environmental effects into a network analysis of a road system to determine road management priorities. It builds on past efforts that used expert judgment to consider both environmental and economic factors in the prioritization of road management activities. This effort will include network analysis comparing overall road costs and environmental costs of different scenarios using information from the rapid survey. This information will be used to quantify environmental risk and both short and long term road stability. We will then use a multi-criterion decision analysis method to set road management and repair priorities and to determine four primary transportation planning decisions: 1) maintenance as is; 2) new construction; 3) improvement; and 4) permanently vacating a road or road system. Weights will be assigned to environmental risks versus road management costs.

These will be displayed with different color schemes for an entire road system, both as a map, and with summary tables and graphs. Tools for identification of alternate or duplicate access will be discussed.

We will summarize the paper with potential uses of these analysis techniques, including determining where there is duplicate access, and evaluate potential for alternative access with less effect on the environment. We will close with recommendations for standardizing this process to compare costs and environmental risks, and conclude with potential applications to other regions.

Study Site

The study area lies within the 364,000 acre (147,000 ha) Tillamook State forest in the northwest coastal mountains of Oregon, and includes tributaries of the Little North Fork Wilson River. Elevation in the study area ranges from near sea level to 2,907 feet (887 m), and rainfall (and occasional snow) of between 100 and 210 inches (254 to 533 cm) annually support a mostly coniferous temperate forest. Major wildfires burned portions of the area in 1933, 1939, 1945, and 1951. After the fires, roads were constructed in order to salvage burned trees quickly. These roads were not built to current (or any) environmental protection standards. The study area contains a mixture of these old roads (often abandoned), new roads, and old roads that have been improved to lower environmental risk and improve performance. Roads in the watershed were surveyed with a comprehensive current condition and environmental risk protocol (Mills et al 2007).

Methods

Current Condition and Environmental Risk Survey

A rapid survey of road conditions affecting aquatic habitat has been developed for use on ODF lands. All open roads and a sample of closed roads in the study area were surveyed with this protocol. It is designed to consistently evaluate current road conditions and also road conditions in the immediate future as they are likely to be affected by flood-producing storms (Mills et al 2007).

Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) was used to assess the current environmental cost of each road segment within the Wilson River study area. AHP involves four steps: structuring the problem as a hierarchy, making pairwise comparisons among attributes to determine the user's preferences, reducing attributes to relative values, and ranking alternatives (see Coulter et al. 2006).

For this analysis, seven road performance metrics were chosen from the data collected during the road inventory. These seven road performance metrics were arranged into a problem hierarchy shown in Figure 1.

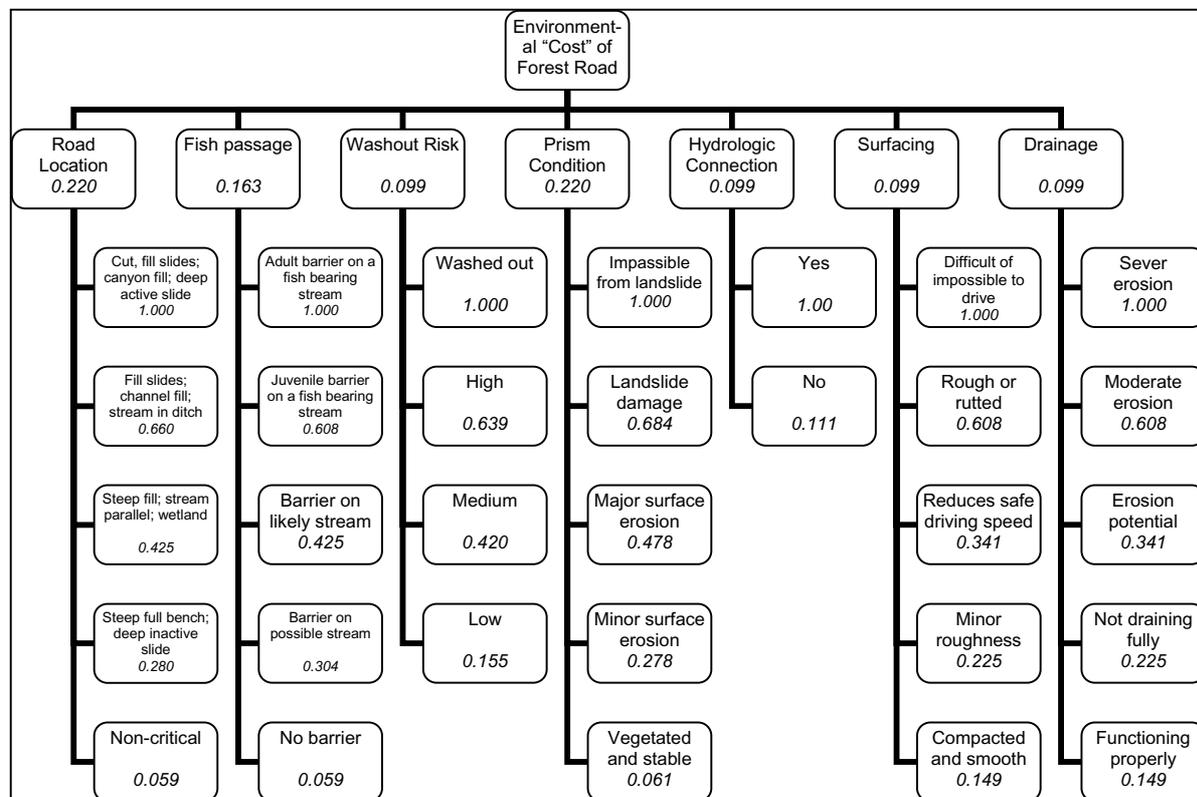


Figure 1 AHP hierarchy used to calculate the environmental cost of a forest road segment. Numbers in italics are relative weights calculated using pairwise comparisons

In order to use AHP to estimate the environmental cost of road management actions, several decisions rules were set (Table 1). The environmental cost used in network analysis was equal to the relative

score generated by AHP multiplied by an environmental costs adjustment multiplier. This value of this multiplier was varied between model runs.

Table 1 Decision rules used to estimate the environmental cost resulting from various road management actions

Road Management Action	Attribute	Current Value	Resulting Value
Maintenance As-Is			(no change)
New Construction	Road Location		Dependent on planned road location
	Fish Passage		No barrier
	Washout Risk		Low
	Prism Condition		Vegetated sand stable
	Hydrologic Connection		No
	Surfacing		5
	Drainage		5
Road Upgrade	Washout Risk	Washed out	Medium
		High	Low
		Medium	Low
	Prism Condition	Impassible from landslide	Minor surface erosion
		Landslide damage	Minor surface erosion
		Major surface erosion	Minor surface erosion
		Minor surface erosion	Vegetated and stable
	Hydrologic Connection	Yes	No
	Surfacing	1-4	Compacted and smooth
	Drainage	1-4	Functioning properly

Harvest Scheduling

Forest management activities are normally planned over periods of decades or longer, since forests take many years to grow to maturity. To help plan its forest management activities, the ODF developed the Harvest and Habitat Model to balance timber harvesting and wildlife habitat under four different management scenarios on seven districts covering 620,000 acres (250,000 ha) of ODF lands. This is a spatial forest planning model that predicts outputs for 150 years (in 30 5-year periods) that also identifies the potential locations of the harvest operations.

The transportation system was prepared for the model by compiling all existing roads on ODF lands and other roads necessary to connect the forests to mill sites on a GIS layer. Where roads did not access any of the planned harvest units, additional roads were planned with the location based on the shortest reasonable route that met a number of environmental protection and alignment criteria. The roads were classified into five use categories based on land area accessed by the road or road system. Road construction and reconstruction cost estimates were applied to each road based on road classification, slope steepness, and number of and type of stream crossings.

A network analysis of the road system was conducted to insure that all harvest units were connected to a potential mill site in a reasonably efficient manner. The network analysis was used to identify a specific haul route for each harvest unit that was used to calculate specific road maintenance and log hauling costs associated with that harvest unit in the model. The roads and their costs were incorporated into the overall model to ensure that any future harvest operations were economically feasible.

Network Analysis

A cost efficient way of maintaining a road system while minimizing environmental impacts requires a tradeoff between environmental cost and road improvement cost. A timber transportation planning model, NETWORK2000 (Chung and Sessions 2003), was used to analyze the tradeoffs for the entire road system in the study area. NETWORK2000 uses the heuristic network algorithm developed by Sessions (1985) as a solution technique. The algorithm calculates the minimum cost network by using a shortest path algorithm to solve the variable cost problem similar to that proposed by Dijkstra (1959). In addition, the algorithm includes a heuristic approach to solve forest transportation planning problems which often become nonlinear due to the inclusion of both fixed and variable costs. Although the algorithm does not guarantee solution optimality,

NETWORK2000 has been widely used to identify least-cost transportation routes because of its capacity to quickly and easily solve large fixed and variable cost network problems.

Solution Procedure

For this study a subset of the road inventory data was used and included road location, fish passage, washout risk, prism condition, hydrologic connection, surfacing, and drainage. These factors as well as the potential road conditions for each were compiled into a hierarchy used to calculate the environmental "cost" of a forest road (Figure 1). Forest engineers for ODF completed pairwise comparisons and weights for each element in the problem hierarchy were calculated using the LLSM technique. These weights were then applied to each road segment in the road inventory and an overall score calculated for each. The overall score values for each road segment consists of both distance-dependant variables that apply to the entire road segment (i.e. road location and surfacing) and point measures (i.e. fish passage and washout risk). Additionally, road segments were of different lengths. Therefore, the overall score for each road segment was considered a score per 1000 feet (305 m) of road. Score values were then weighted by the length of each road segment. A total of 9,286 road segments were generated and used for analysis.

In order to estimate the environmental cost of road segments after upgrade or new construction, the decision rules set out in Table 1 were used. It was assumed that when a road was upgraded, all aspects of that road would be upgraded. For example, it was not an option to upgrade the road surfacing while leaving a fish passage barrier in place. Regional average new construction and upgrade costs were used for all roads: \$62,000 per mile of new construction (\$11.74/ft or \$38.52/m), \$31,000 per mile of road upgrade (\$5.87/ft or \$19.26/m). It was assumed the use of an existing road in its current condition would incur no fixed cost.

Variable costs used in NETWORK2000 were the sum of hauling costs and environmental costs. For variable hauling costs, \$60 per hour and 20 miles per hour (32 km/hr) were assumed for all roads within

the study area regardless of current road condition or if an upgrade or new construction was recommended. Additionally, a timber volume of 5 MBF (thousand board feet) per truck (25 m³/truck) was assumed for all sales within the study area using harvest estimates from the Harvest and Habitat Model.

Environmental cost was treated as a variable cost in this analysis and was calculated as the product of the AHP score for each road segment weighted by segment length, timber volume hauled over the road segment (also assuming 5 MBF/load), and a variable environmental cost multiplier ranging from \$0 to \$1000. NETWORK2000 was run multiple times, changing the value of the environmental cost multiplier with each run.

After routes have been selected for use in a particular scenario, the remaining road segments not chosen for use can be analyzed for potential decommissioning. Those roads with the highest AHP overall score receive the highest priority for decommissioning.

Results

Table 2 shows the results from NETWORK2000 with different environmental cost multipliers. When a multiplier of zero was used, no environmental costs were considered in the network analysis, and NETWORK2000 identified the least cost routes to transport timber from each stand to the exit point (Figure 2a). The total hauling cost was estimated at \$855,194 (\$9.6/mbf), and some new road construction was required to access stands that are not accessible with the current road network. However, the least cost transportation routes changed when environmental costs were considered (Figure 2b, c, and d). With the multiplier of 10, environmental costs imposed on the existing roads increased the hauling costs on inventoried roads. With the inclusion of environmental costs, NETWORK2000 chose some longer routes that have less or no environmental costs (see upper left corner of the road network), which caused an increase in hauling costs. Table 2 also shows that as the environmental cost multiplier is increased, more upgrade options are chosen resulting from the trade-off analysis between environmental and upgrade costs.

Table 2 Results using different environmental cost multipliers

Cost items		Environmental Cost Multiplier			
		0	10	100	1000
Hauling cost		\$855,194 (\$9.6/mbf)	\$1,183,407 (\$13.3/mbf)	\$1,361,477 (\$15.3/mbf)	\$1,372,046 (\$15.4/mbf)
Environmental cost		\$0	\$587,757	\$4,005,537	\$34,466,957
New road construction		\$52,797	\$52,797	\$52,797	\$52,797
Upgrade	Cost	\$0	\$86,744	\$359,525	\$1,484,809
	Length	0 mi.	2.80 mi.	11.60 mi.	47.91 mi.

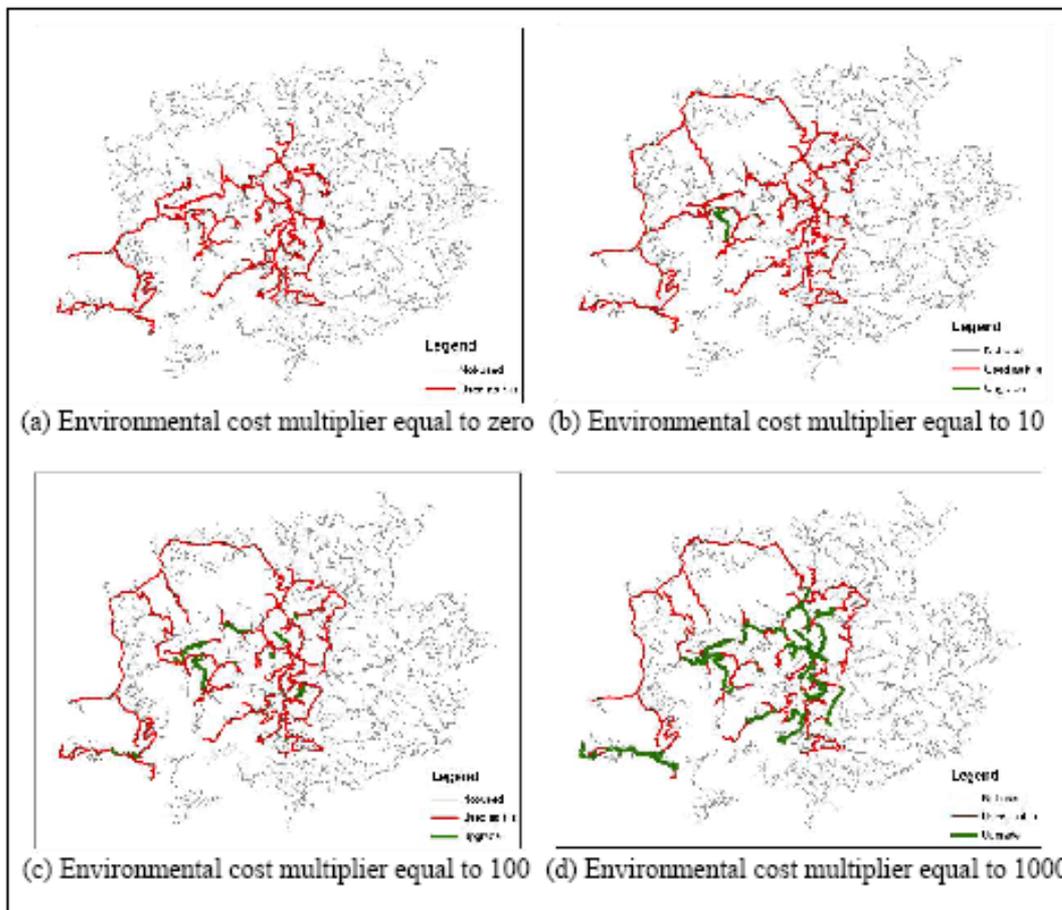


Figure 2 Results using different environmental cost multipliers

Discussion

Several assumptions were used in this analysis that warrant further exploration, refinement, and/or data collection. Most of the assumptions that were made for this analysis were necessary because of either a lack of road-specific data or data not in a format that could be used in this project.

The assumption that the use of roads outside ODF ownership had no environmental cost had the consequence of shifting traffic to these other routes when the environmental cost modifier increased. This shift does not mean that negative environmental impacts are no longer a concern. Additionally, the shift towards the use of roads outside ODF lands actually caused an increase in the miles of forest road used as the environmental cost modifier increased.

Within this study area, our analysis indicated new roads were to be constructed in order to access planned timber sales. As the environmental costs modifier increased the amount of new road construction remained the same, meaning the option to build new roads to avoid using existing roads with high environmental impacts either were not available or were not financially attractive.

We assumed environmental costs could be modeled as variable costs. For environmental impacts that increase with use such as sedimentation this is likely a good assumption. With other impacts such as fish passage that are of concern weather or not the road is in use, this assumption may be suspect.

Conclusion

The analysis presented in this paper used AHP to convert forest road inventory data into an environmental cost that was then used in a network analysis performed in NETWORK2000. By varying an environmental cost modifier multiple road use and upgrade strategies were produced to reflect different weightings of environmental impacts and economic costs. It is believed that with further refinement in input data that allows for fewer, more targeted assumptions, this analysis technique will be a useful tool in the management of forest roads.

This process could provide a forum for different road system stakeholders to have input in the decision making process. There are many people interested in the decisions made on access to these State forestlands in Oregon, including the environmental community, recreational users, fish and wildlife management agencies, timber purchasers and logging contractors, county governments, and a common school trust fund that receive funds generated by sales of forest products. Each might have a different perspective on the relative importance on the environmental risks and tradeoffs. This could provide an opportunity for these stakeholders to reach a common understanding on the benefits and risks of different road management decisions.

Literature Cited

Chung, W. and J. Sessions 2003. NETWORK 2000: a program for optimizing large fixed and variable cost transportation problems. In: G.J. Arthaud and T.M. Barrett (eds.) Systems Analysis in Forest Resources, Kluwer Academic Publishers. pp. 109-120.

Coulter, E.D., J. Coakley, J. Sessions. 2006. The Analytic Hierarchy Process: A Tutorial for Use in Prioritizing Forest Road Investments to Minimize Environmental Effects. *International Journal of Forest Engineering* 17(2):51-69.

Dijkstra, E.W. 1959. A note on two problems in connection with graphs, *Numerische Mathematik*, 1, 269-271.

Mills, K, L. Dent, J. Cornell, and J. Middel. 2007. Rapid survey of road conditions to determine environmental effects and maintenance needs Draft Paper submittal for 9th Intl. Low Volume Road Conference. 2007

Sessions, J. 1985. A heuristic algorithm for the solution of the variable and fixed cost transportation problem. In *Proceedings of the 1985 Symposium on Systems Analysis in Forest Resources*. Edited by Dress and Field. 1985. Society of American Foresters. p. 324-336.

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USING THE WEPP:ROAD MODEL IN ESTIMATING SEDIMENT YIELD FROM A ROAD NETWORK IN THE KSU BASKONUS RESEARCH AND APPLICATION FOREST IN KAHRAMANMARAS, TURKEY

Alaaddin Yuksel, Abdullah E. Akay, W. J. Elliot

Abstract: Forest roads are the main source of sediment yield in managed forest areas. The sediment delivered to a stream from a road section highly depends on road template, road surfacing, road gradient, traffic density, soil types, terrain conditions, and vegetative cover. There are various sediment prediction models to estimate average annual sediment production from forest road sections. The Forest Road Erosion Predictor model (WEPP:Road) is widely used to calculate the amount of transported soils and sedimentation as a result of runoff. Using the WEPP Road model integrated with a Geographic Information System (GIS) is very effective in predicting place, time, and extent of sediment yield from forest roads. This allows us to plan and implement proper road construction and maintenance activities. WEPP:Road has been used in only a few applications for estimating sediment production from a forest roads in Turkey. In this study, average sediment production from the road network in the Baskonus Research and Application Forest of Kahramanmaras Sutcu Imam University (KSU) was estimated using WEPP:Road and GIS technologies. The required GIS coverages such as roads, streams, Digital Terrain Model (DTM), soil types, and vegetation types are generated to provide input data for calculations in WEPP. The results indicated that using WEPP:Road technologies provide results with a high accuracy and time effectiveness.

Key words: WEPP:Road, Forest Roads, Erosion Factors, Sediment Yield, GIS

Introduction

Designing a forest road network in a watershed can be time-consuming and complex subject to economic and environmental constraints. Constructing and maintaining forest roads is considered as the most costly activities in the process of timber production (Akay and Sessions, 2005). Due to removal of vegetation from the area of road prism, road construction can produce more sediment yield than any other activity in forest management (Grace, 2002). Therefore, accurately predicting sediment yield from forest roads is important to plan and implement proper road construction and maintenance activities.

There have been several sediment prediction models developed to estimate average sediment from a road section to streams. The common models include FROSAM (WFPB, 1997), WEPP:Road (Elliot et al., 1999a), X-DRAIN (Elliot et al., 1999b), and SEDMODL (Boise Cascade Corporation, 1999). To estimate sediment yields, these models consider the specific erosion factors such as soil type, climate, ground cover, road surface, ditch, and topography. Among these models, WEPP:Road (WEPP Forest Road Erosion Predictor) is widely used to predict runoff and sediment yield from low-volume forest

roads, compacted landings and skid trails, and off-road vehicle trails. The WEPP:Road model integrates with a geographic information system (GIS) to predict place, time, and extent of sediment yield from forest roads.

WEPP:Road is an interface to the Water Erosion Prediction Project (WEPP) soil erosion model which is a physical based computer program that predicts soil erosion. WEPP:Road generates climate data by integration with the ROCK:Clime model (Arnold and Elliot, 1996), which is a climate generator with a database from more than 2600 weather stations. Then, the WEPP:Road model presents the results as a summary and extended WEPP output. In the model, the user can specify the road characteristics such as climate, soil and gravel addition, local topography, drain spacing, road design and surface condition, and ditch condition.

In the WEPP:Road model, it is assumed that sediment yield is generated from road surface, fill-slope, and a forested buffer area. Then, the sediment yield is predicted by considering five major erosion factors including road gradient, road width, surface type, road design, and traffic density.

The objective of this study was to utilize the WEPP:Road model in estimating sediment yield from the road sections in the KSU Baskonus Research and Application Forest in Kahramanmaras, Turkey.

Material and Methods

Study Area

The KSU Baskonus Research and Application Forest is located approximately 45 km from the city of Kahramanmaras. The common tree species are *Pinus brutia*, *Pinus nigra*, *Cedrus libani*, and *Abies cilicica*. The average side-slope and ground elevation are 73% and 1165 m, respectively. In the research forest, there are secondary forest roads and asphalt roads, with the lengths of 3155 m and 7250 m, respectively. The stream network in the research forest consists of medium and small streams.

WEPP:Road Model

The WEPP:Road model can be applied to any condition where the necessary input data are available. In the WEPP:Road model interface, the input data include climate, soil texture, road design, gravel addition, topography, road width, and management (Figure 1). To simplify the application of WEPP to forest roads anywhere in the U.S., a user can utilize internet based the WEPP:Road interface model to estimate sediment yield from the forest road (Elliot et al., 1999a). The users from the outside of the U.S. have to generate a climate file by changing the original data used in the US.

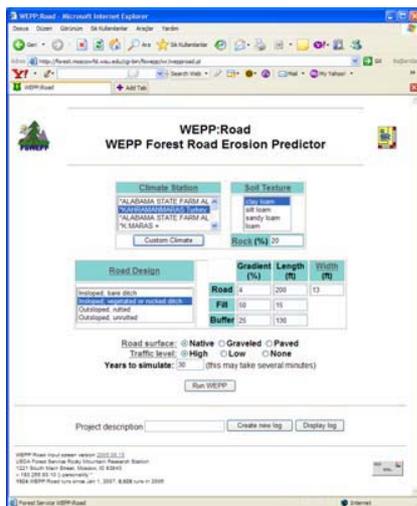


Figure 1. WEPP:Road Input Screen.

Climate

To run WEPP:Road model, the Rock:Clime, weather generator interface, has been generated to specify a climate from the database. When Rock:Clime is run from WEPP:Road model, the selected climate should be added into the “Personal Climate List” of a user (Figure 2). A user can have up to five different climates to run in the WEPP:Road model.

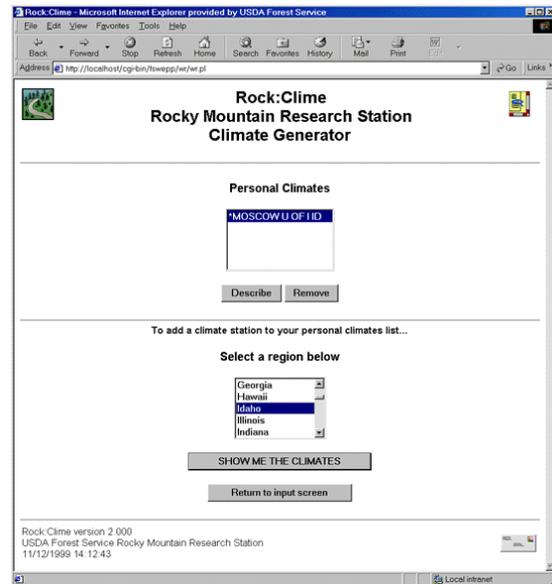


Figure 2. Initial screen for running Rock:Clime from WEPP:Road.

In the summer 2006, a series of collaborative studies were conducted between the authors and the WEPP: Road Project team members in Rocky Mountain Research Station in Moscow, Idaho. During previous work, a specific climate file for Kahramanmaras region, covering Baskonus Research and Application Forest, was generated in Rock:Clime Generator and included in the FS-WEPP database as “Non-US Climate Station” under “International Regions” (Figure 3, 4).

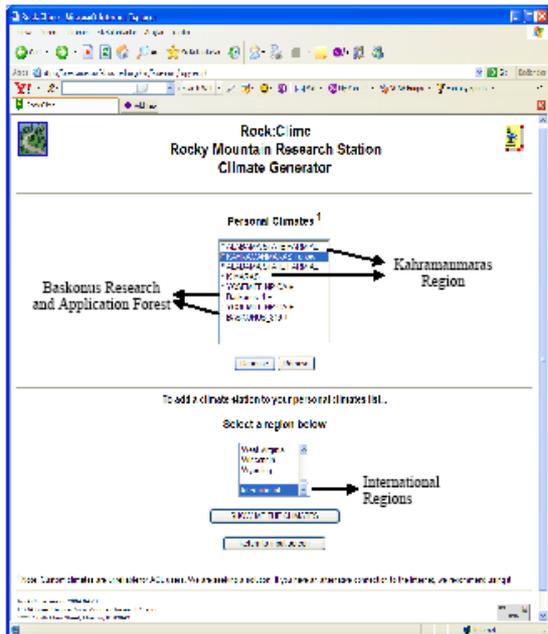


Figure 3. Initial Screen for running Rock:Clime from FS WEPP.

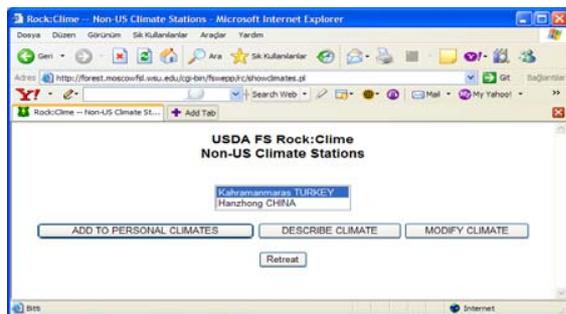


Figure 4. Non-US Climate station screen in Rock:Clime.

To obtain monthly based climate parameters (Min and Max Temperature, Average Precipitation, and Number of wet days) for the study area, 20 years of climate data from the Kahramanmaraş region were entered into the Rock:Clime Generator and climate files were generated in WEPP:Road model (Figure 5).

Month	Mean Maximum Temperature (°C)	Mean Minimum Temperature (°C)	Mean Precipitation (mm)	Number of wet days
January	8.7	-3.5	143.57	8.7
February	7.4	-2.8	133.57	7.9
March	4.6	-0.7	126.57	10.7
April	8.8	2.5	79.45	7.6
May	22.6	6.7	31.57	6.2
June	27.7	6.1	13.57	2.1
July	35.7	12.5	12.83	1.3
August	35.0	11.7	4.97	1.7
September	29.1	8.8	29.84	3.3
October	23.0	4.5	47.97	3.9
November	4.4	-0.5	169.45	6.8
December	8.6	2.0	148.17	8.6
Annual			858.65	67.1

Figure 5. Climate description screen for the study area.

Soil Texture

The erosion potential of a given soil depends more on the vegetation cover than on the soil texture. In the WEPP:Road model, the texture and other physical properties for up to 10 layers of soil can be described in the soil file. Among these properties, the erodibility and hydraulic conductivity of the surface layer are the most critical inputs (Elliot et al., 1999a). In the research area, the soil texture was generally clay loam with 20% rock content. Figure 6 indicates the soil parameters defined in the WEPP:Road model. In the WEPP model, it was assumed that hydraulic conductivity of the soil is reduced in direct proportion to the rock content (i.e., 20 percent rock will reduce the hydraulic conductivity by 20 percent). Table 1 indicates the categories of common forest soils in the WEPP:Road model.

Table 1. Common Forest Soils in relation to WEPP:Road soil parameters.

Soil type	Soil Description	Classifications
	Native-surface roads on shales and	
Clay loam	similar decomposing fine-grained sedimentary rock	CH
Silt loam	Ash cap native-surface road; alluvial loess native-surface road	ML, CL
Sandy loam	Glacial outwash areas; granitics and sand	GP, GM, SW, SP
Loam	Glacial tills, aluvium	GC, SM, SC, MH

WEPP:Road Soil Parameters

Road texture: clay loam		
Albedo of the bare dry surface soil	0.6	
Initial saturation level of the soil profile porosity	0.5	m/m
Baseline interrill erodibility parameter (K_r)	1.5e+006	kg*s/m ⁴
Baseline rill erodibility parameter (K_r)	0.0002	s/m
Baseline critical shear parameter	10.0	N/m ²
Effective hydraulic conductivity of surface soil	0.1	mm/h
layer 1		
Depth from soil surface to bottom of soil layer	200	mm
Percentage of sand	30	%
Percentage of clay	30	%
Percentage of organic matter (by volume)	0.01	%
Cation exchange capacity	24	meq per 100 g of soil
Percentage of rock fragments (by volume)	20	%
Fill texture: clay loam		
Albedo of the bare dry surface soil	0.12	
Initial saturation level of the soil profile porosity	0.45	m/m
Baseline interrill erodibility parameter (K_r)	1.5e+006	kg*s/m ⁴
Baseline rill erodibility parameter (K_r)	0.0002	s/m
Baseline critical shear parameter	2.0	N/m ²
Effective hydraulic conductivity of surface soil	6.3	mm/h
layer 1		
Depth from soil surface to bottom of soil layer	300	mm
Percentage of sand	30	%
Percentage of clay	30	%
Percentage of organic matter (by volume)	4	%
Cation exchange capacity	26	meq per 100 g of soil
Percentage of rock fragments (by volume)	20	%
Forest texture: clay loam		
Albedo of the bare dry surface soil	0.02	
Initial saturation level of the soil profile porosity	0.40	m/m
Baseline interrill erodibility parameter (K_r)	1e+004	kg*s/m ⁴
Baseline rill erodibility parameter (K_r)	0.0002	s/m
Baseline critical shear parameter	2.0	N/m ²
Effective hydraulic conductivity of surface soil	20	mm/h
layer 1		
Depth from soil surface to bottom of soil layer	300	mm
Percentage of sand	30	%
Percentage of clay	30	%
Percentage of organic matter (by volume)	8	%
Cation exchange capacity	27	meq per 100 g of soil
Percentage of rock fragments (by volume)	20	%

Figure 6. WEPP:Road Soil Parameters for Clay Loam.

Road Design

In the WEPP:Road model, four main road design types are considered: (1) Insloped, bare ditch, (2) Insloped, vegetated or rocked ditch, (3) Outsloped, unrutted, and (4) Outsloped, rutted. In the study area, the forest roads are insloped with a vegetated or rocked ditch (Figure 7). The "Insloped, vegetated or rocked ditch" design option uses a critical shear for the road element of 10 N m⁻². The ditch is to transport the sediment eroded from the road surface. In WEPP:Road model, the vegetated or rocked ditch generally reduces road erosion by 50 to 90 percent.

Insloped, rocked ditch



Figure 7. Diagram of the road design in WEPP:Road model (Elliot et al., 1999a).

Gravel Addition

The previous studies indicated that using surface gravel changes the flow path length of the road due to the hydraulic conductivity of the soil (Foltz and Truebe, 1995). Increasing the amount of gravel can increase the porosity and the hydraulic conductivity of the road, which leads to reduction in the runoff (Flerchinger and Watts, 1987). In the WEPP:Road model, there are three alternatives for road surface types: (1) native, (2) gravel, and (3) paved. In the study area, the county-maintained roads were paved while secondary forest roads were graveled surface.

Topography

After selecting road design type, WEPP:Road allows the users to describe the topography by entering data such as road gradient, length, width, fill slope and buffer slopes, and length of fill slope and buffer. In the study area, average road gradient was 7% and the average fill slope was 50%. Topography data was generated by using the GIS tool, Ilwis 3.2 Academic (ITC, Enschede, Netherlands).

Road Width

In WEPP:Road, the road width includes the width of the ditch or ditches if they are eroding. If the road is outsloped and rutted, only that portion of the width of road contributing runoff to the ruts should be specified (Elliot et al., 1999a). In the study area, the road widths for the county-maintained road and secondary forest road were 10 m and 5 m, respectively.

Road Traffic Level

The traffic level of road section was divided into high traffic, low traffic, and no traffic. The high level is associated with roads that receive considerable traffic during much of the year. Low traffic roads are roads with administrative or light recreational use during dry weather. No traffic roads are roads with restricted or no access, and have vegetation growing on more than half of the road surface. In the study area, the traffic levels in county-maintained roads and secondary forest roads are defined as high level and low level traffic, respectively.

Results and Conclusions

The road grade and length for each road segment was found based on a 10 meter DEM. Figure 8 shows the DEM of the study area with road and stream layers. Total average annual sediment yield from two county-maintained and four secondary forest road sections in the study area was computed using WEPP:Road. The sediment yield summary is illustrated in Table 2. The results indicated that the total sediment yield from paved road sections and graveled road sections were 45.47 and 7.89 ton, respectively.

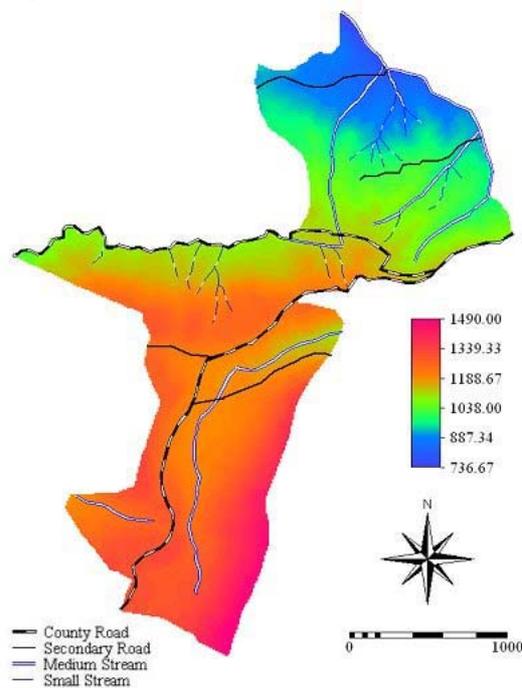


Figure 8. DEM of the study area.

It can be concluded that in paved road sections, the amount of road surface erosion was reduced, but the runoff was increased, which resulted in high amount of erosion on fill slopes, ditches, and flow paths leading from the road to the forest. Elliot et al. (1999a) indicated paved roads are least beneficial for insloped roads, or roads a moderate distance from the stream.

Table 2. Specification summary for road sections located in the research forest.

Road Classes	Length (m)	Road Width (m)	Traffic Level	Average Road Grade (%)	Sediment (ton/year)
Paved	7249	10	High	9.50	45.47
Graveled	3155	5	Low	12.25	7.89

The average annual sediment delivery from a square meter of the road sections was also computed. The amount of sediment yield (i.e. in ton/m²) from paved and graveled roads was 0.00063 and 0.0005, respectively. Therefore, the highest amount of total sediment yield in tons per square meter was also produced by paved roads.

Even though increasing road gradient increases the sediment yield from a road section (Luce and Black, 1999), the results indicated that paved road sections with 9.5% road grade produced more sediment than the graveled road sections with 12.25% road grade. Therefore, the effect of road surface type and road length factors on sediment yield were more significant than the road grade factor in the study area.

The results from the simple application indicated that WEPP:Road model is an effective tool to help forest engineers estimate sediment yield from forest road sections. They can also evaluate the performances of the alternative sediment prevention techniques by using the WEPP:Road interface.

The limitation of the current version of the model is that there are only few international data sets available in the FS WEPP database. In order to use the model in areas outside the US, local data must be preprocessed by the Rock:Clime Generator to build input files in WEPP:Road. It is anticipated that having climate data available in the database from outside the US can make WEPP:Road model more attractive for the researchers from around the world, especially in the field of forestry.

Literature Cited

- Akay, A.E. and Sessions, J., 2005. Applying the Decision Support System, TRACER, to Forest Road Design, *Western Journal of Applied Forestry*, 20(3):184-191.
- Arnold, C. D. and W. J. Elliot. 1996. CLIGEN weather generator predictions of seasonal wet and dry spells in Uganda. *Transactions of the ASAE* 39(3):969-972.
- Boise Cascade Corporation, 1999. SEDMODL-Boise Cascade road erosion delivery model. Technical documentation. 19 p.
- Elliot W.J., Hall D.E., and Scheele, D.L., 1999a. WEPP Interface for Predicting Forest Road Runoff, Erosion and Sediment Delivery. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, San Dimas Technology and Development Center.
- Elliot, W.J., Hall D.E., Graves, S.R., and Scheele, D.L., 1999b. The X-DRAIN Cross Drain Spacing and Sediment Yield Program Version 2.00. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, San Dimas Technology and Development Center.
- Flerchinger, G. N., and F. J. Watts. 1987. Predicting infiltration parameters for a road sediment model. *Transactions of the ASAE*. 30(6):1700-1705.
- Foltz, R. B., and M. A. Truebe. 1995. Effect of aggregate quality on sediment production from a forest road. *Conference Proceedings of the Sixth International Conference on Low-Volume Roads*. (1):57.
- Grace, J.M., 2002. Control Of Sed ment Export From The Forest Road Prism, ASAE Annual Meeting. Paper No. 995048. Vol. 45(4),1-6.
- Luce, C.H. and Black, T.A., 1999. Sediment Production from Forest Roads in Western Oregon. *Water Resources Research*. 35(8), 2561–2570
- WFPB, 1997. Washington Forest Practices Board Manual: Standard Methodology for Conducting Watershed Analysis Version 4.0.

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SESSION C.2:

**FOREST ROAD
EROSION/INTERNATIONAL
MOUNTAIN LOGGING
EXPERIENCES AND
INNOVATIONS**

WHEN IS LOGGING ROAD EROSION WORTH MONITORING?

David Tomberlin, Teresa Ish

Abstract: Efficient allocation of funds for erosion control on logging roads depends on information about current and potential future erosion on different road segments. Acquiring this information is typically expensive, and may make no immediate contribution to erosion control. Thus, managers face a trade-off between spending funds on information gathering versus on actual erosion control measures. Here, we develop a framework for examining this trade-off when current erosion, future erosion, and the efficacy of erosion control measures are all uncertain. Specifically, casting the manager's problem of allocating funds between erosion control and erosion monitoring as a partially observable Markov decision process (POMDP) allows us to identify the conditions under which costly estimates of erosion levels are worth obtaining as part of an adaptive erosion control program, and, in contrast, under what conditions the better strategy is to skip data acquisition and proceed directly to erosion control treatments. We demonstrate the POMDP approach through an application to a stylized road erosion control problem.

Key words: road erosion, monitoring, partially observable Markov decision process

Introduction

Sediment loading from logging roads impairs water quality and habitat conditions in many Pacific coastal rivers and streams. In this paper, we address the question of whether logging road erosion monitoring is worth the time and expense, given that we could decline to monitor in favor of either applying rehabilitative treatments immediately, without bothering to collect erosion data, or deferring the decision to implement road treatment or monitoring schemes (the more common practice). We examine this question within the framework of a partially observable Markov decision process (POMDP), which is well-suited to this purpose for at least two reasons. First, surface erosion is by its nature difficult to assess, even with special equipment, making the partial observability approach very apt. Second, logging road erosion control can be meaningfully represented in terms of a few states and actions, and the costs of these actions can be reasonably well estimated. Our model assumes the land manager wants to minimize long-run discounted total cost and will engage in monitoring only if it's expected to help with long-term performance. The model's purpose is to help the land manager decide when monitoring is worth the expense. Here, we apply the model to a single road segment, but it could also be applied to an entire watershed.

While there seems to be no consensus on a definition of 'adaptive management,' a necessary condition for management to be adaptive is that it account for the arrival of new information. Within the natural resource management literature, most work has focused

on 'passive adaptive management,' in which new information is incorporated into decision making as it becomes available. A more difficult approach is that of 'active adaptive management,' in which new information is sought optimally: the manager considers the short-term cost of information gathering vs. the potential long-term benefits, and decides whether the costly information is worth having¹.

Markov decision processes (MDPs), when solved with the techniques of stochastic dynamic programming, yield a mapping from the system state into an optimal policy, and may be thought of as a formal representation of adaptive management. However, MDPs assume that state variables are observed perfectly, an assumption that clearly does not hold in many natural resource management problems: animal populations, mineral reserves, and water quality, at least in many situations, cannot be known with certainty, and even developing good estimates is generally expensive and time-consuming.

The theory of partially observable Markov decisions processes (POMDPs) was developed in response to this shortcoming of MDPs, but no numerical algorithms existed for POMDP solution until Sondik (1971). Despite a steady stream of improvements in both exact and heuristic solution techniques, most applied work in dynamic optimization (including control engineering, economics, and behavioral ecology) has continued to rely on MDPs built around

¹ Though these ideas are taken from the control engineering literature, the most thorough treatment in a natural resource management context seems to be Walters (1986).

certainty-equivalent measures, rather than facing the numerical difficulties inherent in POMDPs. These difficulties are two-fold. First, POMDPs inherit from MDPs the well-known ‘curse of dimensionality,’ by which is meant that solution times explode as the number of admissible states and the length of the time horizon increase. Second, POMDPs are fundamentally Bayesian decision processes, in the sense that an agent’s *beliefs* about state variables become the basis for the optimal decision rule. The agent may change these beliefs, via Bayes’ Theorem, when new information becomes available. While this is conceptually appealing, the practical result is that we move from a world with finite MDP states to one with an infinite number of possible belief states, since an agent may come to have any set of beliefs, depending on how their prior beliefs and new information combine to yield updated beliefs. Thus, for POMDPs we can no longer use the standard techniques of stochastic dynamic programming as presented in, for example, Bertsekas (2000).

The difficulty in implementing POMDP solutions is a strong incentive to assume certainty-equivalence and stay within the relatively comfortable confines of MDPs. However, the substantial uncertainty inherent in many natural resource management problems really demands a better response. In our own work on salmon habitat management, for example, we have found that the amount of sediment loading from logging roads is highly uncertain, that simulation models do not inspire a great deal of confidence among managers, and that ascertaining empirical estimates of sediment loading requires a commitment of at least several years and tens of thousands of dollars. How can managers reasonably approach sediment control decisions when they don’t even know (either at the watershed level or at the operational level of a particular road segment) the magnitude of the problem? More specifically, how much time and money should they sink into developing empirical estimates of sediment loading rates, when that time and money could be spent instead on road upgrades and decommissioning?

Questions of the same form arise anytime we consider resource management under uncertainty with an opportunity to invest in learning, which will generally mean incurring some short-term cost to achieve greater overall long-term net benefit. We believe the POMDP is the best existing tool for addressing such questions. Rather than make that argument directly, however, here we offer an expository example that we hope shows how the POMDP is precisely the tool needed to address the question of when road erosion monitoring programs are worth their costs. We em-

phasize that this model is for expository purposes only: while we believe the parameter values in our model are quite reasonable, they are not derived from field data. The results reported below relate only to this parameter set and no general lessons can be drawn from these results alone.

While our focus here is on logging road erosion, the question of whether to monitor or not is of considerably broader interest in natural resource management. In the context of Pacific coastal watersheds, various federal, state, and local governments, as well NGOs and community groups, are either monitoring or developing plans to monitor stream conditions, especially as they relate to fish habitat suitability. All this monitoring seems unobjectionable from a conservation point of view, and a lot of it is actually quite fun, so it might seem ungenerous to ask whether it’s justified. However, even given the high level of enthusiasm and public funding for fish habitat monitoring, only a small fraction of streams can be monitored, and those only for a few habitat indicators and for a limited period of time. Given these practical constraints on monitoring, our question is an important one if we’re serious about seeing that conservation efforts result in as much conservation benefit as possible.

Model

We begin with some general notes on POMDP models and then construct a stylized model that illustrates the use of POMDP for analyzing the desirability of an erosion monitoring program on a particular road segment.

The traditional MDP is a collection of sets $\{S, P, A, W\}$, where S represents state variables, P represents state dynamics as transition probabilities, A represents the actions available to an agent, and W represents the rewards to taking particular actions under particular conditions. A POMDP is an MDP with two additional components, a set of observations, Θ , and an observation model, R . Observations $\theta \in \Theta$ are the only information the agent has on the true state, S , which is unobservable. The observation model R describes the probabilistic relationship between observations θ and the true state S . In other words, the agent uses the observation model R to make inferences about the true state S based on noisy observations θ .

Solution of MDPs and POMDPs proceeds through a recursively defined value function V . In the case of POMDPs, this value function is:

$$V_t(\pi) = \max_a \left[\sum_i \pi_i q_i^a + \beta \sum_{i,j,\theta} \pi_i p_{ij}^a r_{j\theta}^a V_{t+1}[T(\pi | a, \theta)] \right] \quad (1)$$

where

π_i = subjective probability of being in state $i \in S$ at time t

q_i^a = immediate reward for taking action $a \in A$ in state $i \in S$ at time t

β = discount factor

p_{ij}^a = probability of moving from state $i \in S$ at time t to state $j \in S$ at time $t+1$ after taking action $a \in A$

$r_{j\theta}^a$ = probability of observing $\theta \in \Theta$

after taking action $a \in A$ and moving to state $j \in S$

T = function updating beliefs based on prior beliefs and observed θ

The value function V is simply the greatest expected net benefit that the agent can achieve over time, taking into account that as conditions change in the future, different actions may be warranted. From the solution of V we can also derive an optimal policy

$$\delta_t^*(\pi_t) = \arg \max_{a \in A} \left[\sum_i \pi_i q_i^a + \beta \sum_{i,j,\theta} \pi_i p_{ij}^a r_{j\theta}^a q_j^a \right] \quad (2)$$

which is a mapping from beliefs about the current state, π , into the optimal action. In other words, for any possible set of beliefs about the true state S at any time in the decision problem, the optimal policy identifies the action that will have the greatest long-term expected net benefit.

While the above formulation may seem abstract, the concept it represents is very intuitive. We live in a world that we understand almost exclusively through limited and imperfect observations. In terms of our road erosion management problem, we do not develop erosion control prescriptions based on known sediment loading rates, rather on the basis of what we *think* those rates are. Even an extensive (and expensive) field study can never tell us exactly how much sediment a particular road segment is producing—in most cases, a field study will only be able to generate an estimate of production on a few segments.

To make the POMDP formulation more concrete and its significance clearer, we now construct a particular POMDP that addresses the question of whether an erosion monitoring scheme should be implemented on a road segment. We consider the problem faced by a manager who has three actions available to address erosion on a road segment suspected of producing an unacceptable level of sediment: to maintain the road as it is, to monitor the road's erosion level (by installing field instruments), or to treat the road (by adding rock or making design improvements). The first of these is quite inexpensive but does nothing to reduce current erosion rates or generate better estimates of these rates; the second is more expensive

and does nothing to reduce erosion, but does provide information for subsequent decision-making; the last is quite expensive but has a good chance of effectively reducing sediment production on the road (though, to reiterate, the manager can't know with certainty either the erosion rate or the effectiveness of treatment).

In terms of the POMDP formulation, the action set A thus consists of $\{\text{maintain}, \text{monitor}, \text{treat}\}$ and the state variable S is erosion. To keep the model computationally tractable and for ease of exposition, we restrict this state variable to only two possible values, *High Erosion* and *Low Erosion*. The observation set consists of the same two possible values, *High Erosion* and *Low Erosion*, but an observation of $\theta = \text{High Erosion}$ does not necessarily mean that the true state $S = \text{High Erosion}$. Instead, we define an observation model R as follows:

$$R_{j\theta}^1 = \begin{bmatrix} 0.6 & 0.4 \\ 0.4 & 0.6 \end{bmatrix} \quad R_{j\theta}^2 = \begin{bmatrix} 0.9 & 0.1 \\ 0.1 & 0.9 \end{bmatrix} \quad R_{j\theta}^3 = \begin{bmatrix} 0.5 & 0.5 \\ 0.5 & 0.5 \end{bmatrix}$$

Each matrix, with the state $j \in S$ defined by row and each observation θ defined by column, defines the probabilistic relationship of observation to true state under a different action. Because we have no data on these relationships, we have chosen parameters that provide a reasonable relative information content to observations under different actions. $R_{j\theta}^1$, for example, tells us that after taking action $a=1$ (*maintain*) and moving to the unobservable state $j=\text{Low Erosion}$, we would observe $\theta=\text{Low Erosion}$ with 60% probability and $\theta=\text{High Erosion}$ with 40% probability. That is, maintaining the *status quo* provides some information, presumably through casual observation of the road, but it is weak information. $R_{j\theta}^2$, in contrast, tells us that implementing a monitoring plan ($a=2$), yields a much stronger basis for inference based on observations: in this case, taking an observation when the true state is $j=\text{Low Erosion}$ yields $\theta=\text{Low Erosion}$ with 90% probability and $\theta=\text{High Erosion}$ with 10% probability. Finally, $R_{j\theta}^3$ indicates that immediately after treating the road, observations tell us nothing about the true state of erosion. We impose this condition to reflect the fact that treatments themselves often cause transient changes in erosion rates that tell us little about the true state of the road.

The stochastic dynamics of the state S (the sediment production level) are given by transition probability matrices which we define as follows:

$$P_{ij}^1 = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \quad P_{ij}^2 = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \quad P_{ij}^3 = \begin{bmatrix} 0.95 & 0.05 \\ 0.80 & 0.20 \end{bmatrix}$$

The first two matrices indicate that under actions $a=1$ and $a=2$ (*maintain* and *monitor*, respectively), a *Low Erosion* road will stay a *Low Erosion* road and a *High Erosion* road will stay a *High Erosion* road.

P_{ij}^3 tells us that under $a=3$ (*treat*), a *Low Erosion* road stays in that same state with 95% probability, but allows a 5% chance that the treatment will actually backfire and create a *High Erosion* road. Similarly, treating a *High Erosion* road has an 80% chance of successfully creating a *Low Erosion* road and a 20% chance of failure (meaning the *High Erosion* road stays that way). As with the observation model, these values are not derived from field data, but are chosen by us to reflect a plausible scenario for analysis.

Finally, the reward structure (actually, cost structure) in our model is as follows:

$$W_{ij\theta}^1 = \begin{bmatrix} -1 & -20 \\ -1 & -20 \end{bmatrix} \quad W_{ij\theta}^2 = \begin{bmatrix} -3 & -22 \\ -3 & -22 \end{bmatrix} \quad W_{ij\theta}^3 = \begin{bmatrix} -6 & -6 \\ -6 & -6 \end{bmatrix}$$

Here the columns of each matrix represent the possible states j and the rows represent possible observations θ . [We have suppressed the i -dimension of the cost structure since we assume the cost depends only on the state and not how the transition to the state occurred, as in the general POMDP formulation.] In each submatrix of W , the rows are the same because in our case the observation does not directly affect costs, which are in thousands of dollars. The matrix W^1 tells us that maintaining the road in *Low Erosion* state will cost \$1000, which is very cheap compared to \$20,000, the cost of maintaining the road in *High Erosion* state. W^2 , the payoffs to monitoring, are the same as W^1 plus the cost of the monitoring program itself (\$2000). That is, monitoring does nothing to change the costs associated with the erosion *per se*, it is a pure additional cost. W^3 tells us that treating the road will cost us the same \$6000 regardless of whether the road is in *Low Erosion* or *High Erosion* state. Comparing all these costs, it's obvious that if the decision-maker knew the true state to be *Low Erosion*, the best choice would be to maintain the current situation ($a=1$), and if the decision-maker knew the true state to be *High Erosion*, the best thing to do would be to treat the road right away ($a=3$).

However, the premise of our model, and the reality that managers generally face, is that the true state is unknown.

Finally, we assume a discount factor of $\beta=0.95$, which completes our model specification.

Results

A POMDP solution consists of the recursively defined value function $V_\lambda(\pi)$ and the associated optimal policy $\delta_\lambda(\pi)$. Because the solution technique is rather complicated, we will not describe it here; interested readers can consult Cassandra (1994, pp. 45-54) for a good discussion of the Monohan/Eagle algorithm we used. POMDP algorithms share with MDP algorithms the basic notion of backward recursion from an arbitrarily defined end of time, T . In our model, time T comes after all decisions have been made and after uncertainty about the true state has been resolved (which allows unambiguous values to be assigned to each of the possible final states).

Figure 1 shows the value function at the final time period in which a decision is to be made, $T-1$. The x-axis is the belief simplex for the two possible states in S : $p(\text{Low Erosion})$ runs from left to right, and since $p(\text{High Erosion})$ must be $1-p(\text{Low Erosion})$, $p(\text{High Erosion})$ runs from right to left. The y-axis is the expected value of taking particular actions. The blue line is the value function, giving the expected value at $T-1$ of taking whichever action has the lowest expected cost. Here, since there is only one decision period before the end of the problem, these values have very straightforward interpretations. If the manager's current belief is that $p(\text{Low Erosion})$ is anything less than 74%, the optimal action is to treat the road, which has a payoff of -6 regardless of the current true state. If, however, the manager's current belief is that $p(\text{Low Erosion}) > 74\%$, then the optimal action is to maintain the *status quo* road, which has an expected value of $[-1 * p(\text{Low Erosion}) + -20 * p(\text{High Erosion})]$. In other words, the more certain the manager is that the true state is in fact *Low Erosion*, the greater the expected payoff to doing simple maintenance work. Thus, Figure 1 not only shows the value function but also partitions the belief space into regions on which each possible action is optimal, i.e., visually lays out the optimal policy.

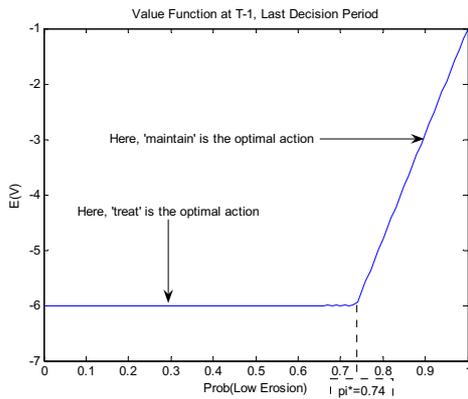


Fig. 1: The value function in the last decision period, showing the partition of the belief space into regions associated with different optimal actions. Here, *treat* is optimal for beliefs $p(\text{Low Erosion}) \leq 74\%$, and *maintain* is optimal for beliefs $p(\text{Low Erosion}) > 74\%$.

Notice that the action *monitor* does not appear as part of the optimal strategy in Figure 1. The reason is simply that, with no further actions to be taken after $T-1$, there is no justification for paying to gather information that can't provide future benefits in the form of improved decision making.

Of course, we are almost always interested in problems that have at least several decision periods. Figure 2 shows the evolution of the value function over a 10-year time horizon. The most obvious effect of lengthening the time horizon is that the value function moves steadily downward, due to the expectation of increased future costs (a direct result of our model setup). However, the shape of the value function also changes, as do the actions that form the optimal policy. Specifically, for $T-3$ and all earlier periods, *monitor* becomes part of the optimal strategy. The belief ranges for which *monitor* is optimal are between the two black curves; the beliefs to the left of the left-most black curve are those for which the optimal action is *treat*, and those to the right of the right-most black curve are those for which the optimal action is *maintain*. The belief range over which *treat* is optimal is neither strictly increasing nor strictly decreasing with time, because the optimal policy has not fully converged to a stable mapping, but the general picture is clear. Monitoring enters the optimal policy at $T-3$, once the time horizon has become long enough that information generated by monitoring can yield sufficient benefits (in expectation) to offset the cost of the monitoring program. As the time horizon deepens, the range of beliefs over which monitoring is part of the optimal strategy increases, from about $[0.81 \ 0.90]$ at $T-3$ to about $[0.81 \ 0.97]$ at $T-10$. Immediate treatment is still the opti-

mal action for beliefs up to around $p(\text{Low Erosion})=0.8$, and simply maintaining the status quo is preferred only for beliefs such that $p(\text{Low Erosion})$ is well over 0.9.

The above discussion and figures may seem abstract, but in fact they correspond quite nicely to the way most of us get through life. We routinely make decisions that are based not on directly observable facts, but on our beliefs about those underlying facts, which for a variety of reasons we either can't or don't want to know with certainty. Both the facts and our beliefs about them may change over time, but at any point in time we make decisions based on our beliefs at that time. People can't apply Bayes' theorem with the efficiency that a computer can, but the general notion of combining new information with prior beliefs seems to reflect a lot of human decision making. Perhaps more importantly for our present purposes, the partition of the belief space into regions corresponding to different optimal actions is very intuitive and also useful. As Figure 2 shows, one person may believe that $p(\text{Low Erosion})=0.1$, another that $p(\text{Low Erosion})=0.4$, and a third that $p(\text{Low Erosion})=0.7$, but the POMDP makes clear that they should all still be able to agree on treating the erosion problem immediately.

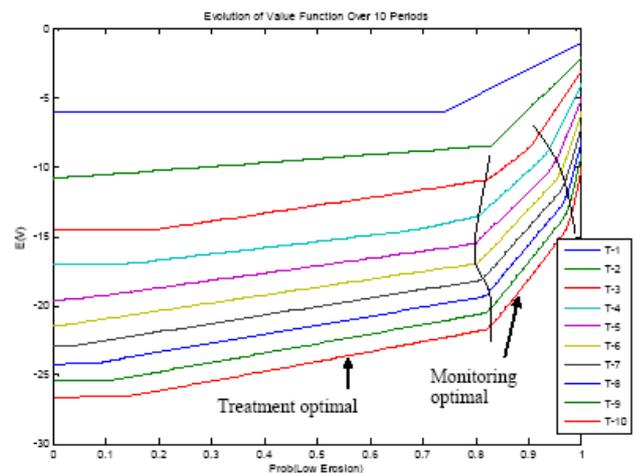


Fig. 2: The evolution of the value function over 10 decision periods. The value function moves monotonically downward as the time horizon increases, which is an artifact of our cost-only model. For $T-3$ and earlier periods, monitoring becomes part of the optimal strategy for those beliefs between the two black curves.

As we mentioned at the outset, these results are a function of our model's structure and parameters, and are not to be understood as generally applicable.

Conclusions

The partially observable Markov decision process (POMDP) provides a formal framework for exploring when information-gathering is likely to be worth the cost and when not. Given the expense of monitoring programs in natural resource management, budgetary realities ensure that managers have to choose among candidate monitoring programs. The POMDP provides a tool for thinking carefully about such choices.

Here, we have presented an application of POMDP to a stylized problem in logging road management. Because POMDPs are even more subject than traditional MDPs to the ‘curse of dimensionality,’ research on numerical techniques for POMDP solution is a very active field in engineering and artificial intelligence—more fully developed applications in natural resource management will have to draw on recent advances in heuristic techniques such as interior-point methods and witness algorithms. However, even our simple example has shown that, under plausible parameter values, the costs of monitoring can easily exceed the benefits. For the parameter set assumed above, we found that, for problems with a time horizon of at least 3 decision periods, implementing erosion control treatments *without first monitoring* was optimal as long as the subjective probability of the road being highly erosive was more than about 20%. Monitoring was optimal over a narrower range of beliefs, specifically when the belief that existing road conditions were good was between about 80% and about 95%. That is, monitoring in our example was preferred only when the manager had a pretty strong hunch that current conditions were good, in which case the monitoring served essentially to rule out the need for more aggressive and expensive treatment.

In developing our case for the POMDP as a useful decision-making tool, we deliberately touched lightly on the nature of the subjective probabilities π , which are really the heart of the POMDP. While from a technical point of view there’s not much to say about π , which is simply a vector of conditional probabilities, we should address a concern that might arise from a philosophical point of view. Some may object that subjective probabilities have no place in management or policymaking, which should strive at all times to be as objective as possible. Without rehashing the centuries-long Bayesian-vs-frequentist struggle, we note that many Bayesians consider subjective probability the only sensible notion of probability,

and so would dismiss this criticism as invalid on principle. For our purposes, it doesn’t seem necessary to take that rigorous Bayesian position. We are satisfied with the more mundane argument that subjective probabilities are so manifestly the basis for current natural resource management and policymaking that few (if any) decisions would be made without them. In short, we think subjective probabilities in natural resource decision making are perfectly sensible and almost perfectly unavoidable.

The deep uncertainty we face in many aspects of natural resource management requires that we think carefully about when to invest in learning about the systems we manage. The POMDP provides a coherent framework for such thinking.

Literature Cited

- Bertsekas, D. 2000. *Dynamic Programming and Optimal Control*. Belmont, MA: Athena Scientific.
- Cassandra, A. 1994. *Optimal Policies for Partially Observable Markov Decision Processes*. Brown University Department of Computer Science Technical Report CS-94-14.
- Sondik, E.J. 1971. *The Optimal Control of Partially Observable Markov Decision Processes*. Ph.D. dissertation, Stanford University.
- Walters, C. 1986. *Adaptive Management of Renewable Resources*. New York: Macmillan Publishing.

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REDUCING SEDIMENT PRODUCTION FROM FOREST ROADS

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Abstract: Wet weather use on low-volume roads can be a source of turbidity and fine sediment to streams that is detrimental to aquatic organisms especially salmonids. With water quality in mind, regulations governing wet weather hauling in the Pacific Northwest have become increasingly restrictive. An option for road managers to remain productive during the wet season is to improve the road pavement and thus reduce fine sediment produced from the road.

This research evaluates the environmental benefits of upgrading forest roads for use during wet weather. We developed alternative treatments for unbound aggregate pavement with the goal of minimizing turbid runoff during wet weather use. We compared sediment production from these pavement treatments with truck traffic and simulated rainfall with a standard design of unbound aggregate pavement for forest roads. Suspended sediment concentration was lower from pavement treatments that did not develop ruts in the wheel paths.

Key words: Water quality, sediment, forest roads, road runoff, suspended sediment concentration

Introduction

Forest roads in the states of the Pacific Northwest are often constructed with a layer of unbound aggregate over a subgrade of native soil. Roads are hydrologically connected to streams through roadside ditches, gullies, and stream crossings (Wemple 1994). Wet weather use on forest roads can be a significant source of turbidity and fine sediment in streams that in turn may be detrimental to aquatic organisms especially salmonids. Regulations governing the traffic use of forest roads during wet weather have become increasingly restrictive to protect water quality. As a result, road managers are interested in ways to reduce the production of sediment from forest roads.

The characteristics of road segments and traffic influence the volume of sediment generated by unbound aggregate roads and available to runoff. Luce and Black (1999) found that sediment production from the surface of a forest road was a function of the length and slope of the road segment. Bilby *et al.* (1989) determined that the depth and type of the aggregate surfacing affected the sediment yield from a forest road where less sediment was produced from roads with a thicker aggregate layer. A study in the Pacific Northwest found that a road segment that was heavily used by haul trucks (more than four loaded trucks per day) contributed 130 times as much sediment as an abandoned road (Reid and Dunne 1984). Burroughs *et al.* (1984) determined that a road

with ruts in the wheel paths produced twice the sediment as a smooth road.

Forest roads may produce sediment from three different processes. Fine sediment is available in the surface aggregate at construction, especially for well-graded aggregate. Fine sediment is produced from the degradation of the surface aggregate during traffic. Finally, fine sediment is available in the subgrade and is described to “pump” through the aggregate layer with repeated loading during wet conditions (Koerner 1998). No research has been conducted to determine the origin of fine sediments in road runoff; however it is commonly assumed that pumping of the subgrade is the major source.

Current methods of design for unbound aggregate roads do not consider environmental performance but design for load support. Road managers who upgrade the standard road design for use in wet weather do not know the true environmental benefits of their efforts. The objective of this research is to evaluate the environmental benefits, in terms of sediment production, of upgrading forest roads for use during wet weather. We placed emphasis on minimizing fines from the subgrade as a source of sediment.

Methods

We designed a control and two alternative pavements for forest roads, including one we developed based on theories from soil mechanics. An industrial land

owner, Green Diamond Resource Company, installed these designs on a new road on their property in northern California. The goal of the road designs was to minimize turbid runoff during wet weather hauling. We compared sediment production from the different treatments caused by log truck traffic during simulated rainfall to a standard design (control) of unbound aggregate pavement for forest roads.

The experimental road is a 91 m (300 ft) section of a spur road that Green Diamond Resource Company constructed from Hammond Truck Road approximately 5.3 km (3.3 miles) northeast of Trinidad, California. They built the road in September of 2005 for extracting timber January through April of 2006. The section of experimental road has a consistent gradient of 8 percent and is at approximately 412 m (1350 ft) above sea level. The average precipitation for this area is 150 cm (59 in) a year, occurring predominately as rainfall between October and April. The U.S. Department of Commerce, National Oceanic and Atmospheric Administration maintains a weather station located nearby that recorded 244 cm (96 in) between the study time period of October 1, 2005 and April 29, 2006 (weather station ID: WEDC1).

We designed the road with an outsloped cross-section and an inboard ditch to allow hillslope runoff to bypass the section of experimental road. We talked to road managers to determine a design of the aggregate pavement for the control segments that represents a standard design for forest roads. The pavement structure for the control is 20 cm (8 in) of open-graded, aggregate as a base and a cap of 5 cm (2 in) of well-graded, crushed aggregate with a diameter up to 3.8 cm (1.5 in). We designed two alternative treatments for the aggregate pavement to minimize the pumping of sediment from the subgrade. The design for the first treatment is the same as the design for the control but includes a geotextile placed between the subgrade and aggregate for separation. The design of the second treatment is similar to the design of the control but with a greater depth of base aggregate. We determined the depth of base aggregate to minimize bearing capacity failures at the subgrade/aggregate interface. We developed a method that uses variables of local soil strength and traffic to calculate aggregate depth to allow for strain hardening of the subgrade.

There are two sections of the control treatment and the design with the geotextile and one section with the added depth of base aggregate. We randomly assigned these treatments to an 18 m (60 ft) road segment within the 91 m (300 ft) of the experimental

section of road. We separated the treatments with a flexible water bar constructed from conveyor belting (Figure 1).

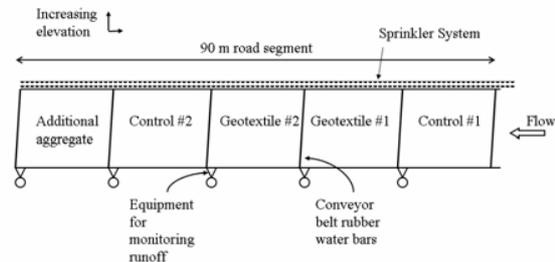


Figure 1. A schematic of the experimental road segment with five treatment segments.

A sprinkler system connected to a water truck delivered 1.2 cm/hr (0.46 in/hr) of precipitation to the road surface. ISCO automatic water samplers (Teledyne Technologies) collected runoff from the road at the water bars. Log trucks drove over the experimental section of road as they came to the harvest unit (unloaded) and then left the harvest unit (loaded) (Figure 2). Scale tickets from weigh stations determined the number of trips of loaded log trucks on the road until logging in the harvest unit ended.



Figure 2. A loaded log truck traveling over the experimental road section during simulated rainfall.

We measured sediment production from the pavement treatments twice; once at the beginning of the logging when truck traffic commenced and again toward the end of logging. In a laboratory we analyzed water samples for turbidity and suspended sediment concentration (SSC). We compared SSC from the different treatments to SSC from the control. At the end of hauling, we surveyed the road surface and dug a trench through each of the treatments and into the subgrade to determine the depth and condition of the surface aggregate.

Results and Discussion

Green Diamond Resource Company constructed the road with locally available aggregate. The base aggregate was open-graded with a diameter up to 8 cm (3 in) and had very little fines. The cap material was crushed aggregate with 35 percent passing the 4.75 mm sieve. The geotextile used in the two geotextile treatments was woven with a weight of 136 g/m² (4 oz/yd²). After testing the subgrade we calculated a depth of 40 cm (16 in) for the base aggregate for the treatment with additional aggregate. This is exactly twice the depth of the aggregate in the control and geotextile treatments.

We sampled suspended sediment in the runoff from the road surface after 145 trips by loaded log trucks in February of 2006 and again after 276 trips by loaded log trucks in April of 2006. We mapped the road surface and dug trenches through each of the treatment segments in July of 2006 after 292 trips by loaded log trucks.

The precipitation delivered by the sprinkler system produced runoff. However, with the open-graded aggregate for the base layer, much of the precipitation infiltrated into and percolated through the aggregate and drained off the road at the surface of the subgrade. The wheel tracks produced most of the surface runoff and directed it down the road to the water bars where the ISCOs sampled the runoff for 1.5 hours at four minute intervals during both of the sampling periods.

The analysis included seven passes of a loaded log truck that occurred during the sampling periods. We were able to clearly identify truck passes in graphs of SSC over time. A peak value of SSC occurred immediately after a truck pass and then SSC returned to pre-pass values within 20 minutes. Figure 3 is a graph of SSC versus time for the five treatments during two passes of a loaded truck.

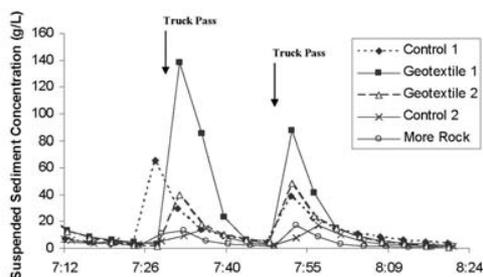


Figure 3. A plot of suspended sediment concentration with time for the five treatment plots during the April of 2006 sampling period.

We compared the peak values of SSC for each treatment during the seven passes of the loaded log truck. The means of the peak values of SSC from the treatments significantly differed after accounting for differences in truck passes ($p < 0.001$ from an ANOVA test). The two geotextile treatments and the first control treatment consistently had higher values of SSC with truck passes than the second control and the treatment with additional base aggregate.

Ruts developed in the wheel paths with time and total traffic. We observed substantial ruts in the geotextile treatments and in the first control treatment. These are the same treatments that produced the highest values of SSC with truck passes. When hauling ended on the road, ruts in the wheel paths of these treatments were up to 6.4 cm (2.5 in) deep. Overall, the pavement treatments that held their shape produced lower values of SSC than the pavement treatments that developed ruts.

The greatest rutting occurred with the geotextile treatments. This is possibly due to the failure with loading of the open graded rock on top of the geotextile. Because there was little fine material available in the base aggregate as placed, the aggregate in the pavement structure was not able to lock together into a stable structure. Also, the geotextile prevented the aggregate from being pushed into the subgrade material and held in place.

As ruts developed in the wheel paths they directed more runoff down the road. The pavement treatments that did not develop ruts efficiently directed surface runoff off the road and little runoff collected at the water bars. We were unable to measure the total volume of runoff from the treatments because the pavement treatments did not deliver surface runoff to a single location. This characteristic is ideal for a road surface to minimize sediment yield when surface runoff occurs.

Although the subgrade was outsloped, the surface aggregate developed a crowned cross-section with traffic. Upon further inspection at the end of hauling it was clear that the aggregate depth varied across each pavement treatment and the hillslope side of the road had increased aggregate depth. One of the geotextile treatments had an aggregate depth of 13 cm (5 in) on the hillslope side of the road and 27 cm (11 in) on the fillslope side (Figure 4). Although the subgrade was outsloped, Green Diamond Resource Company did not grade the surfacing aggregate to maintain an outsloped cross-section and thus with traffic the road developed a crowned cross-section

creating the differences in aggregate depth across the pavement treatments.

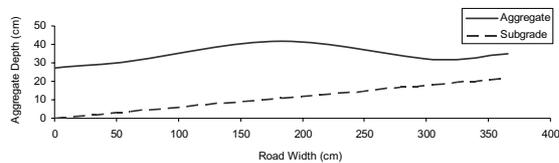


Figure 4. A sketch of a trench dug across the first geotextile treatment that shows the depth of aggregate above the subgrade. The fillslope side of the road is on the left and the hillslope side of the road is on the right.

The difference in aggregate depth across the treatments may have affected rutting, however ruts developed in both wheel paths indicating that even the wheel paths on the fillslope side of the road did not have sufficient aggregate to prevent rutting. We hypothesized that the second control treatment had more aggregate than called for to transition to the neighboring treatment that had twice the base aggregate. A trench dug across this treatment showed aggregate depths similar to the first control treatment; however, we dug the trench closer to the geotextile treatment (upslope) than the additional aggregate treatment.

Trenches dug across the treatments revealed a clear boundary at all treatments between the aggregate and the subgrade (Figure 5). There was no evidence of pumping of the subgrade. The suspended sediment that we measured in the road runoff was thought to originate from fines that existed in the aggregate as placed. This suggests there is a fine line between too much and too little available fine material in the capping aggregate. Fines are needed for adequate compaction, stabilization, and for a smooth running surface but this research shows that this material is also available for transport from the road.



Figure 5. A trench across a geotextile treatment that shows a cross-section with significant rutting and differences in aggregate depth. The hillslope side of the road is on the left and fillslope side is on the right.

Conclusions

The pavement treatments that held their shape produced less sediment. Aggregate depth was an important factor in sediment production. The treatment with greater depth of aggregate did not

develop significant ruts. Road managers that want to minimize the production and delivery of sediment from forest roads should design the unbound aggregate pavement to resist rutting.

Over a sampling period of one wet season and 292 passes with loaded log trucks, pumping of the subgrade material did not occur. This suggests that the gradation of the surface aggregate plays an important role in the production of fines from the road surface. Fines that we measured in the runoff originated from the surface aggregate.

Acknowledgements

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Literature Cited

- Bilby, R.E., Sullivan, K., and Duncan, S.H. 1989. The generation and fate of road-surface sediment in forested watershed in southwestern Washington. *Forest Science* 35(2): 453-468.
- Burroughs, E.R., Jr., Watts, F.J., and Haber, D.F. 1984. Surfacing to reduce erosion of forest roads built in granitic soils. *In* Symposium on effects of land use on erosion and slope stability, Honolulu, Hawaii. pp. 255-264
- Koerner, R.M. 1998. *Designing with Geosynthetics*. Prentice Hall, Upper Saddle River, New Jersey.
- Luce, C.H., and Black, T.A. 1999. Sediment production from forest roads in western Oregon. *Water Resources Research* 35(8): 2561-2570.
- Reid, L.M., and Dunne, T. 1984. Sediment production from forest road surfaces. *Water Resources Research* 20(11): 1753-1761.
- Wemple, B.C. 1994. Hydrologic integration of forest roads with stream networks in two basins, Western Cascades, Oregon. Oregon State University, Corvallis, Oregon, 88 pp.

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MECHANIZATION OF HILL FORESTRY IN THURINGIA (THÜRINGEN)

Erik Findeisen

Abstract: Thuringia (Thüringen) is one of the young federal states of Germany. The change of the political system included a change of costs for manual forestry work. Therefore the mechanization of forest procedures is necessary for a successful enterprise. Another reason is founded in the natural conditions of Thuringia. Only 65% of the total forest area is passable for normal forest machinery (inclination of up to 35%). Areas with an inclination of more than 50% make up 15% of the forested area – and logging procedures use cable cranes. Between the extremes many combinations of different techniques are used. In the state forest of Thuringia (approximately 200,000 hectares), mechanization is developed by state machinery bases (Maschinenstützpunkte) with their state-owned staff and machines. This type of structure is successful if planning, organization, implementation and staff training are optimized. Other prerequisites for effective forest management are the well-developed forest infrastructure and good possibilities for selling timber.

Key words: forest logging systems; forest organization; mountain forestry

Introduction

The German federal state of Thuringia is known for its wealth of wooded areas. Because of its central geographical site it is often called “The green heart of Germany“. In fact, about 34% (547,108 hectares) of its total territory is wooded land. The forest is concentrated on areas where agriculture is not so efficient - especially in the hills. About 39% of the wooded area is in privately owned – most owners have no more than one hectare. This is a reason for a difficult mobilization of wood in the small private forests. Communal forests make up about 16% of the total forested area. In the socialist era of East Germany, the state forest enterprises managed all forest property – since the political change in 1990 the private owners have had to develop a new understanding for their property. The governmental forest office named “ThüringenForst” assists them on this path. The results of the “Second German National Forest Inventory” (Bundeswaldinventur - BWI II) in 2002 show that Thuringia features a medium stock of 301 m³ solid volume over bark per hectare, and the annual medium increment is about 10 m³ solid volume over bark per hectare. This equals nearly 8.3 m³ of useful timber. The total use increased from about 1.1 million m³ in 1996 to 2.6 million m³ in 2006. The areal distribution of the main tree species is shown in Table 1.

Table 1. Areal distribution of main tree species

Norway spruce (Fichte – picea abies)	42.6%
Scots pine (Kiefer – pinus sylvestris)	15.7%
European beech (Buche – fagus sylvatica)	20.1%
Oak (Eiche – quercus petraea, quercus robur)	6.6%

Important for the applicability of logging systems and the structure of timber-using industries is the age class distribution of the main tree species. Regarding Norway spruce (*Picea abies*), the biggest part of stock is located in the age classes III to V, whereas the biggest stock of Beech (*Fagus sylvatica*) is in the age classes VI to VIII.

This paper presents the mechanization in the state forest as a progressive example for general developments in hill forestry in Germany. One important aim of this paper is to publish the current problems as an invitation to have an exchange about existing experiences.

The Thuringian state forest makes up 36.4% (about 200,000 hectares) of the total wooded area of Thuringia. ThüringenForst has three important tasks:

- management of state forests
- provides assistance to private and communal forest owners with respect to management and development
- enforcement of forest law in the total forest area .

Under the direction of the Thuringian Ministry of Agriculture, Nature Protection and Environment, 28 local offices realize these tasks. The average size of such an office, called “Gemeinschaftsforstamt”, amounts to 19,000 hectares of wooded area. Only in the state forest, the offices are responsible for the management. As a service, communal and private owners can use the assistance by ThüringenForst in forest management, planning or timber sale. Only large private forest owners employ their own staff. Because of the bundling function, the state forest plays an important part in the wood mobilization process. In Germany, the demand for wood increases from month to month while the current prices also rise up to the level of global markets. German wood industries and sawmills can use the advantage of a large timber stock and well-developed transport logistics. In Thuringia, the industry processes 3.3 million m³ round timber - more than the yield of our own forests.

After the reunification of the two German states in 1990, staff in the state forest offices was reduced from about 12,000 to 1,766 at present. Some of the 28 regional offices have special tasks. Concerning forest operations, two forest machinery bases are specialized. They have their own state-owned machines and staff. These machinery bases are an important engine for the mechanization of forest operations.

Conditions for Forest Operations in the Thuringian State Forest

Most of the state forest is located in the medium-range mountains, making up a large part of the useful timber stock. The hills are between 500 and about 1000 meters above sea level. The slopes often have an inclination ranging from 30 to 80 %, but the slope lengths differ between 100 and 500 meters. It is important to know that the management does not include clearcuts – all normal timber use is based on thinnings. Thus, natural regeneration is encouraged. The average diameter at breast height of the removed trees is approximately 25 to 35 cm – not very large! So, the economical demands are great, because logging costs are high. Ergonomical and ecological demands are also highly-developed in Germany. It is necessary to introduce new logging technologies and systems. The state machinery bases and the Department of Forest Operations and Techniques in the “Fachhochschule”, have trained young forestry engineers for many years.

Timber sale possibilities

According to the analyzed timber yield, large companies have built new saw mills, pulp mills and chip board factories in the 1990's. Examples are the saw mill “Klausner Holz Thüringen” (annual saw capacity of 2.2 million m³ round wood from conifers) of the Klausner Group, which exports lumber to the U.S.A., the beech saw mill of Pollmeier (annual saw capacity of 0.4 million m³ round wood) or the pulp mill “Blankenstein” (annual demand of 0.6 million m³ round wood) of the Mercer Group. In the last few years, the market for energy timber has greatly increased. Apart from some large heat and power plants using biological materials (f.i. Biomasseheizkraftwerk Stadtwerke Leipzig – 0.14 million m³ per year), private households ask for even more energy wood. It is a result of the increasing prices of oil and gas.

The big timber customers make contracts with the sales department of ThüringenForst. Thus, they can be sure to get the needed timber – in quantity, quality and in due time. The state offices deliver timber from the state forest, but also from other forest owners – it also includes owners who only possess a few hectares of forest. One percent of the harvested wood is sold by means of submission. These are only logs of best quality – for veneers for example. Sales on the stump are usually only done in very small dimensions.

Forest opening-up

Until 1990, the forest roads in the former German Democratic Republic (GDR) were built for trucks with seven tonnes of axle load. Since the political change, trucks with 11 tonnes of axle load and 42 tonnes of total weight use these roads. For that reason a way construction program has been implemented. The road network has increased from a density of 17 meters per hectare to 24 meters per hectare. Because of the newly-developed logging technologies the original density goal (35 meters per hectare) was changed. Now a density of 20 to 25 meters is needed, and in the hills a density of about 30 meters is required. As far as the hill area is concerned the roads have to fulfil the cross profile shown in Figure 1. In forest areas with a slope inclination of between 35 and 50 % and a maximal slope length of 200 meters primitive machinery tracks are constructed. These are without stabilization by materials and have a cross profile as shown in Figure 2. The construction costs amount to \$5 per meter and the construction is made by a specially-equipped tracked excavator. The cheaper construction by means of a bulldozer is not desired in Germany because it is more intrusive to the environment. From 1991 to 2006 over 450 km of these simple tracks were constructed in the hills.

Logging costs in areas with the inclination and the slope length specified above have thus been reduced from 45 \$/m³ to 32 \$/m³.

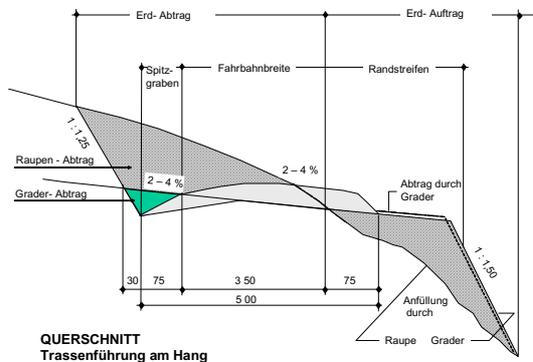


Figure 1. Cross profile of forest road in hills terrain (ThüringenForst)

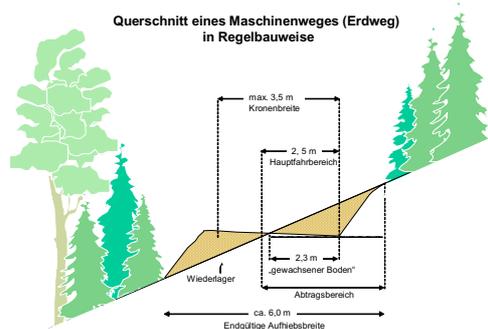


Figure 2. Cross profile of machinery track (ThüringenForst)

All construction measures were intensively planned and take the demands of the new logging technologies into consideration. In fact, the timber transportation were optimized.

The costs of road maintenance were included in this optimization. In the state forest, the machinery bases are able to realize all the measures of road construction and maintenance. Along with the up-keep and the implementation of a digital road-information system (Wegeinformationssystem – WIS) the current forest planning, the financial and organizational realization are a special task of the bases. In total, the annual maintenance costs amount to \$0.65 per meter. Figure 3 shows the most important machinery system for forest road construction and maintenance - the grader with

vibrating roller. In the state machinery base such a system runs 1800 machine hours per year.



Figure 3. Grader with vibrating roller (photo: Erik Findeisen)

Mechanization of logging methods

Very soon after the political change and as an important precondition for German reunification in 1990, the “German Mark” became the currency and, in tendency, the wages of forest workers increased. Under this condition, the mechanization of all the measures in forest management got a higher importance. A large group of the state forest workers used the possibility to become machine drivers. The high level of technical training in the former GDR was a good basis for this development. In Thuringia, a forest center of education was created where the university, the forest office, the forest technician trade school and the machinery bases work together profitably. In this way some well-informed and trained staff is created, especially with respect to modern logging systems. In the hills in particular, where cable cranes are the preferred logging method, a high percentage of useful timber is located. For cable crane operations well-trained personnel are needed.

The following points are important for the increasing degree of mechanization:

- Most sales of timber were realized in short logs (lengths of 2 up to 6 meters), because transportation by trucks is easier and the saw mills use small logs more efficiently. Only logs of larger dimensions can be sold as tree length (6 to 19 meters), but logging of long trees during thinning operations is more damaging and transport by truck in Germany is limited to logs up to 19 meters. Log length varies by logging system. Forwarders represent the short-tree methods, while skidders are linked with tree-

length methods. The cable crane stands for timber harvest on steep slopes. In the following Table 2, the development of logging system use from 1995 to 2004 is shown:

Table 2. Development of logging system use

logging method	1995	2004
Skidder	48%	19%
Forwarder	22%	68%
cable crane	3%	7%
Others	27%	6%
Total	100%	100%

- The use of wheel-harvesters became the most efficient wood harvest method in coniferous forests and on sites with slope inclinations of up to 35%. Also, the harvester can be used successfully in younger hardwood stands. The productivity and capacity of the fully-mechanised harvest has grown rapidly during the last 12 years. Table 3 shows the development in the state forest company:

Table 3. Development in the state forest company

Harvester ThüringenForst	1995	2004	2006
Total annual production	4,500 m ³	135,600 m ³	164,300 m ³

Each state harvester runs about 3000 machine hours per year. In this way the costs per m³ are very low (\$13 – \$20 for thinning timber with a breast height diameter between 15 and 35 cm).

- The wood harvest under hillside conditions is characterized by a high cost. Hence, special procedures are necessary. Medium-sized short corridor cable cranes are used - in spite of high costs - on slopes with inclination of more than 50% and slope lengths of up to 150 meters. A special combination of a cable crane and a crane processor - the so called “Gebirgsharvester”- is also used (Figure 9). The cable cranes have low soil disturbance. Naturally, there are also attempts to fully mechanize the wood harvest on steep sites. After several practical attempts with tracked harvesters and forwarders ThüringenForst ruled that for the state forest in areas with more than 50% of slope inclination there should be only cable crane applications. The tracked machines caused unacceptably high damages to the forest. Also the ergonomic load for the machine leaders was too high. Especially in absence of trees to guy the cable crane, ThüringenForst bought a

machine from the “Hochleitner”-company – it is an excavator with a Valentini cable crane. The mast can be telescoped from 8 meters (without guying) to 12 meters high (with guying). The skyline has a diameter of 18 mm is 550 meters long – the load-carrying capacity amounts to about 3 tonnes. The weight of the machine is about 22 tonnes, the engine power being 110 kW. The machine system is shown in the Figure 4.

- In the transitional area between slightly inclined sites and the steep slopes varying wood harvest procedures are applied. There are assortment procedures and the full tree logging with subsequent processing on the forest road.



Figure 4. Cable crane on excavator for stands without possibilities for guylines (photo: Andreas Gleichmann - (ThüringenForst))

The creation of a forest work compendium by ThüringenForst turned out to be very favourable for practice in forest offices. Also, for the purpose of the certification by PEFC (Programme for the Endorsement of Forest Certification schemes – www.pefc.org), a uniform system of requirements for wood harvest procedures was implemented. At the same time, prices were compiled which guarantee a lasting foundation for the purpose of meeting the qualitative requirements.

The forest work compendium is suited for the choice of the best logging procedure to be applied with regard to the realisation of measures with certain priorities. At first three area types are distinguished by their average slope inclination. In Figure 5, this division is shown:

- passable positions with up to 35% of slope inclination,

- medium steep areas between 35 and 50% and

- steep slopes with more than 50% inclination.

Slope inclination and length	Opening-up	Length of assortment	Harvesting procedure	Logging	Skidding	Remarks	
Inclination of up to 35%	machinery track	≤6m	harvester		forwarder		
			motor-manual		forwarder		
	width of work area 20m	>6m	harvester		skidder		
			motor-manual		skidder		
Inclination from 35 to 50% and of more than 50%, when slope length up to 150 m	machinery tracks with distances of 70 - 100m, rope lines (if required), machinery tracks for short-wood procedures by forwarder with auxiliary winch for traction	delimbed, not divided	motor-manual rope-supported		skidder	motor- manual processing and subsequent piling	
		delimbed, divided	motor-manual rope-supported		skidder		
			Trackwd harvester or motor-manual (perhaps rope-supported cases of trees)		forwarder (with auxiliary winch for traction)		
		not delimited	motor-manual; rope-supported cases of trees; possibly topped		forwarder	processing on the machinery track	
motor- manual, rope-supported; perhaps topped			skidder	processing on the forest road, piling by processor			
Inclination over 50% and slope length of more than 150 m	Rope lanes in distance of 30m	delimbed, not divided	motor-manual	cable crane	skidder	motor- manual processing on the forest road; piling	
		delimbed, divided	motor-manual	cable crane	skidder		
		not delimited	motor-manual; perhaps topped		cable crane		processing on the forest road; piling by processor
			cable crane with processor		cable crane with processor	processing on the forest road; piling by processor	

Figure 5. Optimal logging procedures in ThüringenForst (compendium of forest work)

According to slope length and assortment, different technologies came into application. Also, the ground-load carrying capacity now plays a big role. For short-wood procedures, distances of 20 m between skid trails are aimed. These distances can be extended if damage to the soil is to be expected. There are of course a number of possible combinations. The use of horses for example is also possible up to pre-skidding delivery distances of up to 50 m. In Figures 6 to 9, the essential methods of operations are shown for the forest areas that are not passable for normal forest machinery. The gross margins (difference between wood proceeds and wood harvest costs) of the wood harvest could be decisively improved by the application of these technologies. For every method, there are the special spreadsheets that make possible a uniform planning in the state forest.

Work organization

The forest work compendium of ThüringenForst also gives fundamental tips concerning the work organization. The block approach was used to intensify forest operations. Harvesting operations on forest surfaces are thus summarized in larger complexes. The following advantages are linked to this block approach:

- optimization of organizational expenditures
- minimization of conversion costs
- concentration of road maintenance
- optimization of wood removal
- restriction of concerns linked with forest operations and machinery tracks.

Intensive planning is the prerequisite for a sensible processing of the operation blocks. In addition, to develop more independent forest technician teams and to create motivating ‘elbowroom’ for responsible individuals to influence corporate

success, partially-autonomous working groups were organized.

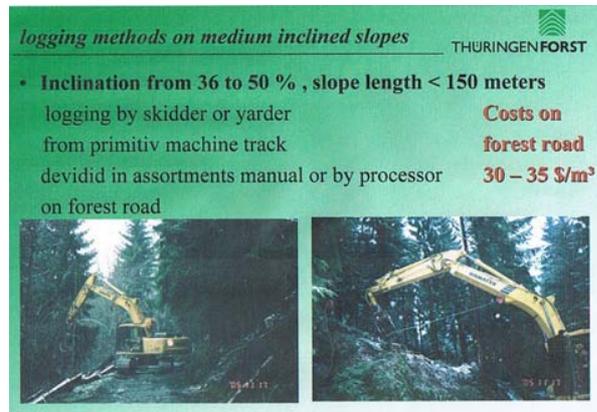


Figure 6. Skidding by means of tracked excavator with winch (ThüringenForst)

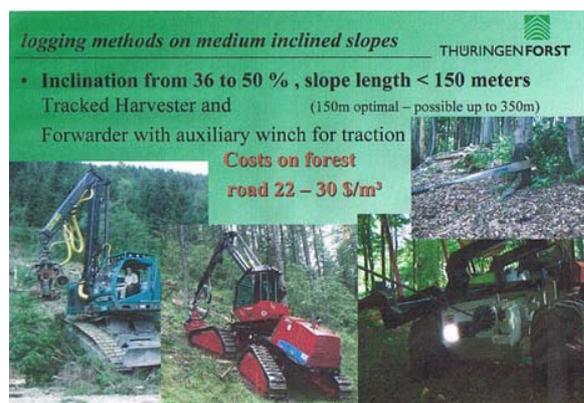


Figure 7. Highly-mechanized wood harvest on medium inclined slopes (ThüringenForst)

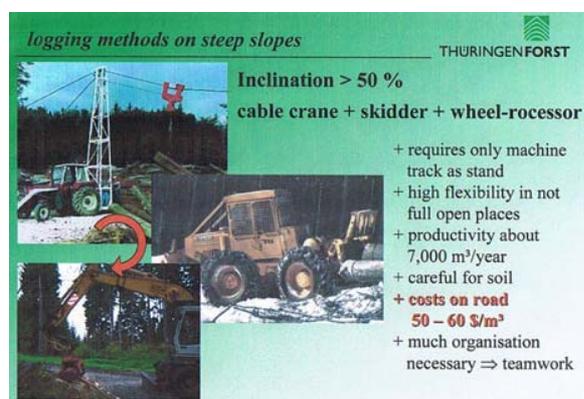


Figure 8. Logging by cable crane (ThüringenForst)



Figure 9. Logging by mountain harvester – “Gebirgsharvester” (ThüringenForst)

Current Investigations

Following the information above, the current investigations are bundled in wood harvest in steep locations. Numerous tests of different techniques and technologies have shown that the development of a new kind of tracked or wheel chassis is necessary. But it is not possible to develop it in a short period of time – it will be a project with some partners in the specialized industry.

At the moment tests are underway with forwarders with an auxiliary winch for help them to keep traction on steep locations. The most important detail of the winch is the synchronization between the speed of wheels and winch. The current investigations show that the use of the winch is good for the soil, because the traction is always guaranteed. The 12 tonnes forwarder is planned for the application in slopes with an inclination from 30 to 60%, but it can surmount road slopes with up to 80% inclination. The cable of the auxiliary winch has a length of 200 meters; downhill logging is possible as well as uphill. Further the investigations show that the efficiency of this method is very high – about 10 to 17 m³ per machine hour. The total costs depend more of the distance to the next road than of the degree of inclination. The method is shown in Figure 7.

The next investigation will start with a newly created machine. A very interesting solution is given by the company “Konrad Forsttechnik” from Austria www.forsttechnik.at/unternehmen-team.php. They offer a new harvester, the so-called “Highlander” which is a high-performance harvester for medium sized timber. The machine weight is about 20 tonnes and is equipped with an endless rotation system for cabin and crane. The 10 meter long crane is very

strong (24 tonnes a meter). The harvester can run like a normal wheel-machine but also go by steps in two points. As you can read on the home-page, in extremely inclined terrain the machine has enormous terrain flexibility due to the synchronised step and drive movement. On road the machine runs at a speed of up to 40 km/h using only the front-axle drive. “The Highlander offers more than the climbing ability of a chain driven machine and the advantages of a wheel driven machine.”(Konrad) There is a description of its practicable use:

- “1. The harvester Highlander cuts trees in difficult terrain and passes them on to the clamping bench with the gripping function of the WOODY aggregate.
2. The crane swings to the back and the aggregate is stopped. Therefore, the machine

can overcome long hauling distances quickly and safely.

3. On arrival on the forest road, the logs are trimmed and prepared for transport.

With just one machine, the complete working process is carried out at a previously unattainable economic standard in difficult terrain. For the transport of the machine Highlander, a special trailer and a standard towing vehicle are sufficient. This makes transport not only easier, but also more economic and flexible. The special trailer can be left on site and used for further transport with a common and low cost towing vehicle.”(Konrad)

Figure 10 shows the harvester and Figure 11 the use in combination with the clamping bench.

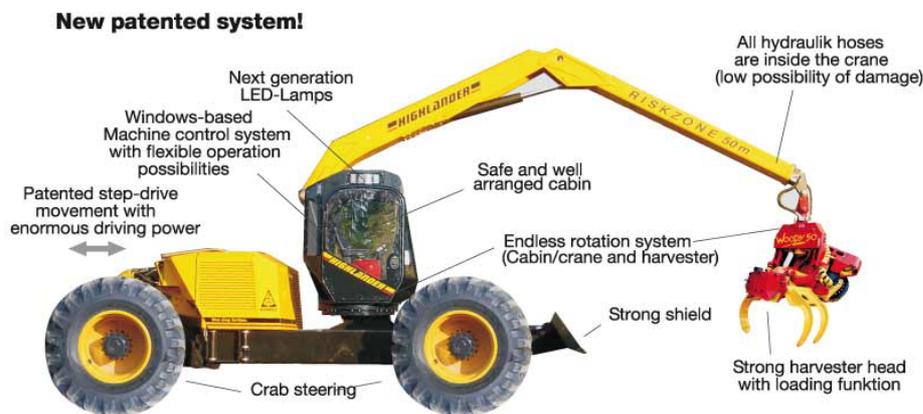


Figure 10. Harvester “Highlander” (Company Konrad Forsttechnik Austria)



Figure 11. Highlander as Harvester with clamping bench (Company Konrad Forsttechnik from Austria)

At the moment the mobilization of wood and the optimization of transportation logistic is a special aim for increasing the useable quantity and quality of wood for the industry. The measurement and the localisation of the transportable timber stacks are included in the current investigation of a mobile,

automated digital measurement by special cameras (stereo vision system) installed on the top of a car and a new developed program for a standard laptop. The data go wireless to a web-based server and are visible as photo with results of measurement and the GPS-coordinates for a transport optimization

program. The Danish company “Dralle A/S” (www.dralle.dk) has developed three systems:

- sScale for the measurement of stack of woods while pass the road by car (15 km/hour)
- aScale for the measurement of single trunks
- tScale for the measurement of transported timber (on truck or railway-wagon) as a fixed system in timber using factories.

For our investigation the sScale and tScale systems are very important for short wood sales to pulp mill and stand-board production. The measurement is automatically possible in the forest and in the timber using factory. In this way measurement costs can be significantly reduced. In a first test 2500 m³ of wood stacks on the forest road are measured in only 3 hours. For selling timber it is very good to recognize the results of measurement (volume, diameter, quality) by the high quality photo. This picture is made from hundreds of pictures. The next investigations in Thuringia start in March 2007. In figures 12 and 13 are shown the kinds of measurement.



Figure 12. sScale – mobile measurement of timber stacks (Company Dralle A/S Denmark)

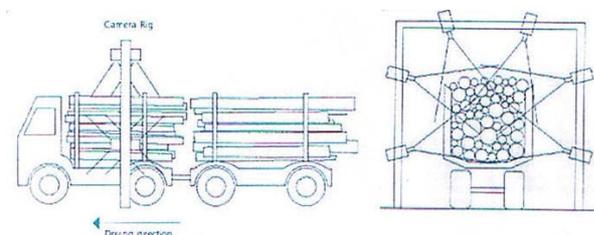


Figure 13. tScale princip – measurement of timber on truck (Company Dralle A/S Denmark)

Summary

As a considerable part of the usable timber stock is located in steep areas of Thuringia, the development of reasonable and ergonomically acceptable methods of operations presents a big challenge. In the state forest of Thuringia, this development is carried out substantially by the state machinery bases. Personnel that turned out to be too expensive when using conventional working methods was qualified as machine drivers for special forest technology as well as for road construction machinery. Bearing all this in mind the operating result can be influenced positively. The use of their own machinery is only efficient from an economic point of view if the operation planning, the working organization and the implementation are optimized and if the further qualification of the staff is actively pursued.

Advantages of the well-organized state company are:

- well-qualified staff
- modern forms of the work organization (partially autonomous group work)
- guaranteed preservation of technical and technological know-how
- internal technology development (wood supply chains)
- relative independence of market
- quick action in case of calamities
- modern forestry training and continued education

Choosing the optimal logging procedure is the basis of a special forest work compendium. Especially for steep areas, tested procedures can be selected according to a pattern and costs can be compared. On the medium steep slopes highly-mechanized harvesting systems (tracked harvester and forwarder with auxiliary traction winch) or hauling by skidder and excavator with winches (from the machinery track) are reasonable procedures. On sites with more than 50% slope inclination, cable cranes and “Mountain-Harvesters” (Gebirgsharvester – truck with cable crane and crane-processor) are used as optimal procedures with respect to ergonomics, productivity and a speedy supply of the harvested wood to the industry. Especially in the field of harvest on slopes investigations are under way by the governmental forest office, the university of applied sciences / forest engineering of Thuringia and some machine producers aimed at finding new solutions with high efficiency and carefulness.

Good forest management in the low mountain range is possible only by sensible development of truck-classified roads and machinery tracks - the chosen road density of the truck-road net in Thuringia is

approximately 22 to 24 meters per hectare. The minimization of the overall transportation costs consisting of road and logging costs must be the basis for the estimation of the optimal road density. Besides, the multi-functionality of the forest has to be taken into consideration. Another condition for the actual management of the medium steep areas are extensive wood sale prospects. In Thuringia, this was achieved by encouraging the settlement of modern wood-processing industries.

The improvement of transportation logistics and timber measurement are among the most important prerequisites for mobilization of wood and the delivery of high quality wood in a short time process.

Literature Cited

The data published in the preceding article came from the annual reports of the Thuringian forest

office, where the author is located. Some data are taken from the internal compendium of forest work of ThüringenForst. Prospective customers interested in more detailed information are encouraged to contact the author.

Konrad – phrases are taken from the official website in February 2007

www.forsttechnik.at/unternehmer-team.php

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FOREST SKYLINES IN TURKEY

Tolga Ozturk, Necmettin Senturk, H.Hulusi Acar

Abstract: Three primary transportation methods are used in Turkish forestry; human power, animal power and mechanization. Skylines are used as the primary transport device in steep terrain. The skyline equipment used are Koller K300, URUS MIII and Gantner. Forest skylines are classified as 1) short distance skyline (300 m – Koller K300), 2) middle distance skyline (600 m – URUS MIII) and 3) long distance skyline (2000 m – Gantner). In this study, the technical features of skylines in Turkey are examined including productivity and costs

Key words: Skyline, Koller K300, URUS MIII, Gantner, Black Sea Region, Turkey.

Introduction

Turkey has 21.2 million ha of forests, which occupies 26.6% of the total land area. Approximately 75% of the forested area is on steep lands with slopes greater than 40%. Therefore, harvesting in mountainous regions have always posed a special difficulty. About 15.4 million ha are considered as high forest and have been managed as high forest systems producing timber for industry. Total standing volume is 1195 million m³ in such forests. The remainder, about 5.8 million ha, is considered coppice forests and have been managed producing firewood for heating and cooking purposes in particular. The average road density is 10.7 m/ha in forested areas. A map of Turkey is shown in Figure 1.



Figure 1. Map of Turkey

The production of timber is still one of the most important forestry uses. The productivity of a forest depends on various ecological factors and their positive and negative effects. In Turkey, Gantner skylines have been in use since the end of the 1950's. Long distance cable cranes (Gantner, etc.) are still in use, but during recent years modern mobile skylines (Koller, URUS etc.) were put in practice. The Forest

General Directorate in Turkey has imported many URUS and Koller series mobile skylines, Koller carriages, Gantner skylines and other equipment.

The Transportation Types in Forestry

The transport of forestry products is done in two stages in Turkey. The first one is the primary transport of timbers to roadside and the second is the secondary transport stage involving trucks and tractor trailers on forest roads (Aykut 1986).

In Turkey, three primary transportation methods are used: human power, animal power and mechanization. Mechanical skidding is carried out by ground based forestry vehicles. The level of harvesting mechanization in developed countries is higher than in Turkey. In Austria, 86% of harvesting is carried out mechanically and in Turkey only 9% although the forests of the two countries have very much in common (Acar 1998).

Ground skidding by hand (man and gravity) is applied in small forest areas for extraction of small amount of timber and a large amount of fuel wood over short distances. Manual gravity skidding is carried out as ground skidding, sliding and dropping. Sometimes, small timber and firewood is transported by forest workers. Animal skidding is carried out simply by skidding with the use of a pulling chain with a hook. The hook of this chain is nailed to the log and the other end of the chain is attached to the animal's yoke. Thus, the logs are skidded on the ground. Animal skidding, mainly by horses, mule, water buffalo and oxes, is used for pre-skidding for bunching distance between 20 m and 100 m.

Harvesting mechanization is done by two different vehicles. The first one is by tractor. Two types of

tractors are used in Turkey; farm tractors and skidders. The farm tractor types include Massey Ferguson, New Holland, and Fiat. The skidder type is Mercedes MB Trac. The second type of mechanized harvesting is by different types of skylines. In Turkish forestry, forest skylines are used to transport forest products between 300 and 2000 meter distances. According to hauling distances, these are classified as follows:

- short distance (less than 300 m)
- middle distance (between 300 – 800 m)
- long distance (between 800 – 2000 m)

The Technical Features of Forest Skylines in Turkey

Forest skylines were first introduced in the 1950's in Turkey following suggestions by FAO in 1956. German, Swiss and Austrian firms came to Turkey and the Forest Ministry of Turkey brought skylines from Baco, Wyssen and Hinteregger (Acar, 1998). The skylines were used until 1970. The Forest Ministry of Turkey brought short and middle distances mobile skylines in 1972. These skylines had used to different mountainous areas in Turkey. Today, the Koller K300 as short distance forest skyline, the URUS MIII as middle distance forest skyline and the Gantner as long distance are used in the East Black Sea Region of Turkey. Technical features of these skylines are described below.

Koller K300 Short Distance Skylines

The Koller K300 cable system is a mobile cable-yarder system designed for uphill logging (Figure 2). The machine is compact with simple engineering, and designed for small wood logging and residue removal operations. The cable system could be mounted on a farm tractor with a three point hitch or could be placed on a trailer for easy transportation over long distances (LeDoux, 1997). The system components and capabilities are:

- * The tractor engine must have a minimum of 50 hp
- * Approximate weight without the tractor is 1580 kg
- * Average mainline speed for the tractor-mounted version is 192 m per minute,
- * Cable capacity is 300 m of 9,5 mm cable for the mainline, 300 m of 16 mm cable for the skyline, and 30 m of 14 mm cable for the guyline,

- * Uses multispan self-clamping carriage and can be set up with intermediate supports and tailspar,
- * The tower height is 7 m (Tunay, et al.2001).

Six workers are employed in operating the cable system. The time of mounting of cable system is 3-5 hours while the dismounting time is 1-2 hours. The number of guyline ropes ranges between 2 and 4 (Ozturk 1997). The installation of the Koller K300 skyline is shown in Figure 2.

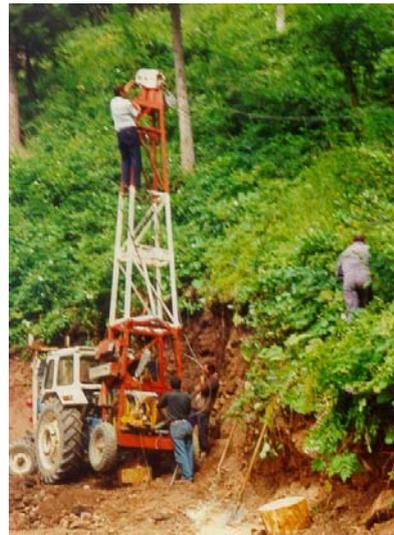


Figure 2. Koller K300 skyline installation

URUS MIII Middle Distance Skylines

URUS MIII skyline is used for both uphill and downhill transport. The maximum installation length of URUS MIII skylines is 600 m. The skylines can be used for the larger timber. The URUS MIII middle-distance skylines are mounted on a T1500 Mercedes truck with an engine power of over 150 HP. The skylines were powered through the power take-off unit of the truck. Four workers are employed in operating the skyline. The skyline has a weight of 2500 kg excluding the truck. The average drawing speed of rope is 192 m/min. The time for rigging the skyline is 5-6 hours while the dismounting time is 2-3 hours. The number of guylines ranges between 2 and 4 (Ozturk, 1997). The URUS MIII skyline specifications for yarding area used are shown in Table 1 and the URUS MIII skyline is shown in Figure 3.

Table 1. Specifications of URUS MIII skyline (Ozturk, 2004)

URUS MIII	Specifications
Base Machine	Mercedes 1500T trucks
Weigth	8500 kg
Height of tower	8.7 m
Maximum number of drums	4
Maximum cable speed	6 m/s
Skyline line (diameter x length)	22 mm x 600 m
Main line (diameter x length)	12 mm x 600 m
Haulback line (diameter x length)	12 mm x 1200 m
Auxiliary line (diameter x length)	10 mm x 600 m
Guyline (diameter x length)	16 mm x 50 m
Carriage	Koller SKA 2.5



Figure 3. URUS MIII skyline at working area

Gantner Long Distance Skylines

The Gantner long-distance skyline used in the study was mounted on a sled. The transport distance of the skyline used is 1500-2000 m and the daily transport capacity is 40-50 m³ on the average. Four workers are employed in operating the skyline. The time for rigging the skyline is 21-49 hours while the dismounting time is 7-14 hours. The number of guylines ranges between 2 and 4. The Gantner skyline specifications for yarding area used are shown in Table 2 and the Gantner skyline is shown in Figure 4.

The URUS MIII is more powerful than the Koller K300. Therefore, it was determined that the Koller K300 is more suitable for the transportation of fuelwood and URUS MIII for logs. Gantner skylines are powerful and productive. It is an important machine for timber transportation at long distances. These machines are used where the transport distance is long or the road density is low (Acar et al. 2005).

Table 2. Technical features of Gantner skyline

Gantner USW 45	Technical Features
- Engine power	45 HP
- Maximum drawing power	6840 kP
- Maximum cable speed	7.5 m/sec
- Skyline length	500-2000 m
- Drum width	800 mm
- Weight	1420 kg
- Maximum load weight	2.5 ton
- Minimum worker number	4
- Main line diameter	24 mm
- Drawing line diameter	16 mm
- Fuel consumption	20 lt/day
- Sizes	2500x1500x1200



Figure 4. Gantner skyline at working area

Cost and Productivity of Skylines

The Koller K300 skyline generally transports fuelwood and small timber from a short distance and the URUS MIII carries out the industrial timber from the middle yarding distance. The Gantner skyline transports generally heavy timber from long distance. The Gantner skyline is use to yard areas where forest road construction is expensive and difficult. The results of some studies on these three skylines in Turkey are in Table 3.

Table 3. The results of some investigations on these three skylines for Turkey

Researcher and Years	Research Area	Skyline Type	Transport Distance (m)	Transport Direction	Average output values		Cost \$/m ³	Average Time min/shift	Average Slope %
					m ³ /hr	stere/hour			
Ozturk, T. 1996	Taslica	Koller	250	Uphill	5.90	--	8.75	10.08	55
	Taslica	URUS	450	Uphill	7.90	--	13.14	11.46	65
	Ortakoy	Gantner	1300	Downhill	3.40	5.20	5.20	29.00	70
Aykut, T. et.al. 1997	Tepebasi	Koller	160	Downhill	12.20	--	--	5.44	50
	Meydancik	URUS	240	Downhill	8.60	--	--	9.56	45
	Tepebasi	Gantner	900	Downhill	--	5.80	--	15.00	60
Erdas, O. Et.al. 1999	Ortakoy	Koller	190	Uphill	4.85	6.60	6.77	8.07	60
Acar, H.H. et.al. 2000	Savsat	Koller	200	Downhill	7.86	--	2.41	10.24	50
	Savsat	Gantner	800	Uphill	4.97	--	3.58	27.40	75
Caglar, S. 2002	Ardanuc	Koller	280	Uphill	4.50	--	--	16.90	60
	Savsat	URUS	600	Uphill	3.80	--	--	27.64	45
	Ortakoy	Gantner	1100	Downhill	4.00	--	--	27.37	65
Ozturk, T. 2003	Savsat	Koller	200	Uphill	--	5.70	4.49	11.58	80
	Taslica	URUS	350	Downhill	12.90	--	5.24	17.13	60
	Savsat	Gantner	800	Downhill	--	4.65	4.10	15.28	80

Conclusions and Recommendations

Forest skylines are necessary for Turkish forestry where steep terrain is typical. But, these machines are used only in some mountainous regions such as the Artvin region in East Black Sea of Turkey. Productivity of forest skylines in Turkey is adequate when they work. But, annual productivity values are low for these machines. Therefore, the work should be carefully planned for skylines before the operations.

Generally, URUS MIII skylines were found more expensive than the Koller K300. The advantage of Gantner forest skylines is that they can be set up for longer distances. But, the rigging and dismounting time for these machines is longer than mobile skylines.

Skylines must be used in mountainous areas where road construction is very expensive or harmful to the environment. Forest products which are hauled with skylines have high quality and lose little value through log damage as compared to ground skidding which can damage the product, the forest soil, and the other plants.

According to these results, the following suggestions have been prepared:

The felling plan must be prepared before extraction and the work organization must be done first including determination of felling direction.

The width of skyline corridors should be 2-3 meters. A greater width skyline corridor is not necessary. Too narrow a corridor is also not desirable because trees at the side of corridors will be damaged during yarding. The products in the corridors should be transported first.

The number of workers for loading and unloading operations should be increased for achieving maximum productivity of the forest skyline. During skyline studies, expert members must be used.

The area should be carefully selected and planned. Skylines should be selected according to the logs in the yarding area. The stacked logs on the side of the forest road must not obstruct the machine's work.

Adequate spare part supplies are necessary to maintain productivity.

During the construction of forest roads, land is lost to forest production and additional land is damaged below the road. During studies of road construction in rocky lands and mountainous lands like the Artvin Region, heavy damage resulted from stones and

rocks which roll to the bottom damaging trees and plants below the road. Because of this, perhaps use of skylines should be increased and a lower road density used in these areas.

The impact of skylines on sustainable forestry should be established by ecological and economic studies.

In respect to this study, the cost of skyline was lower than other hauling methods. If we produce a forest product of high quality more cheaply, the profit of the Forest Districts will be higher.

Acknowledgement

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Literature Cited

Acar, H.H. and Erdas, O. 1992. Comparison on the transport from compartment of forest products by the along distance winch skylines and the forest roads alternatives in Artvin region. Tr. Journal of Agriculture and Forestry 16, Ankara. p.549-558.

Acar, H.H. and Gumus, S. 2000. An evaluation on Koller K300 and Gantner forest skylines from points of view technical and economical in Eastern Black Sea region of Turkey. Int. Scientific Conference Forest and Wood Technology vs. Environment Proceeding Book, Brno, Czech Republic. P. 21-25.

Acar, H.H., Topalak, O. and Eroglu, H. 2005. Forest skylines in Turkish forestry. Mehanizacija Sumarstva, Volume 26, Issue 2, Croatia. P. 137-140.

Aykut, T., Acar, H.H. and Senturk, N. 1997. An investigation on thw comparison of Koller K300, URUS MIII and Gantner skylines used for extraction from compartment in Artvin region. I.U.Review of the Faculty of Forestry, University of Istanbul, 47 (A2). P.30-58.

Erdas, O. and Eroglu, H. 1999. Technical and economical analysis of short distance Koller K300 yarder used for the extraction of timber in Artvin region. Tr. Journal of Agriculture and Forestry 23, Ankara. P.1249-1256.

Ozturk, T. 2004. The research on transporting forest products with varied forest skylines in mountainous forest zone of Turkey. I.U. Review of the Faculty of Forestry, I.U.Review of the Faculty of Forestry, University of Istanbul, 54 (A1). p. 165-187.

Rieger, G., 2001: Costs and Performance of a Koller K300 Yarder. Workshop on New Trends in Wood Harvesting with Cable Systems for Sustainable Forest Management in the Mountains. 18-24 June 2001, Ossiach-Austria. p. 107-113.

Tunay, M., Melemez, K. 2001. Work performance of Koller K300 cable system on difficult terrain in Turkey. Workshop Proceedings, New Trends in Wood Harvesting with Cable Systems for Sustainable Forest Management in the Mountains, Ossiach, Austria, p.103-121

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CABLE-YARDING IN FRANCE : PAST, PRESENT AND PERSPECTIVE

Stéphane Grulois

Abstract: France has a national standing wood stock close to 3,000 million cubic meters, and more than a quarter of its forested area is in steep terrain (slope > 30%). Cable yarding should be a common logging system in the country, but is not. Until the 1960's, the use of cable yarding was traditionally found in the Alps mountains, and to some extent in the Pyrenees mountains. Since then, many developments, among which is the implementation of the logging strategy "forest roads opening + wood extraction by cable skidder", have resulted in the decline of cable systems. The limits of this strategy have been reached, especially with the reduction of public subsidies, which compromised very much the economical feasibility of logging in mountainous areas. New incentives have to be defined to give new perspectives to this environmentally friendly technique.

Key words: harvesting incentives, cable-yarding in flat terrain, training.

Introduction and Context

The forest area in France is 150 000 km². It is 27% of the total surface of France.

The wood stock is close to 3,000 million cubic meters (wood volume up to the terminal bud). France ranks at the first place in European Economic Community (EEC) just in front of Sweden and Germany in terms of forest inventory. The annual roundwood production is 35.4¹ million cubic meters (4th place in EEC). This is a quite small figure considering that annual growth is 91.5 million cubic meters. (Memento AFOCEL 2006)

The data base of the National Forest Survey reveals that more than 35% of the wood stock volume is in mountains. In these areas, coniferous forest (*Pinus sylvestris*, *Picea abies*, *Abies alba*) are predominant except in the Pyrenees where 70% is broadleaved, mainly *Fagus sylvatica* (Barthod, C. and Pignard, J. 1998).

For the last 3 decades the harvested volume has decreased because of the low competitiveness of logging in steep terrain and a lower quality of the wood in the mountainous areas (especially in the Alps and in the Pyrenees). The results are forest ageing and timber capitalization on the stump, gaining 17% in ten years according to the last forest survey.

For the last ten years there has been a high public support toward logging in mountainous forests again with expected benefits in terms of sustainable forest management (renewing and tending of stands), protection against landslides and erosion and economical development of the forest industries, still present in those rural areas. Good forest management means also enhanced landscapes and development of tourism, especially for winter sports.

In this context, forest managers and logging companies would like to give a fair place to cable-yarding and launch some incentive actions to increase its utilization in France.

History and Recent Trends of Cable Utilization in France

Cable-yarding history in France is linked to the situation in Italy where cable transportation was born at the end of the XIXth century. During the First World War, this transportation system has been improved in relation with its utilization for heavy transportation in difficult mountainous areas. Many technicians, trained to use cables during the war, afterwards used their know-how for wood extraction. Those specialists came to France and began to work in the Alps. During 1940-1960, when the first specific motored winch was created in 1939 by Wyssen, Switzerland, many cable systems were used in Switzerland, Austria, Germany and France. This was the golden era of cable-yarding in the Alpine area.

¹ Except fuel wood harvested for self consumption (evaluated to 20 millions cubic meter from forest).

In the 1960s, the rural exodus, increasing wages, and the development of the ground-based system (forest roads opening + wood extraction with skidder) induced the decline of cable-yarding in France. In the 1970s only a few crews were still using this extraction system in competition with some helicopter-logging crews.

Since 1990, forest managers have been trying to create a new dynamic for cable-yarding with the support of public subsidies.

Today, 11 logging companies are equipped for cable-yarding. This number has been decreasing since 1999 (16) but it is still evolving. . During the subsequent 7 year period (1999-2006), 9 companies have been created, but 14 have also disappeared. Only, 4 enterprises created before 1999 are still operating in 2006.

Some foreign enterprises are joining their work capacities to the French ones (Silande G.1999, Le Bois International, 2005).

The kind of material used in France has changed over time: long winch skylines (with lines up to 2,000m long) have been replaced by cable crane. Indeed, in the past, French crews mainly worked with long cables until 2000. Of course these systems remain useful in the hillsides where the road network is not very dense.



Long distanced skylines require skilled and agile workforce

The annual production by cableway was 85,000 m³ in 2004 (and 50,000 m³ in 1999). Foreign enterprises produce 25%. Despite some effort and political willingness, this system has still a very limited place in France, representing less than 0.2% of the total harvested roundwood. (Bartoli, M., 2005)

In Italy, Switzerland, and Austria, 10 to 20% of the harvested wood is extracted by cableway. However, in France, a realistic target would be around 5% for the mountainous areas, that is to say 1% of the national harvest (400,000 m³/year on 35 million cubic meters).

Some measures have already been implemented to achieve such a goal but some others have probably to be considered too.

Recommendations to Develop Wood Extraction by Cable-Yarding in France

Provide financial support for investments and operation costs

Since January 2007, cable systems in France can be subsidized to a total value of 40% of the purchase price like most of the other logging equipment. Grants come from the European Union funds for economical development of rural areas and from local administration aimed at supporting forestry. They are combined and organized in what we call the "incentive program". For the next 7-year incentive program, the grants will concentrate only on cable-crane in order to have a pool of equipment with the latest technological developments. These include the mono-cable system with a self propelled carriage, integration of a knuckle boom loader or a processor-head mounted on the same trailer as the yarder. These systems are preferred because they are quickly installed and moved. Moreover, they require a smaller workforce for the extraction itself.



The cable cranes are now replacing the long distanced skyline equipment.

In the Pyrenees and the northern Alps, the public authorities also allot subsidies for the cable extraction operation itself. In the Pyrenees, the amount of the financial aid is based on the difference between the mean cost of extraction with a skidder and the estimated cost of extraction with a cable system. In the Alps, 10 € (\$US 13.2) per meter of hauling line are given to the forest manager (National State Forest Agency, ONF, for public forests and forest owner cooperatives for private forests). This compensates for the extra costs related to the time needed to calculate the position and to install the lines.

These financial supports have proven to be very essential. Even with the grants dedicated to the investment, technical costs for cable-yarding are definitively higher than the ones for extraction with a skidder (Table 1).

Another way to support the development of cable-yarding in France consists in developing the conditions to improve the rate of utilization and the annual productivity of the equipment.

Table 1. Productivity and cost of different logging systems in France (Chagnon and Pischedda, 2005.)

	Average productivity (m ³ /day)	Cost of felling, trimming and extraction (€/m ³)
Skidder	40	22.7
Long winch skyline	25 to 32	51.8
Cable crane	40	40.7
Helicopter	90	55.0

1 € equal 1.32 US Dollar

Increase the annual production of cable crews

A survey carried out at the end of the 1990s (Silande G., 1999) showed that, generally, the crews work only 6-7 months per year, apart from the snow period. The rest of the year is devoted to another job (working in winter resorts mainly). As a result, the annual production was roughly around only 3,000 m³ per cable equipment and crew (composed of 3-4 people).

To enable the crew to be able to work all the year round, more timber should be sold in areas requiring cable-yarding: in medium mountains (Massif-Central, Pyrenean piedmont) or on sensitive grounds in the plains.

Indeed, in some situations in flat terrain it is essential to limit the risks of soil compaction that can be very prejudicial to long-term forest production. This is the case, for example, for hydromorphic or peaty soils, or in wooded lands with a dense network of streams. In such situations, the self-propelling carriage with one cable seems particularly suitable because it is easy to install and move. Nevertheless we must keep in mind that cable-yarding is expensive. Therefore, cable-yarding can be done in situations where the forest owner is ready to give up a part of his income for environmental considerations. Up to now, the cost of the impact of soil compaction has not been quantified. Such an analysis is needed for a better

assessment of the long term benefit/cost ratio of cable-yarding on flat terrain.



Cable-yarding is an environmentally friendly solution adapted to sensitive flat terrain.

Improve training and knowledge transfer of cable-yarding techniques among foresters and loggers

Forest managers know little about this little used technique. It is essential to inform them better about it. Interactions between silviculture and logging operations are particularly important in steep terrain. For cable-yarding, a dialogue is essential between the forest manager, who marks the trees to be removed, and the logging company who calculates the location

of the lines. This dialogue is not an easy matter to achieve in the French context where each player in the forestry sector is quite independent!

ONF is making great efforts to teach its foresters the technique of cable yarding, for utilization in both mountains and plains.

There is also a need to train the logging operators. Logging companies need a skilled and steady workforce and very motivated. This is because this cable yarding remains very difficult physically despite notable ergonomic improvements over the last 10 years (i.e., automated yarder systems, radio controlled chokers, self-propelled carriage). Versatility and capacities of adaptation are also necessary qualities; each forest site is a particular case.

In France, there is only one training center for cable-yarding in the Alps. The trainees, 4-5 each year, alternate periods in the center and in a logging company during 47 weeks. They all have basic forest education before entering the training center.

A recent inquiry performed among the cable logging companies shows that they encounter serious problems of recruitment. This applies to the whole logging sector in France but for cable-yarding, it is a particularly accurate point because the work is carried out by a crew. The difficulties of recruitment and the turn-over in the crews are undoubtedly the major explanatory factor of the weak performance of the French cable-yarding companies.

Perspectives

The keyword of forest managers in France is "we need to harvest more in mountainous areas because the wood stock is too high". The ground-based system (forest roads + skidder) has reached its limits. Funds for creating new forest roads are not available any longer. However, the skidder operators can't go further than 100 m downhill and 50 uphill from the existing forest roads. Cable-yarding should take advantage of this situation.

In this paper several common-use actions to boost the development of cable-yarding have been presented. But more than financial aids, French small enterprises need also some individualized assistance in different fields: techniques, workforce, and organization. A small guidance unit, made of 2-3 specialists, should be set up to provide assistance to the new enterprises, particularly to those who are benefiting from public subsidies.

Another important topic is the cooperation between logging contractors, timber buyers and forest managers. There is a lack of communication between these different actors of the wood procurement chain. Two topics are particularly important:

- the benefits/cost ratio of cable-yarding must be re-estimated considering the sustainable development point of view: reduction of soil compaction, regeneration of aged forest stands...
- contractors are very small enterprises that need to have a clear view of their order-book. Long-term selling contracts should be proposed to them by the forest owners or managers.

There is a large need to study the different kinds of cable systems that can be implemented under the French conditions and especially in broadleaved stands. All the equipment is designed outside France under different logging constraints in terms of silviculture and the forest road network as well as under a different socio-cultural background.

As a last point, with the target to increase the production of renewable energy in Europe, new concepts of cable extraction should be tested in mountainous areas, especially for whole trees.

Literature Cited

- Barthod, C. and Pignard, J. 1995. De la forêt de montagne...aux forêts en montagne. *Aménagement et Nature* n°120. 14p.
- Bartoli, M. (ONF) 2005. Le câble est-il une alternative au débardage en forêts de plaine ? *Le Bois International*. 2p.
- Bartoli M., Pischedda D, Chagnon J.-L., 2006. Pour une exploitation respectueuse des sols. Chantiers de démonstration; rapport final. DGFAR, ONF, CTBA. 75 p. + annexes
- Chagnon, J-L. and Pischedda, D. (CTBA) 2005. La forêt câblée. *Le Bois International*. 3p.
- Collective. Dossier spécial sur le débardage par câble. 2005. *Le Bois International*. 24p.
- Collective. Memento de l'AFOCEL, 2006.
- Pischedda D., Chagnon J.L., Grulois S. CTBA 1999. Evaluation de l'aide à la mobilisation des bois en montagne. Rapport final

Pischedda D. (CTBA) : Les techniques de câblage : Outils pour la gestion durable des forêts de montage. 10 fiches pédagogiques; CTBA, Lycée agricole privé de Poisy.

Silande, G. (AFOCEL) 1999. Le débardage par câble en France. Situation actuelle et perspectives. Mémoire de fin d'étude. ENGREF. 80p.

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POSTER PRESENTATIONS

ABSTRACTS

POSTER ABSTRACTS

TRAVERSE PC SOFTWARE HELPS MANAGE TIMBER LANDS

John Balcolm, Rob Ward

Abstract: In managing forest lands, we are often required to identify and analyze units or parcels based on ownership, soil types, standing timber inventories, etc. If units are to be bought or sold, we need inventories, legal descriptions, exhibits and areas. If boundaries are to be located on the ground, we often need them to be surveyed by a licensed professional. In the end, we need real numbers and real world locations.

Old world techniques involving grease pencils, aerial photos and paper copies are woefully inadequate to handle the work load. On the other hand, the scope and budget of the project or personnel limitations often precludes the investment required to implement an adequate GIS solution. We would often give our 'eye tooth' for an elegant solution somewhere in the middle.

Although Traverse PC was written primarily for surveying, it's ability to do surveys over the top of aerial photos (much like using a digitizer) and it's ability to both read and write GIS shape files make it a great tool for forest management and engineering projects as well.

In 2002 and 2003 Ward Northwest helped John Hancock manage and eventually sell 18,000 acres of timber land acquired from International Paper using Traverse PC. Implementing a GIS system for this project would have been an 'over-kill' based on both budget and available personnel. So using digital aerial photos and Traverse PC surveying software, we located and mapped ownership, inventoried timber types and prepared the corresponding maps, reports, spreadsheets, shape files, PDF's, etc. for the sale. Traverse PC surveying software allowed the forester assigned to the project to easily identify the parcels and create both survey and GIS ready outputs without the use of a digitizer or specific knowledge of surveying or GIS.

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POSTER ABSTRACTS

A COMPUTER APPLICATION TO ESTIMATE FOREST ROAD CONSTRUCTION COST

Jarel Bruce, Han-Sup Han, Abdullah E. Akay, Woodam Chung

Abstract: A computer application has been developed to aid in the cost estimation of forest road construction using Microsoft Excel with Visual Basic object oriented programming. The program guides users through road construction components prompting for unit cost inputs, quantities, and survey information to derive total construction cost. In addition, the program uses the geometric specifications of the final road location, soil data, and design characteristics to optimize earthwork activities, estimate surfacing volumes, and calculate culvert lengths. This model is intended to enhance the decision making process for experienced forestry practitioners in new forest road construction regardless of region, company, or agency affiliation.

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POSTER ABSTRACTS

ESTIMATION OF FOREST BIOMASS WITH HEMISPHERICAL PHOTOGRAPHY

Joshua Clark

Abstract: The importance of finding alternative sources of fuel to fossil fuels has grown significantly in the past few years. As a result, the demand for biomass as an energy source has increased— biomass has become the largest renewable energy resource for the United States, providing about 4% of total energy. According to a recent report for the USDA and USDOE, increasing the amount of biomass as an energy source can reduce the need for oil and gas imports, support agricultural growth, and help develop new industries within the United States. It is expected that the demand for biomass will continue to grow. Unfortunately, it is currently not economically viable to cruise low value timber, which comprises much of the total forest biomass. Current methods involve destructively sampling an area, then extrapolating the biomass estimate to a larger area. Cost effective and reliable ground-based and remotely-sensed inventory procedures need to be developed that can determine not only how much biomass is available, but also where it is located and distributed. This project explores the relationship between biomass and gap fraction, which can be estimated through hemispherical photography (HP). Specifically, it will test the effectiveness of HP for Douglas-fir, ponderosa pine, and lodgepole pine. If proven an effective estimator of biomass, HP can greatly reduce the cost of cruising low value timber while improving the economics of forest stewardship projects and timber sales and the viability of biomass collection and fuel treatment operations.

Key words: hemispherical photography, biomass estimation, gap fraction

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IMPACTS OF FOREST ROADS AND FIRE BREAKS ON FOREST FIRE FIGHTING IN TURKEY: EVALUATION, LIMITATION AND OPPORTUNITIES

Murat Demir, Tolga Ozturk, Mesut Hasdemir

Abstract: In the last few years, forest fires have received increased public attention worldwide due to their significant short and long term threats to forest ecosystems and to public safety and property. This manuscript presents the results of scientific research aimed at developing procedures for managing forest fires in Turkey. In recent years, these forest fires have resulted in the loss of many hectares of forests, the loss of lives, property and infrastructure. Ecosystems and the environment were also degraded. In this paper, we evaluated forest fire damage and studied the function of forest roads and fire breaks on forest fire management in Turkey.

At the end of 2006, the total forest area in Turkey is 21.2 million hectares. This figure is 27.22% of Turkey's total area. Timberland (productive) forests, spread over 15.4 million hectares, account for 72.9% of the total forest area, coppice forests, spread over 5.7 million hectares, account for 27.1% of the total forest area. Coniferous forest makes up 53.9% of the total forests and the remainder is deciduous forest. Production capacity is approximately 31.4 million m³/year in timberland forests and 6.4 million stere/year in coppice forests. Of the 201,810 km of forest roads needed in Turkey, 143,251 km (70.98%) were constructed by the end of 2006. Also, 69.80% of the planned fire breaks were constructed by the end of 2006.

The General Directorate of Forestry in Turkey spent \$82.92 million for forest fire suppression in 2003 and \$677.71 million over the last decade. The number of forest fires in Turkey and the area burned fluctuate each year. In the last decade the number of forest fires has increased but the area burned per forest fire has decreased. Since 1937 there have been an average of 1,145 fires per year with an average burned forest area of 19.61 ha per fire.

Key words: Forest fires, Fire breaks, Forest roads, Turkey.

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POSTER ABSTRACTS

WESTERN JUNIPER HARVESTING METHODS FOR WATERSHED RESTORATION AND WOOD UTILIZATION: A REVIEW

E. M. Dodson, T. Deboodt

Abstract: Western juniper has increased its ecological hold on Oregon's landscapes over the last 140 years. Research efforts have focused on the impacts of juniper occupation including the loss of herbaceous vegetation, increased soil erosion, and decreased infiltration. Traditional juniper treatment prescriptions have focused on the elimination of juniper and the post-treatment response of herbaceous vegetation. As a wood species, juniper has been traditionally viewed as a non-marketable tree, commonly used as fence posts and firewood. Its stereo-typical description has been a tree that is short in stature, low in volume, difficult to saw and mill and is hard on equipment. Growing niche-markets utilizing juniper are developing. Due to the increased demand for juniper in these non-traditional markets, harvest techniques are being evaluated for the purpose of achieving watershed restoration goals while providing family wage jobs and marketable products. Myths continue to exist about the lack of economic value and the impractical use of mechanical harvesting systems. Harvest demonstration trials and time/motion studies have been conducted in central Oregon that compare various mechanical (ie. feller-bunchers and stroke-boom delimiters) and traditional (ie. chainsaw felling and skidding with rubber-tired grapple skidders) harvesting systems. Impacts on soils, vegetation, and the value of products removed have been monitored as a part of these efforts. Conclusions from these trials indicate that watershed restoration goals can be achieved while utilizing juniper for use in log-home construction, dimensional wood, and other products. Results from these trials are presented here along with suggestions for future work.

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POSTER ABSTRACTS

DISSOLVED NITROGEN IN A MULTI-LAND USE BASIN: THREE YEARS REVEAL TEMPORAL AND SPATIAL TRENDS

Daniel Evans, Stephen Schoenholtz, Stephen Griffith, Jim Wigington, Jr., George Mueller-Warrant.

Abstract: Surface water quality is a growing concern in Oregon's Willamette River Basin because 70% of Oregon's population lives within this basin. This growing population puts pressure on the basin's surface waters to provide drinking water, recreation, transportation, aquatic habitat and irrigation for crops as well as countless other market and non-market amenities. Because of the predominance of agriculture and forestry in the Willamette Basin, which have the ability to increase surface water nutrient levels, research on nutrients and their relationship with land use are a high priority for protecting the Willamette Basin's surface waters. Dissolved nitrogen (DN) draining or leaching from managed forests and agricultural settings is an important concern for surface water quality. Excess levels of DN, particularly nitrate-N, are associated with multiple water-quality concerns. The foremost of which is caused by DN adding to the eutrophication of surface waters which can exacerbate effects of high water temperatures on oxygen levels, leading to hypoxia or 'dead zones'. It is well-documented that an excess supply of N in soil systems and misapplication or poor timing of N fertilizer can lead to conditions favoring leaching of DN in agricultural and forestry operations. Land use has also been linked to DN export into aquatic systems. Strong relationships are often noted between the amount of agriculture in a basin and nitrate-N concentrations in that basin's streams with higher concentrations of nitrate-N in streams draining agriculturally dominated basins. This study was conducted in the Calapooia Basin, a sub-basin within the greater Willamette Basin that has its headwaters in the Western Cascade Mountains of Oregon. The Calapooia Basin has a similar mix of land uses as the greater Willamette Basin. Forest management and agriculture, particularly grass seed production, are the primary land uses with rural residential and urban development as minor components. This study includes a basin wide synoptic DN sampling regime in surface waters of the Calapooia River and its tributaries. The sampling was maintained for three water years to address seasonal and annual variation in DN in surface waters of the Calapooia River and to evaluate relationships between 44 independent sub-basin's land use and their DN concentrations. Additionally, we provide exploratory analysis addressing agricultural soil conservation techniques' relationship to DN for two water years.

Key words: hemispherical photography, biomass estimation, gap fraction

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MECHANIZATION OF HILL FORESTRY IN THURINGIA (THÜRINGEN)

Erik Findeisen

Abstract: Thuringia (Thüringen) is one of the young federal states of Germany. The change of the political system included a change of costs for manual forestry work. Therefore the mechanization of forest procedures is necessary for a successful enterprise. Another reason is founded in the natural conditions of Thuringia. Only 65% of the total forest area is passable for normal forest machinery (inclination of up to 35%). Areas with an inclination of more than 50% make up 15% of the forested area – and logging procedures use cable cranes. Between the extremes many combinations of different techniques are used. In the state forest of Thuringia (approximately 200,000 hectares), mechanization is developed by state machinery bases (Maschinenstützpunkte) with their state-owned staff and machines. This type of structure is successful if planning, organization, implementation and staff training are optimized. Other prerequisites for effective forest management are the well-developed forest infrastructure and good possibilities for selling timber. (Full paper is included in Section C2 of proceedings)

Key words: forest logging systems; forest organization; mountain forestry

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POSTER ABSTRACTS

THE ALSEA WATERSHED STUDY REVISITED

George G. Ice, Cody Hale, Stephen Schoenholtz, Jeff Light, Jeff McDonnell, Terry Bousquet, John D. Stednick

Abstract: The original Alsea Watershed Study assessed the effects of timber harvesting on water, aquatic habitat, and salmonid resources using a paired-watershed approach. The Alsea Watershed Study Revisited provides an opportunity to evaluate water resource and salmonid resource responses to current forest practices compared to unmanaged conditions. It also allows a comparison to the original study results that included an extreme manipulation in the 1960s. Flynn Creek was an undisturbed control watershed in the original study and remains an undisturbed Natural Research Area under the USDA Forest Service. Deer Creek was partially cut and demonstrated the effectiveness of streamside management zones in the original study. Needle Branch was completely clearcut with subsequent slash burning, with no streamside vegetative buffers. Needle Branch experienced some of the most dramatic water quality impacts for temperature and dissolved oxygen ever observed in response to forest management. Increases in discharge, sediment, and nutrients were also measured, although these changes were more subtle. The water quality impacts observed for Needle Branch, especially temperature, are sometimes erroneously cited as the inevitable consequence of clearcutting in the Pacific Northwest. The regenerated forest in the Needle Branch watershed is again ready for commercial harvest. The proposed timber harvesting plan in Needle Branch involves two harvesting units and will provide an opportunity to assess cumulative effects on water resources. This new study, using paired watersheds, synoptic surveys of water quality, and biological monitoring, will test how effective current forest practices are in maintaining water quality. Lessons from the original and revisited Alsea Watershed Studies will help support decisions about appropriate forest practice rules. The Alsea Watershed Study Revisited is part of the Watersheds Research Cooperative. Additional information can be found at: <http://www.ncasi.org/programs/areas/forestry/alsea/default.aspx>

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POSTER ABSTRACTS

OPTIMIZING SPATIAL AND TEMPORAL TREATMENTS TO MAINTAIN EFFECTIVE FIRE AND NON-FIRE FUELS TREATMENTS AT LANDSCAPE SCALES

Greg Jones, Woodam Chung, Janet Sullivan, Kurt Krueger, and Pablo Aracena

Abstract: Forest managers faced with limited budgets, limited prescription-burning days, air quality issues, and effects on other critical forest resources must establish priorities for where, when, and how to apply and maintain hazardous fuel reduction treatments. Various modeling systems provide guidance in different aspects of fuel management, but the most effective way to address the problem involves the use of several diverse systems. There is a critical need to merge these systems into one decision support system that streamlines analyses for identifying where and how to treat to achieve desired fuel reduction goals, while meeting given resource and operational constraints. This study integrates existing fire behavior, vegetation simulation, and land management planning tools into a system for optimizing fuel treatments in time and space, given resource and accessibility constraints. The system solver will incorporate FlamMap fire behavior parameters in a Simulated Annealing algorithm for choosing treatment locations that are most effective at changing undesirable fire behavior while satisfying specified constraints affecting treatment location decisions, such as resource impacts, budget, and operational feasibility. The system will include the user graphical interfaces of its model components to specify problem setup and view results. To validate the system, we will develop spatial fuel treatment schedules for two areas in the Northern Rockies, and conduct a sensitivity analysis. This easy-to-use decision support system will facilitate analyzing effective spatial and temporal fuel management strategies in an ecosystem management context.

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POSTER ABSTRACTS

BIOMASS ENERGY AND BIOFUELS FROM OREGON'S FORESTS

Roger Lord, Carl Ehlen, David Stewart-Smith, John Martin, Loren Kellogg, Chad Davis, Melanie Stidham, Mike Penner, James Bowyer

Abstract: The Oregon Forest Resources Institute commissioned this study to better understand the potential for renewable energy development using biomass and biofuels derived from Oregon's forests. After reviewing existing research, biomass stakeholders were interviewed and current biomass efforts were explored. The report assesses constraints and challenges to woody biomass energy, and recommends how Oregon can overcome the barriers and constraints to make it a viable alternative.

Woody biomass can be harvested from overstocked, fire-prone forests and be used to make electricity, biofuels and other products. In doing so, the process would address three current needs in Oregon. It would restore forest health, fire resiliency and wildlife habitat to our federal forests. It would establish a renewable energy source for Oregon. It would revitalize the rural economies of the counties that contain these overcrowded forests.

Contributing partners of this study include Mason, Bruce & Girard, Inc., Pacific Energy Systems, Inc., Oregon State University College of Forestry, Oregon State University College of Agriculture and Dr. James Bowyer, Wood Science & BioProducts Consultant.

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POSTER ABSTRACTS

BELOWGROUND CARBON POOLS IN RESPONSE TO SILVICULTURAL MANIPULATIONS AT A PONDEROSA PINE PLANTATION IN NORTHERN CALIFORNIA

Karis McFarlane, Stephen Schoenholtz, Robert Powers

Abstract: In the late 1980's, the Garden of Eden Study was established to test the effects of repeated fertilizer applications (F), competing vegetation control via application of herbicide (H), and the combined effects of each type of treatment (HF) on productivity of three ponderosa pine (*Pinus ponderosa* (Dougl. ex Laws.)) plantations of varying site quality in Northern California (Powers and Reynolds, 1999; Powers and Ferrell, 1996). Treatment effects on aboveground biomass are striking. The study provides a unique opportunity to investigate the effects of plantation management on soil C storage and distribution. Forest floor, mineral soil, and fine root cores were collected during summer of 2005 from the Whitmore Garden of Eden site. Forest floor, mineral soil, and fine root C pools were determined for each treatment combination. Regardless of application of herbicide, fertilization increased the belowground C pool via an increase in forest floor mass and in mineral soil C concentrations. Competing vegetation control increased forest floor C concentrations, but the increase was not enough to affect the forest floor C pool.

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POSTER ABSTRACTS

ASSESSING SOIL ORGANIC MATTER QUALITY IN RESPONSE TO SILVICULTURAL MANIPULATIONS ALONG A SITE QUALITY GRADIENT IN NORTHERN CALIFORNIA

Karis McFarlane, Stephen Schoenholtz, Robert Powers

Abstract: In the late 1980's, the Garden of Eden Study was established to test the effects of repeated fertilizer applications (F), competing vegetation control via application of herbicide (H), and the combined effects of each type of treatment (HF) on productivity of three ponderosa pine (*Pinus ponderosa* (Dougl. ex Laws.)) plantations of varying site quality in Northern California (Powers and Reynolds, 1999; Powers and Ferrell, 1996). Treatment effects on aboveground biomass are striking. The study provides a unique opportunity to investigate the effects of plantation management on soil organic matter quality. We measured the quantity of C in the top 20 cm of mineral soil and evaluated the quality of that C by density fractionation and laboratory incubation. Preliminary results for mineral soil C content and quality in response to these silvicultural treatments are presented. Because C and N cycles are intricately linked, N content of the whole mineral soil and of the light and heavy density fractions will also be presented.

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PRODUCTIVITY OF THE YARDING OPERATION SYSTEM WITH KOLLER K300 SKYLINE IN TURKEY

Tolga Ozturk

Abstract: There are three primary transportation methods in Turkey's forestry; human power, animal power and mechanization. Ground skidding by hand (man using gravity) is applied in small forest areas for extraction of small amounts of timber and large amounts of fuel wood over short distances. Animal skidding, mainly by horses, mules and oxen, is used for pre-skidding for bunching distances between 20 m and 100 m. Mechanical skidding is carried out by ground based forestry vehicles. Skylines are the primary log transportation method. The machines used for these skylines are Koller, URUS and Gantner.

The purpose of this study is to investigate the productivity of the Koller K300 skylines when carrying Spruce timber from mixed forests of Spruce, Scotch pine and Beech tree species in North Eastern Turkey. Skylines productivities are determined by using the methods of work and time study. The research concludes that some working characteristics of the Koller K300 skylines such as transportation speed of the carriage (loaded and unloaded), load volume, time consumption during yarding, fuel consumption, productivity of the skylines and transport distance have an absolute impact on the productivity of the cable crane.

Key Words: Koller K300 skyline, carriage, productivity, Turkey, Artvin.

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POSTER ABSTRACTS

WORK ORGANIZATION OF TIMBER PRODUCTION IN TURKEY

Tolga Ozturk, Murat Demir, Mesut Hasdemir

Abstract: The purpose of work organization is to plan the best use of available labour, machinery and techniques in production in accordance with the specific task assigned. The purpose of planning and opening-up of a site in detail is to develop working conditions which guarantee the best use of labour and equipment on the one hand and the careful treatment of the growing stock on the other. The interrelationship of the various elements in the system have important influences on the work to be performed and the final results. Planning of the work must be preceded by an analysis of the significance of the individual elements of the system. On the basis of these findings, the limits of each element can be determined.

This study explains the steps of timber production in Turkey's forests. Felling, delimiting, debarking, hauling and transporting steps are described in detail.. Also, the uses of various production equipment in Turkey are described.

Keywords: Timber, Felling, Delimiting, Debarking, Skidding, Skyline, Turkey

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POSTER ABSTRACTS

REDUCING HARVESTING COSTS AND ENERGY CONSUMPTION BY REDUCING TREE WATER CONTENT: TIME TO CONSIDER THE OPTIONS?

John Sessions, Kevin Boston, Jim Kiser, Dzhamel Amishev

Abstract: Logging costs are directly related to log weight for many logging system components. Skidding or yarding, loading, hauling account for more than 90% or more of logging costs for most logging systems. Energy use in logging is also proportional to log weight. For lumber that is kiln dried, the kiln is the largest energy consumer. In a time of increasing competition and rising energy costs, there is a potential savings to be gained by reducing log weight through reducing tree moisture content before yarding? The average moisture content of common western US conifers is 60 percent or more. The sapwood contains much higher moisture content than the heartwood. How effectively can water be pulled from the sapwood through transpiration following girdling of the tree? The potential stakes are large. Reduced tree weight would reduce costs down the entire supply chain from yarding to drying. If girdling is to be effective, a number of questions must be addressed:

- 1) How much water can be removed from a tree as a function of species, size, and environmental variables (temperature, day length, wind, initial saturation)?
- 2) How fast can the water be removed from the tree with severed sapwood through transpiration and other water use?
- 3) How much of the sapwood will need to be cut to achieve moisture reduction goals?
- 4) Can water be removed from a girdled standing tree more rapidly than a felled tree left with its crown? What are the tradeoffs?
- 5) How fast do agents of decay attack the standing tree as a function of species, size, and environmental variables?
- 6) How does the reduced water content affect wood quality by species and product type? At what moisture content does checking become a problem? Does a lowering of moisture content influence sawing, peeling, or chipping operations? For example, how will lower moisture in the sapwood affect lumber kiln drying schedules and energy requirements? How will lower moisture contents affect the value of green lumber?
- 7) What is the best operational way to girdle sapwood in motor-manual and mechanized operations?
- 8) What is the cost to girdle sapwood in motor-manual and mechanized operations?
- 9) How is skidding and yarding productivity affected by lighter logs? Can smaller equipment be used, larger loads, or cutting longer lengths?

The OSU Forest Engineering Department initiated exploratory experiments Spring 2007.

Key words: log weight reduction, sapwood girdling, logging and transport costs

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POSTER ABSTRACTS

STRATEGIES FOR MANAGING ROCK AGGREGATE FROM DECOMMISSIONED, TEMPORARY, AND INTERMITTENT USE ROADS

John Sessions, Kevin Boston, Rick Thoreson, Keith Mills

Abstract: The purpose of work organization is to plan the best use of available labour, machinery and techniques in production in accordance with the specific task assigned. The purpose of planning and opening-up of a site in detail is to develop working conditions which guarantee the best use of labour and equipment on the one hand and the careful treatment of the growing stock on the other. The interrelationship of the various elements in the system have important influences on the work to be performed and the final results. Planning of the work must be preceded by an analysis of the significance of the individual elements of the system. On the basis of these findings, the limits of each element can be determined.

This study explains the steps of timber production in Turkey's forests. Felling, delimiting, debarking, hauling and transporting steps are described in detail.. Also, the uses of various production equipment in Turkey are described.

Keywords: Timber, Felling, Delimiting, Debarking, Skidding, Skyline, Turkey

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POSTER ABSTRACTS

CONTROL OF COMPETING VEGETATION FOLLOWING HARVESTING: EFFECTS ON NITROGEN LEACHING, MINERALIZATION, AND DOUGLAS-FIR FOLIAR STATUS

Robert A. Slesak, Timothy B. Harrington, Stephen H. Schoenholtz

Abstract: Competing vegetation control (CVC) following timber harvest has an immediate and lasting positive effect on crop tree growth by increasing water, light, and nutrient availability to crop trees. CVC has also been shown to increase in situ nitrogen (N) mineralization, reduce total vegetative N uptake, and decrease organic matter inputs to soil. We are measuring soil N pools, N leaching, and foliar N of planted Douglas-fir following CVC with herbicide at two sites in the Pacific Northwest that differ in soil characteristics and annual precipitation to determine the effect of CVC on N cycling. Increased nitrate leaching was observed at both sites following CVC in the first year after planting, but significant effects were only observed at the high soil N site in the second year. At both sites, summer potential net N mineralization measured in a laboratory incubation was decreased by approximately 40% following CVC, but available N (KCl-extractable) measured in situ was approximately two times higher in CVC. Increased in situ available N is most likely due to increased N mineralization associated with increased soil temperature and moisture following CVC, as well as reduced vegetative uptake from competing vegetation. Increased available N was utilized by Douglas-fir crop trees which had significantly higher foliar N following CVC in the first year after planting, but only the high N site maintained this increase into the second year. Douglas-fir growth was correlated with foliar N status (data not shown), demonstrating the positive effect of CVC on crop tree growth. Reduced N mineralization potential and increased N leaching can potentially reduce long term soil quality by reducing both available N supply and total soil N. However, the magnitude of effects observed here appear to be dependent on total soil N, which may act as a buffer to alterations of the N cycle following CVC. Although continued measurement is needed to determine the long term effects of CVC on soil N, it appears that the large increases in growth associated with CVC outweigh any of the short term N losses measured thus far.

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POSTER ABSTRACTS

DETERMINING OPTIMUM ROAD STANDARDS BY COMBINING ANALYTICAL AND GIS METHODS

Hendrik C. Stander, John Sessions

Abstract: Transportation costs constitute 50% or more of their mill-delivered costs for many forest products supply chains. Minimizing these costs requires the simultaneous optimization of both road standards and transportation modes. The problem is further complicated by the fact that many supply chains utilize multiple road standards and transportation modes. Finding the right balance between road construction costs and transportation costs is often a complicated problem that is computationally difficult to solve. We present a formulation for determining the transport transition point in a problem with two road standards and associated transportation modes. The implementation of this formulation will then be illustrated through a GIS implementation on the road network of the OSU College of Forestry's McDonald-Dunn College Forest.

Key words: Road Standards, transportation planning

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POSTER ABSTRACTS

GUYLINEPC: AN INTERACTIVE GUYLINE TENSION ANALYSIS PROGRAM

Matthew Thompson, Hendrik Stander, John Sessions

Abstract: In the USA Pacific Northwest and other mountainous regions, cable yarding using portable steel towers is a common harvesting system in steep terrain. These systems are expensive and can be unsafe if improperly rigged. For both economic and safety considerations, configurations are employed to ensure the system can sustain the forces applied during yarding operations. We present a computer-based application, GuyLinePC, for evaluating the guyline and anchor loads resulting from an applied load. Our model builds upon previously developed models for a weightless tower on a ball and socket joint. We provide a modern graphical user interface, use optimization methods to determine equilibrium states, and illustrate the capability of the program to be used in landing design. The program is intended to improve a forest engineer's understanding of cable yarding systems and to be used for educational purposes.

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POSTER ABSTRACTS

BIOMASS WASTE: COMMUNITY AND NATURAL RESOURCE SUSTAINABILITY

Rick Wagner

Abstract:

Natural Resource and Community Sustainability is all about Choices:

Reactive Management and Choices = Costs and Consequences

Proactive Management and Choices = Investments and Dividends

Sustainability is that balance or “Sweet Spot” in the middle of social, economic and ecological values

There are over 50 social, economic, or ecological issues directly or Indirectly addressed through biomass waste conversion to energy or “value added” products

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POSTER ABSTRACTS

THE STUDENT LOGGING TRAINING PROGRAM AT THE OREGON STATE UNIVERSITY COLLEGE OF FORESTRY

Jeff Wimer

Abstract: The student logging training program at the Oregon State University College of Forestry has four goals (1) training and teaching, (2) conducting workshops and demonstrations, (3) demonstrating safe work practices, and (4) assisting the College Research Staff in managing the College Research Forests. Management activities include skyline thinning of young stands, salvaging small pockets of blown down timber, clearing roads, and removing hazards. Crew members do all aspects of forest engineering and harvest operations. Student crew members develop complete paper plans, verify feasibility and then complete the final field design and layout of skyline corridors, intermediate supports, tailtrees and all required anchoring systems. Training in harvest operations includes felling and bucking, climbing and rigging, choker setting, skidding, and yarding. Benefits to the students include (1) working in a safe training environment, (2) completing college internship requirements, (3) earning money while attending school, and (4) adding highly sought out work skills to their resume.

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