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Publications Website

2009. ENVIRONMENTALLY SOUND FOREST OPERATIONS
June 15-18. North Tahoe Conference Center, Kings Beach (Lake Tahoe), California

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32nd Annual Meeting of the Council on Forest Engineering
June 15-18, 2009
North Tahoe Conference Center, Kings Beach, California
Compiled by Bruce Hartsough and Bryce Stokes

Forest Operations (Tuesday, 9:00-10:20 am)

Moderator – Daniel Guimier, Vice President, FPInnovations – FERIC Division

Finding the 'Sweet-Spot' of Mechanised Felling Machines
Rien Visser[1], Raffaele Spinelli[2], Jacob Saathof[3] and Simon Fairbrother[4]*
Director[1], Student[3], and Assistant Lecturer[4], Forest Engineering, University of Canterbury, Christchurch, New Zealand, and [2]Head of Forest Operations Research, CNR, Sesto-Fiorentino, Italy

Do Synthetic Ropes Change the Design Principles of Standing Skylines?
Ewald Pertlik
Department of Forest and Soil Sciences, Institute of Forest Engineering, University of Natural Resources and Applied Life Sciences, Vienna, Austria

Development of a New Operation System With Carriages for Turn Back Yarding System
Kazuhiro Aruga[1], Toshiaki Tasaka[1], Akira Nishikawa[2], and Toshihiko Yamasaki[3]*
[1]Utsunomiya University, Utsunomiya, Japan, [2]Kawasaki Machine Company, Kochi, Japan, [3]Kochi Forest Technique Center, Kochi, Japan

Efficiency and Ergonomic Benefits of Using Radio Controlled Chokers in Cable Yarding
Karl Stampfer[1], Thomas Leitner[2], Rien Visser[3]*
[1]Head of School, and [2]graduate student, Forestry Faculty, University of Agriculture and Life Sciences, Vienna, Austria, [3]Director of Forest Engineering, Canterbury University, Christchurch New Zealand

The Human Factor (Tuesday, 10:40 am – 11:40)

Moderator – Tetsuhiko Yoshimura, Shimane University, Matsue, Japan

Understanding the Hazards of Thrown Objects: Incidents, Research and Resolutions
John J. Garland, PE[1] and Robert Rummer[2]*
[1]Consulting Forest Engineer, Garland & Associates, Corvallis, OR, [2]Project Leader, Forest Operations Research, USDA Forest Service, Auburn, AL

Identifying Loggers' Reactions and Priorities in an Increasingly Fragmented Landscape
Matthew C. Moldenhauer[1] and M. Chad Bolding[2]*
[1]Graduate Student, Department of Forestry and Natural Resources
Clemson University, Clemson, SC and [2]Assistant Professor of Forest Operations/Engineering, Virginia Tech, Department of Forestry, Blacksburg, VA

Developing Managerial Behaviors and the Indispensable Information to Do So: a Double Challenge for Small Logging Entrepreneurs

Steve Drolet[1] and Luc LeBel*
[1]Ph.D. Candidate and [2]Professor, Department of Forest and Wood Sciences, Laval University, Québec, Canada

Biomass & Fuel Reduction I (Tuesday, 1:30-3:20 pm)

Moderator – Han-Sup Han, Associate Professor of Forest Operations and Engineering, Humboldt State University

Potential Impacts of Biomass Harvesting on Forest Resource Sustainability

Scott M. Barrett[1], W. Michael Aust[2], and M. Chad Bolding[3]*
[1]Extension Associate, VA SHARP Logger Program Coordinator, [2]Professor of Forestry, [3]Assistant Professor of Forest Operations/Engineering, Virginia Tech, Department of Forestry, Blacksburg, VA

Developing a Decision Support System to Optimize Spatial and Temporal Fuel Treatments at a Landscape Scale

Woodam Chung[1], Greg Jones[2], Janet Sullivan[2], and Pablo Aracena[1]*
[1]Department of Forest Management, College of Forestry and Conservation, The University of Montana, Missoula, [2]USDA Forest Service, Rocky Mountain Research Station, Missoula, MT

Harvesting and Transportation of Logging Residue Logs Accumulated Along Road Side for Woody Biomass Plant in a Local Community

Yasushi Suzuki[1], Youko Hatano[2], Shinpei Murakami[1], Tomoe Okazawa[1], Shouji Sagayama[3], Jun'ichi Gotou[1], Takashi Ichihar[4] and Kazuhiro Miyoshi[4]*
[1]Faculty of Agriculture, Kochi University, Nanoku, Kochi, Japan [2]The MIIKE Inc., [3]Graduate School of Agriculture, Kochi University, and [4]Kochi Prefectural Forest Technology Center

Optimizing the Use of a John Deere Bundling Unit in a Southern Logging System

Steven Meadows[1] and Tom Gallagher[2]*
[1]Graduate Research Assistant and [2]Assistant Professor, Forest Operations, School of Forestry and Wildlife Sciences, Auburn University, AL

Combining Slash Bundling With In-Woods Grinding Operations

Hunter Harrill[1], Han-Sup Han[2] and Fei Pan[3]*
[1]Graduate Research Assistant, [2]Associate Professor of Forest Operations and Engineering, and [3]Research Associate, Department of Forestry and Wildland Resources, College of Natural Resources & Sciences, Humboldt State University, Arcata, CA

Integrating Biomass Recovery Operations into Commercial Timber Harvesting: the New Zealand Situation

Rien Visser[1], Raffaele Spinelli[2], Karl Stampfer[3]*
[1]Director of Forest Engineering, Canterbury University, Christchurch New Zealand
[2]Head of Forest Operations Research, CNR, Sesto-Fiorentino, Italy
[3]Head of Department, Department for Forest and Soil Sciences, University of Natural Resources and Applied Life Sciences, Vienna, Austria

Biomass & Fuel Reduction II (Tuesday, 3:40-5:10 pm)

Moderator – Elizabeth Dodson, Assistant Professor, Forest Management, University of Montana

Estimating the Amount of Available Forest Biomass Using System Dynamics

Tetsuhiko Yoshimura[1*] *and Mitsuhiro Nose*[2]
[1]*Education and Research Center for Biological Resources, Shimane University, Matsue, Japan,* [2]Research Institute for Humanity and Nature, *Kyoto, Japan*

Stump Harvesting

Dana Mitchell
Research Engineer, USDA Forest Service, Southern Research Station, Auburn, AL,

Masticators for Fuel Reduction Treatment: Equipment Options, Effectiveness, Costs and Environmental Impacts

Brian Vitorelo[1*], *Han-Sup Han*[2] *and J. Morgan Varner III*[3]
[1]*Graduate Research Assistant,* [2]*Associate Professor of Forest Operations and Engineering, and* [3]*Assistant Professor of Wildland Fire Management, Department of Forestry and Wildland Resources, College of Natural Resources & Sciences, Humboldt State University, Arcata, CA*

The Benefits and Consequences of a Vibrant Wood-to-Energy Market

Joseph L. Conrad IV[1*] *and M. Chad Bolding*[2]
[1]*Graduate Research Assistant and* [2]*Assistant Professor of Forest Operations/Engineering, Virginia Tech, Department of Forestry, Blacksburg, VA*

Production for a Biomass Harvesting System in Pine

Brandon O'Neal[1] *and Tom Gallagher*[2*]
[1]Graduate Research Assistant and [2]Assistant Professor of Forest Operations, School of Forestry and Wildlife Sciences, Auburn University, AL

Environmental Impacts (Thursday, 8:00-9:40 am)

Moderator – Mathew Smidt, Extension Specialist and Associate Professor, Auburn University

Effects of Soil Compaction on Individual Tree Growth In the Central Appalachian Hardwood Forest Region

Jingxin Wang[1*] *Chris LeDoux*[2] *and William Goff*[3]
[1]*Associate Professor,* [3]*Forest Conservation Technician, West Virginia University, Division of Forestry and Natural Resources, Morgantown, WV, and* [2]*Research Industrial Engineer, USDA Forest Service, Northern Research Station, Morgantown, WV*

Influence of Regeneration Method on Soil Strength in a Sierra Nevada Mixed Conifer Forest

Robert A. York[1*], *Gary Nakamura*[2] *and John J. Battles*[3]
[1]*Center for Forestry, University of California, Berkeley, CA,* [2]*University of California Extension, and* [3]*Center for Forestry and Environmental Science, Policy, and Management, University of California, Berkeley, CA*

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Soil Damage After Skidding: Results of a Meta-analysis

E. Ampoorter[1], K. Verheyen[1] and M. Hermy[2]*
[1]Laboratory of Forestry, Ghent University, Melle-Gontrode, Belgium, and [2]Division of Forest, Nature and Landscape Research, K.U. Leuven, Heverlee, Belgium

A Methodology for Implementing Best Management Practices using WEPP: Road Erosion Modeling and a Simulated Annealing Algorithm

James (Andy) Efta[1] and Woodam Chung[2]*
[1]Graduate Research Assistant and [2]Assistant Professor, Department of Forest Management, College of Forestry and Conservation, The University of Montana, Missoula, MT

The Estimation of Carbon Emissions from Harvested Wood Products in Japan – Application of a New Approach for Appropriate Forestry

Mitsuhiro Nose
Research Institute for Humanity and Nature, Kyoto, Japan

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Designing Skid-Trail Networks to Simultaneously Minimize Skidding Costs and Soil Disturbances

Marco Contreras[*] and Woodam Chung
Department of Forest Management, College of Forestry and Conservation, The University of Montana, Missoula, MT

Forest Road Pavement Design in New Zealand

Simon Fairbrother[1], Rien Visser [2] and Robert McGregor [3]*
[1]Assistant Lecturer, [2]Director, and [3]Honours Student, Forest Engineering, Canterbury University, Christchurch, New Zealand

Application of Hook-lift Trucks in Centralized Slash Grinding Operations

Hunter Harrill[1], Han-Sup Han[2] and Fei Pan[3]*
[1]Graduate Research Assistant, [2]Associate Professor of Forest Operations and Engineering, and [3]Research Associate, Department of Forestry and Wildland Resources, College of Natural Resources & Sciences, Humboldt State University, Arcata, CA

Transportation of Woody Biomass Using Roll-Off Containers

Beth Dodson
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* presenting author

Poster Session (Thursday, 11:15-noon)

Forest Landscape Changes After Clear-Cutting in a Subalpine Coniferous Forest Estimated by Remote Sensing Data

Akemi Itaya[1] and Fumiaki Akahori[2]*
[1]Graduate School of Bioresorces, Mie University, Tsu-city, Mie-Pref., JAPAN and
[2]Faculty of Bioresorces, Mie University

Forest Road Network Planning by Using GIS

JiYoung Son [*], Sooil Suk, Rin Sakurai, Toshio Nitami, and Hideo Sakai
Graduate School of Agricultural and Life Sciences, The University of Tokyo, Japan

Relationships between GPS positional errors and stand conditions

Tetsuhiko Yoshimura[1], Mitsuhiro Nose[2], Hisashi Hasegawa[3] and Tetsuro Sakai[4]*
[1]Education and Research Center for Biological Resources, Shimane University, Matstue, Japan, [2]Center for Environmental Management, Kyoto, Japan, [3]Field Science Education and Research Center, Kyoto University, Kyoto, Japan, [4]Graduate School of Informatics, Kyoto University, Kyoto, Japan

The Role of Soil Hydrophobicity in Soil Evaporation in Sandy Soils

Sangjun Im[*], Sujung Ahn, Sang-ho Lee and Dong Yeob Kim
[*]Associate Professor, Dept. of Forest Sciences, Seoul National University, Gwanak-gu, Korea

Soil Erosion Following Five Bladed Skid Trail Closure Techniques

C.R. Wade[1], B.C. Sawyers[2], M.C. Bolding[3], W.M. Aust[4], and E.T. Roberts[5]*
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The Study of the Automatic Forest Road Design Technique Considering Shallow Landslides With LiDAR Data of the Funyu Experimental Forest

Masashi Saito, Masahiro Goshima, Kazuhiro Aruga[*], Keigo Matsue,
Yasuhiro Shuin, and Toshiaki Tasaka
Utsunomiya University, Utsunomiya, Japan

The Use of Roll-Off Bins and a Hook-lift Equipped Harwarder and Truck for Forest Biomass Utilization

Elizabeth M. Dodson[1], and Aaron E. Kash[2]*
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Maximizing Value (Thursday, 1:00-3:10 pm)

Moderator – Ewald Pertlik, Institute of Forest Engineering, University of Natural Resources and Applied Life Sciences, Vienna, Austria

FPInnovations - Maximizing Value From the Forest

Daniel Guimier[1] and Jean Favreau[2]*
[1]Vice President and [2]Program Leader, FPInnovations – FERIC Division, Pointe-Claire, Québec, Canada

Determining Radiata Pine Tree Value and Log Product Yields Using Terrestrial LiDAR and Optimal Bucking in South Australia

Mauricio Acuna[1] Glen Murphy[2] and Jan Rom*bouts[3]
[1]CRC Forestry – University of Tasmania, Hobart, Australia, Hobart, TAS, Australia,
[2]Oregon State University, College of Forestry, Forest Engineering Department, and
[3]Forestry SA, Mt. Gambier, Australia

Developments in Log-making in New Zealand

Dallas C. Hemphill, PE
Consultant Logging Engineer, Eugene, OR

Product Sorting Impacts on Cost and Productivity of Tree-length Logging Operations

Shawn Baker[*], Randy Cass and Dale Greene
Center for Forest Business, Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA

Financial Feasibility of a Log Sort Yard Handling Small-diameter Logs

Han-Sup Han[1], Ted Bilek[2], Rusty Dramm[2], Dan Loeffler[3] and David Calkin[3]*
[1]Humboldt State University, Arcata, CA, [2]USDA Forest Products Laboratory, Madison, WI, and [3]USDA Forest Service, Rocky Mountain Research Station, Missoula, MT

Assessment of the Potential for Log Sort Yards to Facilitate Forest Health Restoration and Fuel Reduction Treatments

Tyron J. Venn[1], Woodam Chung[1], Daniel R. Loeffler[2], J. Greg Jones[3], Han-Sup Han[4], and David E. Calkin[3]*
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Using Acoustic Technology as a Means for Improving the Economics of Fuel Reduction Operations through an Integrated Value-Adding Approach

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Production & Cost Analysis (Thursday, 3:30-5:00 pm)

Moderator – Woodam Chung, Department of Forest Management, College of Forestry and Conservation, University of Montana

Machine Cost Analysis Using the Traditional Machine-Rate Method and ChargeOut!

E.M. (Ted) Bilek
Economist, USDA Forest Service, Forest Products Laboratory, Madison, WI

Stump to Mill Logging Cost Program (STOMP)

Mathew Smidt, Robert Tufts and Tom Gallagher*
School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL

Western Biomass – A Spreadsheet –based Production and Cost Prediction Model for Integrated Biomass Harvesting

Fei Pan[1], William J. Elliot[2], Leonard R. Johnson[3], Han-Sup Han[4], Christopher J. Williams[5], and Harry W. Lee[6]*
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Updating FRCS, the Fuel Reduction Cost Simulator, for National Biomass Assessments

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Determining Radiata pine tree value and log product yields using terrestrial LiDAR and optimal bucking in South Australia.

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Abstract

Eighteen plots in three radiata pine stands of different tree sizes were scanned using terrestrial LiDAR systems. Tree locations were automatically detected using commercially available software. Stem profiles were measured using three methods: (1) from LiDAR scans, (2) by the harvester and (3) manually after felling. Stems were optimally bucked based on log specifications and prices for Australian log markets. Tree values and log product yields were estimated for the terrestrial LiDAR derived data and compared with estimates based on the harvester and manual stem profiles. Plot preparation and tree characteristics affected the accuracy of automated stem detection and stem profile measurements. Suggestions for future research are provided.

Keywords: terrestrial laser scanning, inventory, optimal bucking, manual and automated methods, radiata pine.

Introduction

Good metrics of the quantity, quality and location of timber resources within each forest are essential for ensuring that wastage is minimized, harvest and volume growth increments are balanced, log products are optimally matched to markets, and the value of the forest is maximized at the time of harvest. New approaches to obtaining these metrics are being examined with the goals of increasing their accuracy and reducing their data gathering costs.

Terrestrial laser scanning (also known as terrestrial LiDAR) is receiving attention in Europe (Keane 2007), New Zealand (Anonymous 2007) and USA (Henning and Radtke 2006, Murphy 2008) as a new approach for gathering detailed descriptions of individual stems and their location. Interest in the technology is also expanding in other parts of the world (e.g. South Africa and Uruguay).

The research presented here evaluated the use of terrestrial laser scanning technology and an optimal bucking algorithm as the bases for determining log product yields and tree value in South Australian radiata pine plantations. Specific objectives of this research were: (1) to compare terrestrial LiDAR with manual measurements, (2) to compare harvester with manual measurements, and (3) to compare terrestrial LiDAR with harvester measurements.

Methods

Site description

Three radiata pine stands were selected on flat terrain (slopes < 5 degrees) near Mount Gambier, South Australia. A total of 18 rectangular plots, each 0.1 ha in size, were located in the three stands (Table 1). Understory vegetation was most plentiful in the clearfelling stand and least plentiful in the thinning stands.

Table 1. Average characteristics of the stands

	Stand type		
	Clearfelling (CF)	Thinning (T3)	Thinning (T2)
Age	41	27	27
Stocking (spha)	207	394	570
Tree height (m)	32.9	31.8	29.8
Volume (m^3 per ha)	398	471	465
Number of plots	6	5	7

Laser scan data collection

Laser scan data was captured in September 2008. Two FARO laser scanners were used: a LS880 HE80 and a Photon 80. Both scanners provided 360^o hemispherical coverage to 30 m+ distances. Four to five scans were taken within each plot – one at the plot center and the others on the plot corners - to facilitate measurement of any trees that were likely to have been occluded by other stems within the other scans.

Standing and felled tree measurements

The breast height diameters of all standing trees were measured to the nearest millimeter using a steel tape. After felling, overbark diameters and bark thickness were measured on all felled trees at 0.5 m and 1.5 m, and then at intervals of 3 m to the top of the stem. Heights were also gathered using a measuring tape to the base of the green crown, to an 80 mm top, and total stem height.

Actual stem measurements from the felled trees were used to develop overbark stem profiles at decimeter increments up each tree (actual profile). The bark thickness at each point on the stem was determined using a set of equations provided by Strandgard (2009). Strangard's equations were developed for South Australia from a sample of about 410 Radiata pine logs. Two sets of coefficients are provided representing the bottom 10% and top 90% of the stem in terms of relative height. Linear interpolation of diameters between measurement points was used.

Harvester measurements

Stem profiles of the 343 trees harvested were downloaded from the harvester *.stm and *.prd files. Overbark diameters were obtained at 10 cm intervals up each stem. The harvester bark thickness equation was used to calculate underbark diameters and volumes. Unfortunately the equation used was inappropriate for Radiata pine; effectively estimating a maximum double bark thickness of only 7 mm. Information for each log cut (type, length, and small end diameter) was also obtained from the *.stm file. The harvester was calibrated once for diameter measurements (two days prior to the trial beginning) and three times for length measurements (prior to starting a new stand type).

Automated laser-scan based stem profile descriptions

Autostem Forest software (Keane 2007) was used to detect tree locations and extract stem profile descriptions from the laser scan data for all trees within each of the eighteen plots. Overbark diameters and sweep (sinuosity) were measured or estimated at decimeter increments up the tree. The Autostem software allows the user to check results and manually intervene in the detection and profiling procedures in a number of ways; objects incorrectly identified as commercial timber production trees can be excluded, and predicted tree heights for individual stems can be over-ridden if their heights are known. Both these features were used to produce overbark stem profiles for each tree. Strangard's bark thickness equations were used to estimate underbark diameters.

Prediction of log product yields and tree value

Radiata pine is of considerable economic importance for the Australian forest products industry. Nine log types destined for domestic Australian markets were included in the analysis (Table 2). The relative prices ($/m3) in the price matrix on the harvester's computer were used to determine tree values. Prices and specifications are based on underbark diameters and volumes.

Table 2. Log types included in the study

Log Type	Length (m)	Small end diameter (mm)	Clearfelling (CF)	Thinning (T3)	Thinning (T2)
CH Saw	6.1	200	✓	✓	✕
CH Saw	5.5	200	✓	✓	✕
SM Saw	5.5	150	✕	✕	✓
SM Saw	4.9	150	✕	✕	✓
DCL	3.8	315	✓	✕	✕
RCL	3.8	155	✓	✓	✕
Pulp	4.5	75	✓	✓	✓
Pulp	5.0	75	✓	✓	✓
Pulp	5.5	75	✓	✓	✓
Waste	0.1	1	✓	✓	✓

Optimal bucking software and analysis

VALMAX optimal bucking software (Murphy 2008) was used to determine the optimal log product yields that could be obtained from each plot based on user defined stem profiles, stem qualities and sinuosity, and market conditions. VALMAX employs a dynamic programming algorithm to maximize value recovery from the stand for unconstrained, supply-limited markets. It is similar to optimal bucking procedures described by Pnevmaticos and Mann (1972) and Murphy et al. (2004).

All harvested radiata pine trees within each plot were included in the value analyses. Because some trees were occluded by others in the laser scans taken from the plot center, Autostem generated center-plot tree profiles were sometimes supplemented with profiles taken from the other scan locations.

Results

In the eighteen plots there were a total of 726 stems that had DBH's of 10 cm or greater (Table 3). Discounting occluded trees, approximately 83 stems were not detected in single scans. Automated detection was considerably more successful in clearfelling plots as compared to thinning plots. Only 2 trees were not detected in clearfelling plots, whereas 60 and 20 trees were not detected in T2 and T3 plots, respectively.

Table 3. Automated tree detection from laser scan point clouds.

	Clearfelling	Thinning (T3)	Thinning (T2)
Total plot stems	125	200	401
Stems not detected in single scans	2%	10%	15%
% of stems detected using multiple scans	100%	99%	98%

The fewer number of trees automatically detected in thinning stands are explained by the higher proportion of lower limbs and needles pockets in these smaller trees, as well as by the presence of bifurcated sections near the bottom of the stems. However, multiple scans eliminated problems with occlusion and reduced to 10 the number of trees not detected automatically.

Figure 1 shows the average diameter difference between actual (manual) and scan measurements. Trends were very similar for underbark and overbark measurements. In both cases, the scan underestimated diameters along the stem, reaching a maximum difference (30 mm) near the top of the stem. This is the consequence of using a taper equation for a species different from radiata pine, which is embedded in the automated software to estimate diameters from scanner measurements. Small underbark diameter differences along the stem (with the exception of the top portion of the stem) are explained by the use of a more appropriate bark thickness equation. Likewise, scan measurements tended to underestimate the overbark diameter near the base of the stem.

Figure 2 shows the average diameter difference between actual and harvester measurements. The average overbark diameter difference is very high near the base of the tree, remains positive up to 15 meters and turns negative from this point up to the top of the tree. This means that the harvester underestimated overbark diameter up to 15 meters and overestimated overbark diameter near the top of the tree.

In comparison, the harvester underestimated underbark diameter at all points up the stem. Average diameter differences were, however, more pronounced in the first 5 meters, remained constant from this point up to a height of about 20 meters and increased from this point up to the top of the tree.

These trends are basically explained by the lack of suitable calibration for diameter and the use of an inappropriate single bark thickness equation used by the harvester. In general, radiata pine bark is proportionally thicker near the base of the tree and more consistent over the middle section of the stem, with a rise in thickness near the top of the tree (Gordon, 1983). If Strandgard's bark thickness equation had been used it the differences between underbark actual and harvester measurements would have been smaller and positive up to a height of about 15 m; that is, the stem would have been bigger than estimated by the harvester.

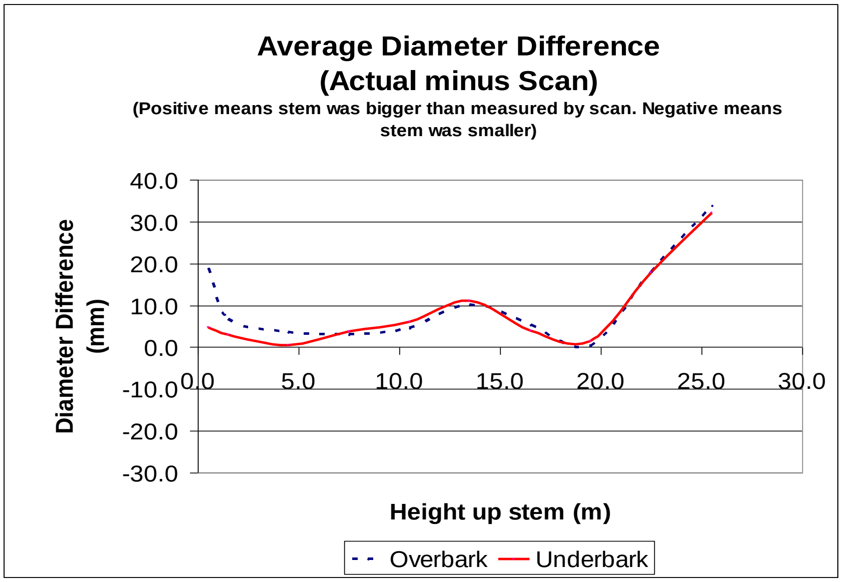

Figure 1. Average diameter difference between actual (manual) and scan measurements.

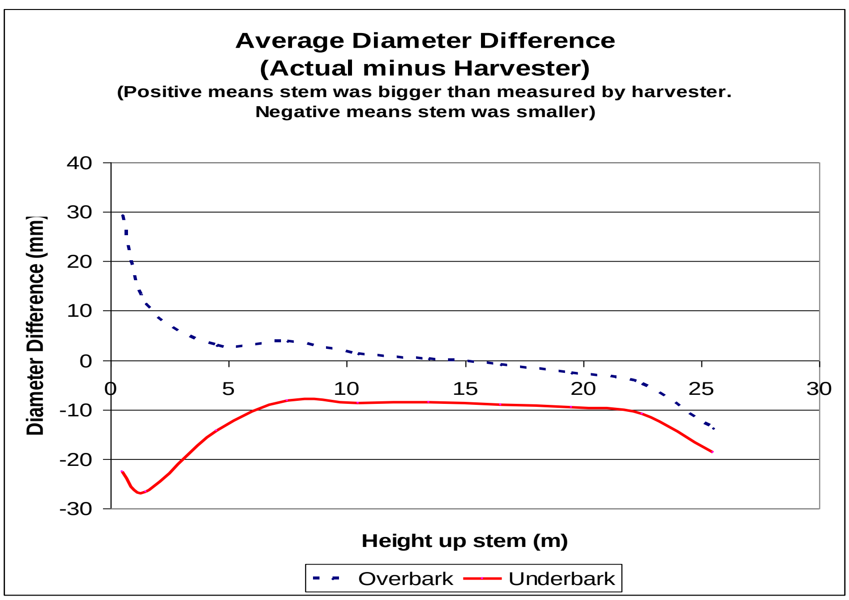

Figure 2. Average diameter difference between actual (manual) and harvester measurements.

A subset of the trees scanned was harvested. A subset of the trees harvested was manually measured. Table 4 shows the volume (underbark) comparison for those trees measured by all three systems; scanner, harvester and manual. In all stand types, the harvester overestimated volume in relation to the actual and scanner volume which is primarily explained by the use of an inappropriate bark thickness equation. Absolute differences between actual and harvester volume as well as actual and scanner volume are consistent for all the plots (CF, T3, T2), whereas the differences varied considerably when comparing scanner and harvester volumes. In this latter case, a bigger difference is observed in clearfelling plots because the scan measurements tend to underestimate underbark volume whereas the harvester measurements tend to overestimate underbark volume.

Table 4. Volume comparisons between actual, harvester and scanner measurements

Stand Type	No. of trees	Measured (m3 u.b. per tree)			Differences		
		Actual	Harvester	Scanner	A-H	A-S	S-H
CF	42	1.81	1.97	1.76	-0.16	0.05	-0.21
% of Actual					-9%	3%	-12%
T3	42	1.04	1.19	1.07	-0.15	-0.03	-0.12
% of Actual					-14%	-3%	-12%
T2	33	0.85	1.00	0.92	-0.15	-0.07	-0.08
% of Actual					-18%	-8%	-9%

Both measurements could be improved by better and prompt calibration procedures and use of appropriate bark thickness equations (harvester measurement), as well as by the use of better taper equations (scanner measurements). Use of Strandgard's bark thickness equation on the harvester would have reduced the volume differences between both the actual and scanner measurements. There was also a range in the accuracy of scanner measurements which affects the comparisons. "Bad" scans were obtained when trees (1) had needle pockets or swelling near the base of the tree, (2) were partially hidden, (3) were out of round (leaning), and (4) had double leaders below breast height. Limby sections at breast height and regeneration around the base also had an impact on the automated detection and on the quality of the images obtained with the laser scanner.

Table 5. Value comparisons (%) between actual, harvester and scanner measurements.

Stand Type	No. of trees	Differences (% of Actual)		
		Actual -Harvester	Actual - Scanner	Scanner - Harvester
CF	42	-12%	7%	-19%
T3	42	-15%	-4%	-19%
T2	33	-21%	-2%	-19%

Table 5 shows the value (underbark) comparison between actual, harvester and scanner measurements. For all stand types, tree value calculated from harvester measurements was greater than tree value calculated from actual and scanner measurements. The greatest absolute difference in value was obtained when comparing scanner with harvester measurements in clearfelling and T3 plots, whereas the greatest difference in T2 plots was obtained when comparing actual with harvester measurements. These results are a consequence of the volume estimates obtained with the three measuring methods and with the mix of product and prices used to calculate tree value.

Conclusions

In this paper we have demonstrated, for one set of Australian markets, that radiata pine tree values and log product yields can be estimated using an optimal bucking algorithm together with stem profiles automatically generated from hemispherical terrestrial LiDAR scans. Currently, the system is only semi-automated and needs human intervention during the data collection and processing phases. Fully automated tree detection and more accurate estimates should be possible as better plot preparation procedures and processing algorithms are developed in the years to come.

Harvester data should only be used for comparison with scanner (or manual) measurements if the harvesters are properly configured and calibrated, and appropriate bark thickness equations are used.

Future studies should embrace a wider range of stand types, investigate the synergies between terrestrial laser scanning and other inventory procedures, and carry out a cost-benefit analysis.

Acknowledgements

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Using Acoustic Technology as a Means for Improving the Economics of Fuel Reduction Operations through an Integrated Value-Adding Approach

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Abstract

Fuel reduction and/or forest stand health improvement operations are usually associated with high costs of treatment because of social, environmental, and operational requirements, making them financially challenging. An integrated value-adding scenario involving a mixed size/species/quality approach may improve their economics.
Acoustic technology has been successfully used as a non-destructive technique for assessing the mechanical quality of various wood products and species based on stiffness. There is a growing interest in incorporating such technologies for measuring internal stem features into a harvester head. Evaluation of hypothetical working procedures for real time measurement of resonance-based acoustic velocity suggested good operational feasibility.
For a sample of >3,000 logs from second growth Douglas-fir stands in Western Oregon, a general methodology was developed to estimate relative mill-door breakeven prices of Douglas-fir peeler logs based on acoustic assessment of veneer stiffness differences. Results suggested that stiffness grading based on acoustic velocity measurements could be used as a surrogate measure for potential net returns and hence for an affordable premium price on such logs.
The additional value recovered from improved log sorting could partially offset the high costs of fuel reduction/stand health improvement operations.

Keywords: Mechanical treatment, financial analysis, high-value product recovery, stiffness

Introduction

Forest Fuels and Forest Fires

Currently more than 10 million ha of seasonally dry coniferous forests in the Western US alone are in moderate or high fire hazard condition classes (NWGC, 2001). These forests include a range of commercial (Ponderosa pine, Douglas-fir, etc.) and non-commercial tree species and forest types. Years of successful fire suppression, past livestock grazing, and timber harvests have led to greater quantities of forest fuel loads in such forests with more small trees and fewer large trees compared to pre-European settlement times (Calkin and Gebert, 2006). In the past few decades, increasing wildland fire hazard and risk have led government policymakers to recognize the need for forest thinning of overcrowded stands. Several recent fire policies and initiatives such as the National Fire Plan and the Healthy Forest Restoration Act have been enacted to address the national US wildfire management problem. All of the statutes emphasize forest thinning, and to a lesser extent, prescribed fire, as integral tools for reducing high fire hazards in Western US forests. The need for forest fuel reduction treatments is further emphasized by the increased number and cost of devastating crown fires in such forests.

Economics of Fuel Reduction Operations

Many forestry researchers and industry professionals have invested significant amounts of funding, resources and efforts into investigating and developing ways to economically treat areas in need of forest fuel reductions.

In some cases, treatments costs can be offset by the value of harvested material, although this may not be true where either product value per ton or amount of product removed is low (Hartsough *et al.*, 2008). Paying for large-scale fuels reduction programs has often proved to be difficult, with the primary economic obstacle being the low value of small-diameter material that needs to be removed (Fight *et al*. 2004), relative to the costs, making large-scale fuels reduction programs cost prohibitive and primarily dependent on federal subsidies. A number of approaches for improving the economics are being taken.

One approach is to focus on reducing the costs of fuel reduction operations. Developing new work methods, identifying and selecting appropriate equipment, optimising harvesting and transportation systems are some methods for reducing costs. For example, Dodson and Kash (2008) have shown that a system of trucks, equipped with hook lifts and the use of roll-off containers for transporting what is typically low-value biomass product, can be economically viable under certain situations.

A second approach is to quantify the additional public benefits that occur because of fuel reduction operations. These include avoided damages and losses to property and life, regional economic benefits, habitat, air and water quality protection, and carbon credits (Mason *et al.*, 2006; Hjerpe and Kim, 2008).

A third approach is to capture more value from each hectare of forest area treated. The net cost results for mechanical treatment are highly sensitive to the values of the products generated by the operation (Hartsough *et al.*, 2008). Although large trees can be removed for valuable products, the market value for the smaller logs may be less than the incurred operation costs, resulting in a net cost for thinning operations. Value for the smaller logs can be improved utilizing smallwood processing plants with both the highest levels of efficiency and value recovery (Schmidt, 2008). These could make "small log system" operating costs competitive relative to mills processing larger logs (Anderson, 2008), thereby allowing the miller to pay higher prices for small logs. Smaller trees and tree tops can also be converted to clean chips (for pulp or board products) or dirty chips (for fuel) but markets (if they exist) for those are widely scattered contributing to highly variable haul distances (Fight and Barbour, 2005). In many cases, woody biomass utilization is not well implemented because of limited accessibility on forest roads and the high costs associated with collection and transportation (Han *et al.*, 2008).

Furthermore, due to the higher proportion of juvenile wood, younger and smaller trees usually yield lower quality timber (Gartner, 2005) with greater variability in product performance (Carter *et al.*, 2005).

Mechanisation as a Platform for Capturing Additional Value

Worldwide forest harvesting has become increasingly mechanized during the last few decades. This is especially true where harvested tree size is decreasing and the capability of one or two machines to fell, delimb, buck, and sort a tree or a group of trees is an appealing advantage. This trend towards mechanization of forest harvesting operations is observed for various forest types, terrains and climatic conditions (Godin, 2001; Murphy, 2008) leading to near elimination of motor-manual felling in thinning operations and continuously increasing use of harvesters and processors. Drivers for this shift from the traditional motor manual harvesting systems to mechanical harvesting systems generally include productivity/cost improvement goals or labor-related issues.

Forestry equipment manufacturers envision a range of new features on their machines such as real-time route and product optimization, update of inventory data, multi-purpose machines, improved energy efficiency and others. Among other things, mechanization also provides a platform for innovative measurement systems which could lead to improved log segregation based on a wider range of wood properties (Murphy, 2003; Murphy, 2008).

Internal Wood Properties and Scanning Technologies

Wood density is the simple measure of the total amount of solid wood substance in a piece of wood. 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. Relative to other spectroscopic techniques Near Infrared (NIR) spectroscopy 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*., 2004). Some commercial spectrometers are also lightweight, easy to operate and economic. Under laboratory conditions, oven dry wood density can be predicted from measurements of green wood chips using NIR technology (Acuna and Murphy, 2006) over wavelengths ranging between 500 and 2500 nm.

Stiffness is correlated to strength and is the most frequently used indicator of the ability of wood to resist deflection and distribute loads in a structure. Wood stiffness and strength have long been recognized as crucial product variables in both solid wood and pulp and paper processing. Raw timber material is highly variable in these properties, dependent upon site, genetics, silviculture, and location within the tree and stand. It is a particularly important parameter in the conversion of raw timber material into high-value veneer and plywood products, requiring high stiffness wood. With the ever growing use of engineered wood products such as roof trusses and laminated veneer lumber (LVL) the demand for high-MOE lumber and veneer has increased.

Unfortunately, readily available tree (e.g. DBH, height) and stand growing (age, spatial location) conditions have been found to have limited or no predictive capability regarding their veneer quality, at least for Douglas-fir (Amishev and Murphy, 2008a; Amishev and Murphy, 2008b).

Stress wave nondestructive testing (NDT) methods are currently used for veneer grading programs and strong correlations have been reported between stress wave velocity and wave attenuation and the corresponding mechanical properties of LVL (Brashaw *et al.*, 2004).

Acoustic NDT's have been successfully used for evaluation of mechanical properties of various wood products (structural lumber, poles, pulp logs, decay detection, etc.), sizes and species based on stiffness (Huang *et al*., 2003).

Kraft pulp yield (KPY) is an important wood feature in the pulp and paper industry. Research has shown that KPY can be predicted by using either NIR measurements of woodchips and woodmeal or acoustic measurements of standing trees and felled logs (Downes *et al*., 2008). In another study, the acoustic velocity of 250 radiata pine peeler cores was found strongly related to the length-weighted fiber length and the wet zero-span tensile strength of the fibers from those cores (Albert *et al*., 2002).

We propose that, together with the above-stated methods, an "integrated value-adding" approach using newer technologies, such as acoustics and NIR, for better automated product differentiation, may improve the economics of forest fuels reduction.

A case study in Coastal Douglas fir

The native range of Coastal Douglas-fir (*Pseudotsuga menziesii var. menziesii*) extends from central British Columbia south along the Pacific Coast Ranges into central California. Conversely, the native range of Rocky Mountain Douglas-fir (*P. menziesii var. glauca*), extends from central British Columbia south along the Rocky Mountains and into the mountains of central Mexico. Both varieties extend into regions in need of forest fuel reduction.

In an ongoing endeavor to optimize merchandizing and enhance timber value recovery, we sampled seven second growth Coastal Douglas-fir stands of similar age class in Western Oregon, totaling 1,400 trees of different sizes (ranging from 14.2 to 78.5 cm) and more than 3,000 logs (Amishev and Murphy, 2008a). While we recognize that the tree sizes in our study are likely to be larger than found in some stands in need of fuel reduction treatment, this study is useful in that it helps to answer a number of relevant questions; "can acoustics be used as a basis for sorting logs?", "what challenges will there be for implementing this technology on a harvester?", and "is this likely to lead to improved value recovery for the log purchaser and the log supplier?"

We investigated the effects of spatial as well as internal and external log characteristics on Douglas-fir wood stiffness. In-forest log acoustic measurements correlated well with the actual G1/G2 veneer grade recovery (Fig. 1) once bark removal adjustments were made.

Although past research has indicated high correlation between yield of structural grades of lumber and acoustic velocity of standing trees (Wang et al., 2007), we found that there was no significant correlation between standing tree acoustic velocity using the Director ST300® TOF device and the actual G1/G2 veneer produced using an in-line commercialized Metriguard® stress-wave grade sorter (Amishev and Murphy, 2008b).

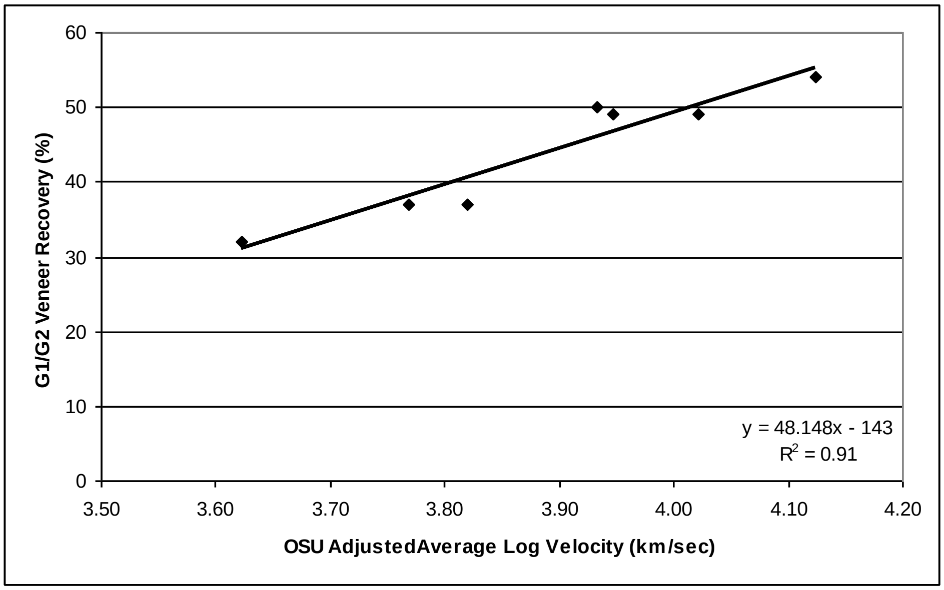

Figure 1. Relationship between G1/G2 veneer recovery and "bark-removal-adjusted" on-site average log velocity (it is assumed that all bark is removed).

Ongoing efforts, by researchers and equipment developers, are addressing potential challenges, opportunities and considerations from installing acoustic instruments on mechanized harvesters (e.g. Carter, 2007, Richard Lawler [John Deere] pers. comm. 2008). Our research suggested good operational feasibility if such technologies for measuring internal stem features are incorporated into a harvester head for real time measurement of resonance-based acoustic velocity (Amishev and Murphy 2008c). Forecasting routines (e.g. linear regression model or a k-nearest-neighbor approach) could be developed to account for imperfect information about tree length and results yielded by these routines were considered rather promising (Fig. 2).

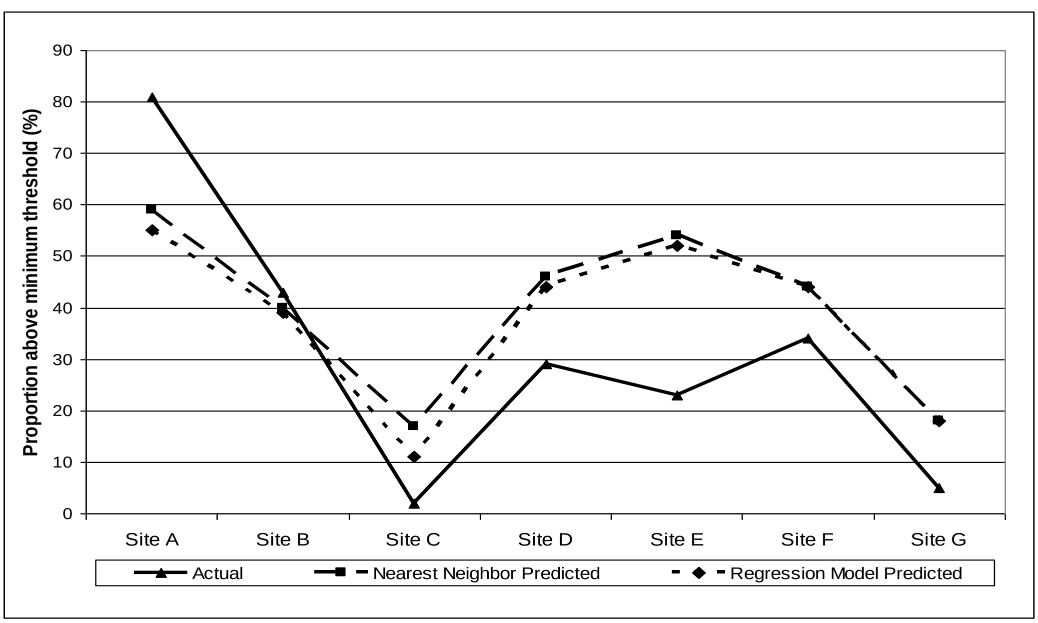

Figure 2. Percent trees above a hypothetical acoustic velocity threshold value for stiffness quality assessment from the validation data set (VDS) of the seven trial stands. The three curves represent the actual, *k*-NN and linear regression method predicted percent, respectively.

A previous study had shown that it was possible to estimate relative Douglas-fir log prices based on wood density (Acuna and Murphy, 2007). We estimated relative breakeven prices of Douglas-fir peeler logs that a log purchaser could afford to pay based on acoustic assessment of veneer stiffness differences. It was shown that, although markets do not yet pay a premium for higher stiffness peeler logs, log purchasers could afford to pay such prices (Amishev and Murphy *in press*). Despite several assumptions and limitations presented, based on the results of the study, it was suggested that stand stiffness grading based on acoustic velocity measurements on Douglas-fir peeler logs at the time of harvest could be used as a surrogate measure for potential net returns from that harvested forest stand and hence for a premium price to be afforded on such stands (Fig. 3). These results were in agreement with previous research where an economic analysis of sorting veneer logs for LVL production in the United States resulted in a gain of about US\$16/m^3 on log volume (about \$80 to \$100 per thousand board feet (Carter *et al*., 2005).

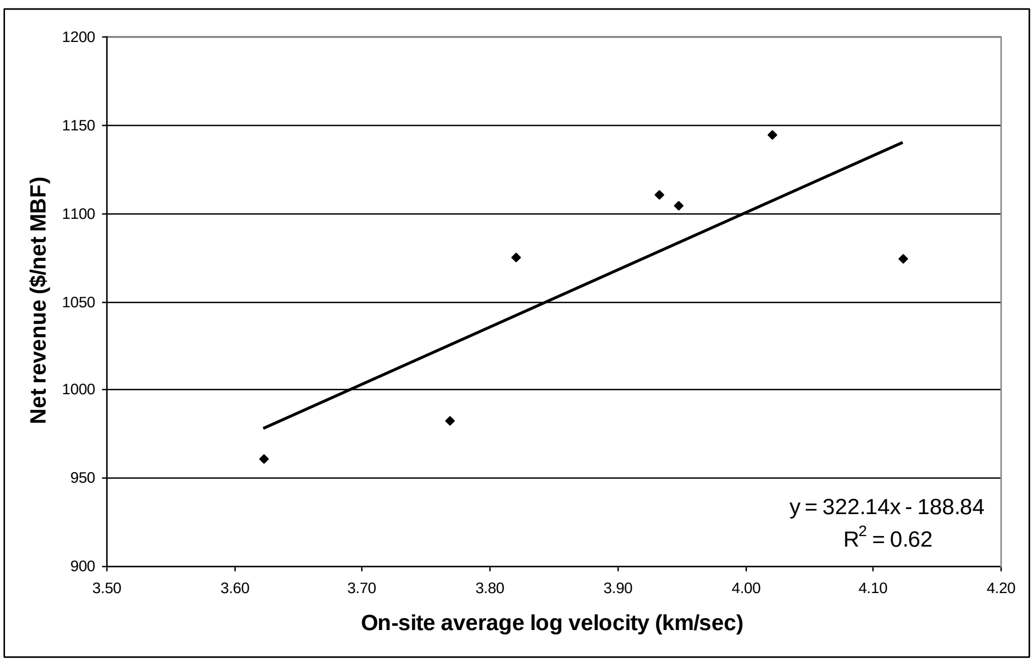

Figure 3. Relationship between breakeven veneer quality log prices and on-site average log acoustic velocity for seven Douglas-fir study sites.

Discussion and Conclusions

The cost of fuel reduction/stand health improvement operations involving mechanical treatment are highly sensitive to the values of the products generated by the operation (Hartsough *et al.*, 2008). In many cases, treatments costs can be offset by the value of harvested material and by including certain credible additional public benefits from fuel reduction investments (Mason *et al.*, 2006).

With technologies such as acoustics and NIR it may be feasible to implement an integrated value-adding approach which, coupled with a high speed, high recovery, highly automated and computer optimized sawmill system, could make "small log system" operating costs competitive relative to mills processing larger logs (Anderson, 2008).

Our work demonstrated that acoustic technologies can be used as a basis for sorting second growth Coastal Douglas-fir veneer logs, that there is potential for implementing this technology on a harvester head, and this is likely to lead to improved value recovery that could be shared by the log purchasers and suppliers. Further work is required, however, to determine if (1) acoustic sorting of log products can be applied to a wider range of species, stand types and tree sizes, (2) acoustics technologies can be operationally and cost effectively integrated into mechanized harvesting heads, (3) value differentials can be identified for other log products, and (4) optimal bucking and allocation of log products to markets can be based on both internal and external log characteristics.

There is no solution where "one size fits all" and careful planning is needed when deciding on the right system and components: products to be integrated, supply characteristics, volume and drivers. Although it may be challenging to find the balance between efficient, low-cost utilization and high-value products recovery, a site-specific, integrated model should ensure increased efficiency while maintaining flexibility, reduced handling and transportation by matching supply to market demands, minimized wastage, and maximized forest value at the time of harvest. Only such integrated manufacturing scenario offers the best opportunity to balance the different objectives that such operations may have.

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Soil damage after mechanized harvesting: results of a meta-analysis

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Abstract

A meta-analysis was performed to draw general conclusions concerning the impact of mechanized harvesting operations on the forest soil. Log response ratios, based on soil bulk density, were used to quantify the impact. Although it is generally assumed that clay and silt are more vulnerable than sand textures, the response ratios for clay and sand are similar. Here, the impact is maximal at the 0-10cm depth class (13 to 14%), and decreases towards the 20-30cm soil layer. For these two textures, the initial bulk density has a strongly significant negative influence on the response ratio as further compaction is prevented by high soil strength. In contrast with general assumptions, bulk densities for silt soils show almost no change, possibly due to relatively high initial bulk densities. For all textures a significant positive relationship exists between the response ratio and the machine weight. Therefore, the deployment of very heavy machines has to be restricted and adjusted to the intensity of the job. For loam, the number of passages also exerts a significant positive influence on the compaction degree, approaching a constant value at higher traffic intensities. As the results shows that clay and sand are vulnerable for compaction, and that it is generally assumed that silt textures are also prone to soil damage, traffic should be restricted on all textures. Moreover, the high impact from the first passage(s), the compacted initial state of many forest soils and the long recovery period, also count in favour of permanent skid trails.

Keywords: meta-analysis, mechanized harvesting, forest soil, soil damage, bulk density, log response ratio, initial bulk density, machine weight, traffic intensity, forest management

1. Introduction

In forest harvesting, heavy machines are often used and despite careful planning of field operations, concern remains over the potential adverse impacts on the forest ecosystem. In

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addition to rutting and churning, the soil may compact, leading to loss of pore volume and continuity, soil aeration (Herbauts et al., 1996; Gaërtig et al., 2002; Berli et al., 2003) and an increase of penetration resistance and bulk density (Miller et al., 1996; Aust et al., 1998). These effects may imply a serious risk for the diversity and functioning of the soil ecosystem as a good soil structure is important to the soil fauna (Jordan et al., 1999), the herb and moss layer (Buckley et al., 2003), tree roots (Greacen and Sands, 1980) and their functionalities. Only a few studies indicate positive effects resulting from compaction, mostly on dry, sandy soils (Brais, 2001; Gomez et al., 2002). The damage degree depends on soil and machine characteristics, such as texture, machine type, number of tyres and traffic intensity. It is generally assumed that soils with a clay and loam to silt texture are more vulnerable to compaction from machine traffic than sandy soils (Hillel, 1998; Fisher and Binkley, 2000). However, Brais and Camiré (1998) and Ampoorter et al. (2007) concluded that mechanized harvesting compacted the soil considerably in forest stands on sandy textures. The potential influence of machine type on soil damage is also of great importance. When machine weight increases, the soil pressure per contact area unit grows and thus the compaction process generally intensifies. The number of tyres is negatively correlated with the compaction degree, as it changes the total contact area between soil and machine (Alakukku et al., 2003). Moreover, each machine passage affects the soil, leading to increasingly higher compaction degrees (Brais and Camiré, 1998), and thus higher soil strength, that protects the soil partially, limiting the additional damage with future passages (Shetron et al., 1988; Williamson and Neilsen, 2000).

The soil damage caused by logging machinery has been frequently studied. Seldom comparisons are made between different levels of these factors, enabling to make general conclusions about the impact of a specific factor on the compaction degree. In this article, a meta-analysis was made to address the following questions: (a) to what extent is the bulk density of forest soils altered by machine traffic, (b) are the results similar for all of the examined soil texture groups, (c) to what extent is this relation influenced by the initial soil bulk density, the number of machine passes and the machine weight?

2. Materials and methods

Relevant studies were identified through searches of the bibliographic database ISI Web of Science, and the cited references in these publications (1955-2007). Only eleven articles contained the needed details (mean bulk density, measure of variance, number of replicates). Each forest stand is classified into one of three main groups sand, silt and clay (Soil Survey Division Staff, 1993). Most measurements were carried out in the upper 30cm of the soil that was divided into three equal depth classes. Each combination of forest stand, soil depth class, machine type and number of passages that was studied, is included as an individual substudy.

The first step in the analysis was to check for publication bias, i.e. the fact that studies with significant results are more likely to be published. In this meta-analysis, the problem of publication bias was approached using a funnel plot (Light and Pillemer, 1984), combined with a statistical test, based on the rank correlation (Kendall's tau) between the standardized effect size and the variance of this effect (Begg and Mazumdar, 1994). The funnel plot shows an index of precision on the vertical axis as a function of effect size on the horizontal axis. In the absence of bias the funnel is located symmetrically round the mean effect size. In the presence of bias, the wider part of the funnel (small study sizes, high standard error) will show a larger concentration of studies on one side of the mean. Statistical analyses to test the impact of machine traffic on forest soils were carried out in accordance with Hedges et al. (1999), using the log response ratio, i.e. the logarithm of the ratio of the mean bulk density before traffic to the mean bulk density after traffic, as measure of effect size. The cumulated mean response ratio for a group of substudies (specific texture group in a specific depth class) is a weighted average, giving more weight to larger studies. To determine the influence of specific factors on the response ratio, the correlation is calculated between the response ratio on the one hand and bulk density before traffic, machine weight and number of passages on the other. In order to take the size of each study into account, the weighted Pearson-product moment correlation coefficient is used (Bills and Li, 2005).

3. Results and discussion

The funnel plot shows that points are dispersed symmetrically around the mean response ratio. It can thus be stated that publication bias is absent and Kendall's tau confirms this conclusion ($p = 0.65$). The majority of the response ratios is positive, indicating a larger bulk density after machine traffic compared to the value before (Figures 1 and 2). The highest values are measured on clayey soils but the meta-analysis indicates that sandy soils may also be prone to compaction. Bulk density values after traffic are 15% higher than the values before traffic. In contrast with general assumptions, silty soils show rather zero to negative response ratios, what may be due to high initial bulk densities as will be explained in the following.

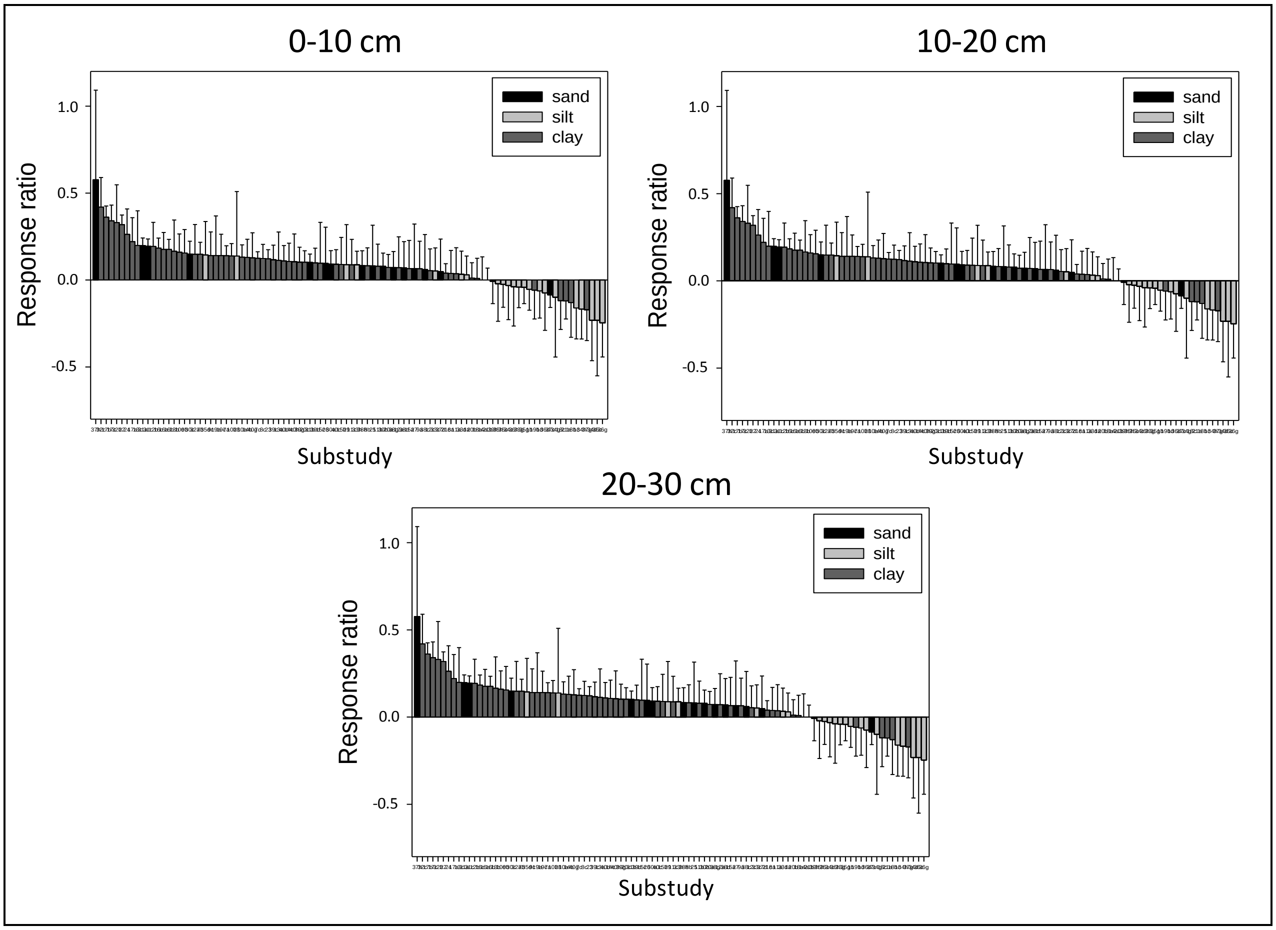

Fig. 1 Response ratios for soil depth classes 0-10 cm (98 substudies), 10-20 cm (102 substudies), 20-30 cm (88 substudies). Error bars indicate 95% confidence interval

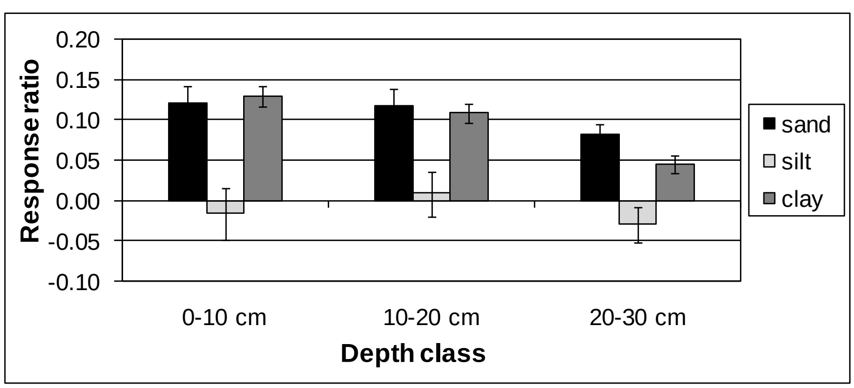

Fig. 2 Mean response ratio per texture group per depth class (with 95% confidence interval)

Some studies have pointed out that the clay content has an important positive influence on the degree of soil damage (Gomez et al., 2002; Smith, 2003), explaining the high positive response ratios for the clay soils. In general, it is assumed that compaction occurs especially on silty and clayey soils, while sandy soils are often expected to be rather indifferent to traffic with heavy machines (Fisher and Binkley, 2000). A reason for that may be the fact that, although particle size is smaller, clayey and silty soils normally have a larger porosity than sandy soils, and are therefore expected to be more sensitive (Hillel, 1998). However, in comparison with the meta-analysis, Ampoorter et al. (2007) stated that sandy soils can be compacted to a considerable extent. Moreover, Brais and Camiré (1998) found that the relative bulk density increase was as high on a soil with a coarse texture in comparison with medium to fine textured soils. Figure 2 also shows that the machine impact is largest at the surface and that the size of the positive response ratios decreases towards deeper soil intervals. Namely, exerted forces are more dispersed and thus weaken when they go deeper into the soil.

For silt, the correlation between the initial bulk density and the response ratio is insignificant (Figure 3). The highest response ratios and lowest initial bulk densities are found for clay. For both clay and sand, the correlation is negative and strongly significant ($p < 0.01$). In other words, the response ratio decreases as the initial bulk density increases. From a certain limiting value, the response ratios approach zero and are in some substudies negative, indicating that the compaction process stops and the soil rather seems to loosen up as a result of machine traffic. Powers et al. (2005) drew similar conclusions, as their research revealed that the higher the initial bulk density, the smaller the increase after machine traffic. An explanation for these results follows from the soil strength that increases as the soil becomes more compact (Shetron et al., 1988; Hillel, 1998). Further exploring Figure 3 seems to suggest a limiting initial bulk density for additional compaction to take place. This is in accordance with the results of Powers et al. (2005) who saw that soils with an initial bulk density of 1400kg/m^3 and over did not compact anymore. Moreover, through the rotation of the tyres the compacted superficial soil layer may churn and break up to a very small extent. Resulting from the increased soil strength at higher bulk densities in the upper soil, the exerted forces are dispersed to deeper soil layers (Shetron et al., 1998; Balbuena et al., 2002).

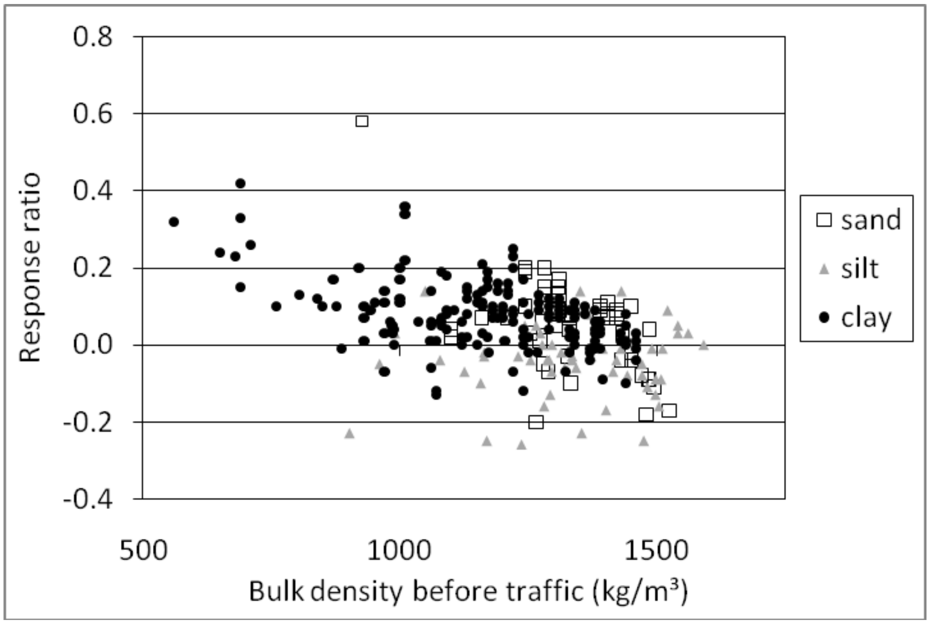

Fig. 3 Correlation between the bulk density before traffic and the response ratio

Figure 4 shows that for forest stands on sand, silt as well as on clay, a significant, positive relationship exists between the machine weight and the response ratio. This can be explained using the mean soil contact pressure. When the machine weight increases strongly, the weight per unit contact surface grows, resulting in a higher soil contact pressure and compaction degree. McDonald et al. (1996) came to the same conclusion. It has to be remarked that different machines with the same weight may have a different number of tyres. The weight per tyre determines, together with other factors such as tyre width and pressure, the soil contact pressure and thus the extent to what the soil is compacted. For this reason, the correlation between the response ratio and the machine weight per tyre is also important. However, for all texture groups this relationship appeared insignificant ($p > 0.05$). This may partially be due to the fact that for a lot of substudies information about the number of tyres was not available.

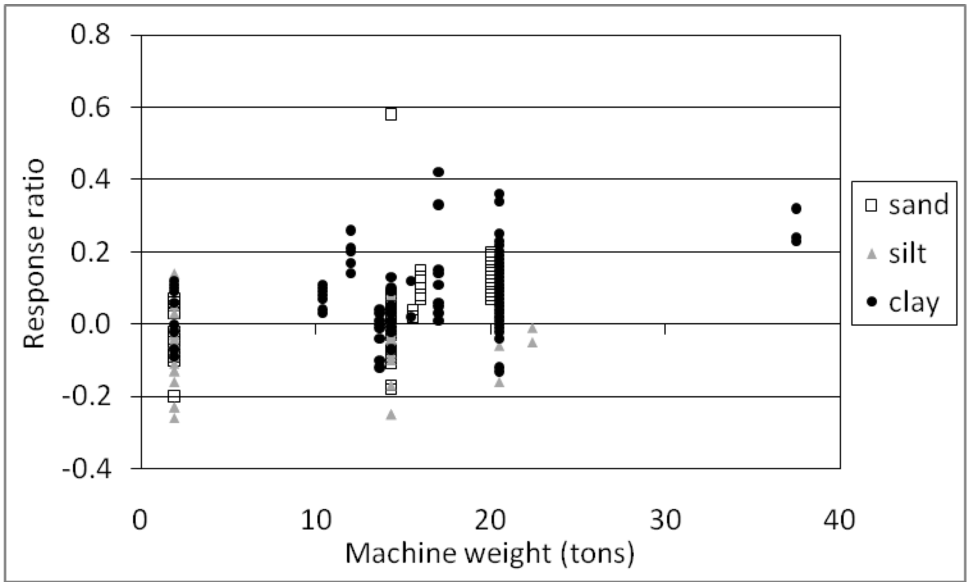

Fig. 4 Correlation between the machine weight and the response ratio

Looking at the relationship between the response ratio and the number of passages that the machines made (Figure 5), it seems that only for silt the correlation coefficient is positive and strongly significant ($p < 0.01$), although the range of traffic intensity levels is rather narrow. This means that the bulk density rises with increasing number of machine passages. The shape of the relationship is also important but was not statistically tested. It seems for clay that the response ratio approaches a constant value at higher levels of traffic intensity (logarithmic relationship). Several studies (Brais and Camiré, 1998; Williamson and Neilsen 2000; Seixas et al., 2003; da Silva et al., 2008) indicate that a logarithmic trend line is the best way to approach the relationship between traffic intensity and the compaction degree. Namely, as a machine pass results in an increase of the soil strength, it prevents further compaction leading to a stabilization of the response ratio at higher traffic intensities.

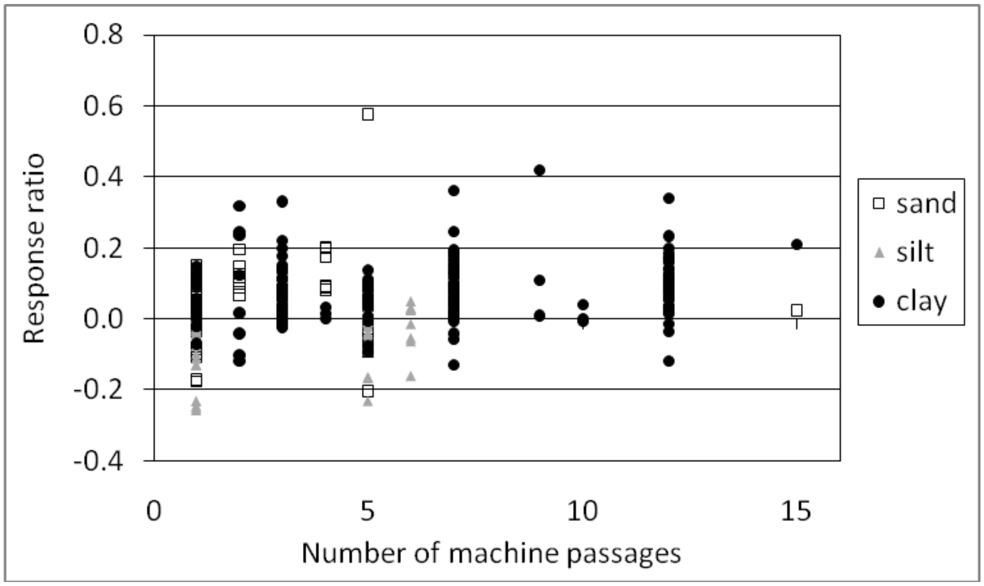

Fig. 5 Correlation between the number of machine passages and the response ratio

In forest management, it is of importance how fast the response reaches a stable value. If most of the potential damage is done in the first passages, then it is appropriate to restrict the machine traffic to designated skid trails so that the rest of the forest stand remains unharmed (Williamson and Neilsen, 2000; Buckley et al., 2003). When the first passage has a relatively small and reversible influence and when the impact increases gradually with successive passages, then it is better to spread the traffic. In this way, a certain area is impacted to a rather small and insignificant extent instead of a smaller area receiving a high compaction degree. Brais and Camiré (1998) showed that on coarse textured soils, the compaction degree increased steadily with the number of passages and that the number of passages necessary to achieve half of the potential impact, was lower for fine to medium textured soils than for coarse textures. Therefore they concluded that, on coarse textures, it is better to spread machine traffic. Ampoorter et al. (2007), however, found for sandy soils that the first passage already induced a high bulk density increase, while the impact of the following three passages remained smaller. Most studies indicate that most of the potential impact occurs after the first passage (Lacey and Ryan, 2000; Startsev and McNabb, 2000; Nugent et al., 2003). This pleads in favour of the use of designated skid trails.

As the soil is an important environment for vegetation and soil biota, compaction should be prevented as much as possible. The more since recovery from compaction is a slow process, especially on sandy soils as they lack effective recovery capacity (Greacen and Sands, 1980; Fisher and Binkley, 2000). Clay and silt textures generally are biologically more active and recover faster through specific processes, such as freezing and melting of soil water (Alban et al., 1994; Startsev and McNabb, 2000), swelling and shrinking of clay particles (Cornelis et al., 2006), and plant roots and soil animals that break up the soil (Jordan et al., 1999; Ponder et al., 2000). However, most results indicate that even on these soils it will take at least 20 to 30 years before recovery is complete (e.g. Croke et al., 2001; Rab, 2004). Moreover, in contrast with the assumptions, meta-analysis results show that sandy soils are as sensitive to compaction as clayey soils. This is also generally assumed for silt soils, although the results showed no clear response. Therefore, irrespective of texture group, the risk for compaction should be taken into account when planning and preparing harvesting activities.

The impact increases with traffic intensity and this relation seems to be logarithmic. Therefore, it is better to concentrate the traffic on designated skid trails. In this way only a restricted area is damaged and the rest remains almost unharmed. The meta-analysis also showed a great influence of the initial bulk density on the damage degree for sandy and clayey soils. Soils with high initial bulk densities (> 1250 kg/m³) possess high soil strength, preventing further compaction. The fact that these soils are already compacted should not be an incentive to allow machines to drive the whole forest stand. On the contrary, by restricting machine traffic to designated skid trails, the soil between the trails is left undisturbed and can recover from the compacted status. As was shown by the meta-analysis for all three soil textures, lighter machines (< 10 tons) have a smaller effect than heavier machines (> 20 tons). The machines used should always be tuned to the demands of the harvesting activity and the field circumstances (soil, weather, slope, tree species…). Heavy machines should only be used in exceptional cases. Several studies showed that a brash mat may be very efficient to reduce the degree of soil disturbance (Schäfer and Sohns, 1993; McDonald and Seixas, 1997) spreading the machine weight over a greater area than the actual footprint of the machine, and hence the mean soil contact pressure declines. A decrease of the tyre pressure and the use of wider tyre dimensions (Benthaus and Matthies, 1993; Ziesak, 2003) may also have a favourable influence. These findings should be taken in consideration at future harvesting activities and contain an incentive to adapt machine characteristics and prevent traffic through the whole stand.

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Product sorting impacts on cost and productivity of tree-length logging operations

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ABSTRACT

The transition of forest ownership from integrated forest products companies to institutional investors has caused numerous changes throughout the forest industry. One of the most important for the timber harvesting community has been an increased emphasis on maximum value recovery from each harvested acre. Product sorting has been steadily increased as additional value opportunities are identified by forest owners. In an effort to quantify the cost and production impacts of increased sorting, we evaluated weekly production records for eight contractors over a six-month period. In addition, we performed a series of time studies on a subset of these contractors to gain further insight into the actions of the loader operator and the impact of additional product sorts on their performance. Key findings also included a more thorough understanding of factors driving loading and processing productivity on a tree-length harvesting operation.

INTRODUCTION

Industrial forestland in recent years has shifted from being predominantly owned by companies that operate conversion facilities to today's dominant ownership by institutional investors. This ownership change is altering the dynamics of how timber is treated in the woods. The new owners that do not operate mills have an increased focus on maximizing value from each acre of land rather than maximizing the volume harvested or minimizing the delivered cost to a facility. This focus is often manifested in the woods by an increase in the number of products that are sorted on a given harvesting site. In an effort to capture additional value, more markets are added to each timber harvest, requiring additional sorting decisions and actions by harvesting contractors.

In the U.S. South, tree-length harvesting predominates (Baker and Greene 2008). With this harvesting system, bucking and sorting decisions are typically made at the landing. As most tree-length crews employ a stationary knuckleboom loader, the area under the loader available for piling wood is limited. Additionally, the loader is often tasked with delimbing, topping, and bucking, in addition to sorting products and loading trucks. Visser and Stampfer (2003) noted that the processing and loading capacity were limiting in a tree-length thinning operation employing two loaders with two skidders, without the use of a gate delimber. Substantial excess

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skidding capacity was found on the stand with an average extraction distance of 670 feet. The added burden of additional product separations could prove to be a substantial restriction on overall production of the operation.

Others have investigated the impact of product separations on productivity. Williams (1989) reported no substantial drop in productivity of a knuckleboom loader shifting from six to nine product separations when the loader was only involved in the product sorting and loading operations. Delimbing and bucking activities were carried out manually. Williams (1989) also found circumstantial evidence of a relationship between truck scheduling and loading productivity, but was unable to quantify this relationship. Lanford *et al.* (1990) performed a detailed examination of knuckleboom loader performance, focusing specifically on loading tree-length products. Average piece size and number of pieces on a load were most influential on loading time when wood was moved directly from skidders to the truck. If wood was already sorted into piles, no measured variables were found to have an impact on loading time. Gingras (1996) reported on impacts to a variety of harvesting systems from product sorting. None of the systems examined relate directly to the current tree-length harvesting systems employed in the U.S. South; however, a tree-length harvesting system employing a stroke delimber and slasher had a 14.5% increase in costs moving from one product separation to six separations. Wang (2007) examined loader performance in bucking and loading hardwood stems. All products handled were cut-lengths, and piece size was the main factor affecting loading productivity.

We initiated a research project to examine what impact(s), if any, additional sorting pressure was placing on tree-length harvesting contractors. Our research examined sorting impacts on gross weekly production levels as well as a finer examination of the effect on hourly production. Loading and processing productivity were examined in addition to the impact of trucking availability.

METHODS

We collected weekly production records from eight harvesting contractors over the course of six months, with some contractors providing over two years of data. Seven contractors, representing nine crews, operated tree-length harvesting systems utilizing stationary knuckleboom loaders paired with pull-through delimbers and hydraulic ground saws. One contractor, operating two crews, employed a modified tree-length system utilizing a roadside processor with a processing head mounted on a track-mounted shovel. Total loads delivered, processing facility destination, product type for each load, hours worked, and number of employees were reported for each day. Data were compiled and examined using linear regression to examine the impact of sorting intensity on weekly production. Dummy variables were used to differentiate tree-length operations from modified tree-length operations using a roadside processor.

We performed short time studies to examine the performance of five loader operators over the course of a two to four day period. Each operation included a knuckleboom loader paired with a pull-through delimber and a hydraulic ground saw. Prior to arrival on the landing, wood was backed through a delimbing gate by the skidder. In four of the operations, wood was taken from the skidder, delimbed, topped, cut by the ground saw if necessary, and sorted into processed piles. In one operation, wood was taken from the skidder and sorted into unprocessed piles. This operator processed the wood immediately prior to loading onto a truck. Two operations studied were in the piedmont of Georgia, and three were in the South Carolina or Georgia coastal plain. Four of the five were performing clearcuts and one was performing a first thinning. All operations were in planted loblolly pine (*Pinus taeda*) stands.

We performed work samples on a two-minute interval using the activity codes listed in **Table 1**. For each truck loaded, we also recorded the start and end time of each load, number of stems per load, product, swings from a processed pile to the truck, swings of unprocessed wood to the truck, swings of unprocessed wood to a pile, and swings of wood from the truck to the ground. Unprocessed wood was typically delimbed and topped prior to placement either on the truck or in the appropriate pile. Load weights were recorded from delivery tickets as trucks returned from delivering products to the mill.

Table 1. Activity codes recorded during the work sample.

Activity Code	Description
Loading	Placing wood on trucks
Sorting	Moving wood into sorted piles
Delimbing	Wood is in the pull-through delimber
Mechanical Delay	Delay resulting from mechanical breakdown or maintenance
Wait Trees	No wood available on landing for processing
Wait Skidder	Skidder is preventing the loader from working
Wait Truck	Trucks are either not present or are preventing loader from working
Misc. Delay	Non-operational delays
Idle	Machine is not operating
Clearing Deck	Moving waste from work area

To provide additional insight into the impact of sorting intensity on production, data were recorded on processing performance. During the processing operation, continuous time-study data were recorded. Three activity codes were recorded: delimbing, bucking, and sorting. Delimbing occurred when wood was processed through the pull-through delimber prior to sorting in a pile. Bucking occurred from the time wood was lifted from the delimber until it was lifted from the ground saw. Sorting occurred either when wood was sorted from the skidder without being processed through the delimber or when it was lifted from the ground saw and sorted. Number of stems in the grapple and products were also recorded. Average stem weights were based on the weight and stem count of delivered truckloads, as sufficient manpower was not available to record individual piece dimensions. Delay times were not recorded but were estimated using the work sample data.

Data were analyzed to determine utilization and main sources of delay. Loading and processing productivity were modeled separately using linear regression to determine the most influential factors. A stepwise regression was performed using improvement in r-squared as a variable selection factor. Optimal model form was selected by examining r-squared and c(p) to ensure the model was not over-parameterized (Freund and Littell 2005).

RESULTS

Weekly Production Data – Eight harvesting contractors reported production data for 487 operating weeks. Production averaged 52.4 loads per week with averages for individual harvesting crews ranging from 36.3 to 137.6 loads per week (**Table 2**). Total product sorts averaged 6.8 per week but ranged from 1 to 14 for a given week. The crews employing roadside processors had the highest number of sorts. No traditional tree-length crew handled more than 10 product separations during the study period.

Regression analysis identified the following equations for prediction of weekly production:

Modified tree length operations:

$$Y = 0.791 + 0.082 * w + 1.312 * \ln(t) - 0.141 * t$$

Tree-length operations:

$$Y = 3.131 + 0.012 * w + 0.964 * \ln(t) - 0.141 * t$$

Where:
Y = Weekly production (No. of loads)
w = Workerdays (No. of employees * No. of days worked)
t = Total product sorts delivered

Table 2. Summary of weekly production data provided by harvesting contractors

Logging Crew	Weeks Reported	Avg. Production (Loads)	Sorts			Workers
			Avg.	Min.	Max	
A	23	79.0	5.7	3	7	5.0
B	27	53.9	3.7	2	5	4.9
C	17	42.5	5.5	2	8	4.0
D	24	53.8	5.4	2	8	3.6
E	28	65.8	4.7	2	7	6.3
F	12	70.6	6.4	3	8	3.7
G	11	62.6	6.1	5	7	3.3
H	16	137.6	5.9	4	10	4.0
I	15	91.1	4.8	2	8	4.0
J[1]	151	41.0	7.4	2	14	3.5
K[1]	163	36.7	7.1	2	13	3.4
Total	487	52.6	6.8	2	14	4.1

[1]Crew utilizing roadside processor

For both tree-length and modified tree-length operations, increasing production was observed as sorts increased for relatively low production levels (**Figure 1**). This pattern was attributed to the ability of crews to avoid production quotas from a limited number of markets by seeking additional markets for the timber they produce. For tree-length crews, production decreased beyond six total product separations. At this level, quota avoidance was less of an impact and true production curtailments took place. We observed a similar impact to modified tree-length harvesting crews beyond nine total sorts, though the production reduction was less severe.

Figure 1. Effect of total number of product separations on weekly production levels for tree-length and modified tree-length harvesting crews operating 20 total worker-days.

Weekly production data highlighted the importance of markets on potential production and provided some indication of the impacts of additional product separations beyond the level where markets may be limiting. To assess the true hourly production impacts of additional product sorts, we examined detailed time-study data for a subset of the harvesting crews from whom we collected weekly production data.

<u>Hourly Production Data</u> - Loading data were collected from 129 loads of wood, representing seven product types; however, these were combined based on product similarities into the five categories listed in **Table 3**. Loading time did not vary based on product type (p=0.396). Average loading time did vary by operator, with Operator B having the longest loading time (**Table 4**). This was the operation where delimbing and topping was performed as wood was being loaded on the trucks.

Lanford *et al.* (1990) detailed the impact of "hot" and "cold" loading as determined by whether wood must be processed during loading ("hot") or if the load can be made from pre-processed piles ("cold"). One contractor used an entirely hot loading approach, and as suggested by Lanford, loading times lengthened considerably (138%) with a corresponding drop in loading productivity (60%). Data were not recorded on skidder utilization, but it was assumed that the approach of sorting unprocessed wood increased skidder productive time by minimizing skidder waiting while the loader processed wood. However, there would be a potentially offsetting increase in waiting time during the much longer loading period. We observed the lowest loader utilization on this hot operation of the five observed with substantial idle time that could have been used to process stems.

Table 3. Loading characteristics recorded by product type.

Product	Number of Loads	Ave. Load Time (min.)	Std. Dev. (min.)	Total Swings	Swings to Truck
Pulpwood	62	13.3	7.8	19	15.3
Super Pulpwood	10	14.3	6.4	16.7	16.1
Chip-n-Saw	34	16.3	9.4	22.4	17.9
Tree-length Sawtimber	22	12.4	8.6	18	14.9
Cut-length Sawtimber	1	16	na	30	30

Table 4. Average loading characteristics by loader operator.

Loader Operator	No. of Sorts	No. of Loads	Load Time (min.)	Tons per Load	Total Loader Swings	No. of Swings from Sorted Pile
A	3	26	11.6 (0.48)[1]	29.3 (0.35)	12.7 (0.27)	12.7 (0.23)
B	4	27	25.5 (1.35)	29.5 (0.37)	35.1 (2.44)	16.5 (2.18)
C	5	27	8.9 (0.36)	30.2 (0.31)	16.4 (0.68)	16.1 (0.70)
D	6	27	12.4 (1.50)	27.9 (0.33)	17.9 (1.72)	11.5 (0.53)
E	6	28	10.2 (1.08)	28.7 (0.35)	14.7 (1.20)	9.7 (0.39)

[1] Standard errors of the means are in parentheses.

As more product separations were processed, more time was required to achieve full piles of each product. When insufficient wood was in a pile to fully load a truck, the loader processed additional wood from the skidders while loading the truck, extending the total loading time and greatly increasing the variability in loading time (**Figure 2**). Each swing of wood loaded on the truck from a sorted pile added 34.5 seconds to the total truck loading time. When wood was loaded directly from a skidded pile, it added 41.3 seconds to the total truck loading time, an additional 6.8 seconds (20%) per swing. If a product other than that being loaded was processed and sorted into a pile, this extended total loading time by 39.6 seconds per swing without putting any additional wood on the truck. The loader operator loading only three products had little variability in number of swings and total loading time (**Table 4**). Operators producing six products, however, experienced large variation in total loading time and often substantial processing time during truck loading.

The ability of the loader operators to maximize the total weight of wood moved with each swing also impacted loading time. Average swing weight was negatively correlated with loading time per truck ($r = -0.623$; $p < 0.001$). With cut-length products, the volume in the loader grapple was filled before the optimum weight could be attained. Loading time per truck for cut products was 17% longer than for tree-length products.

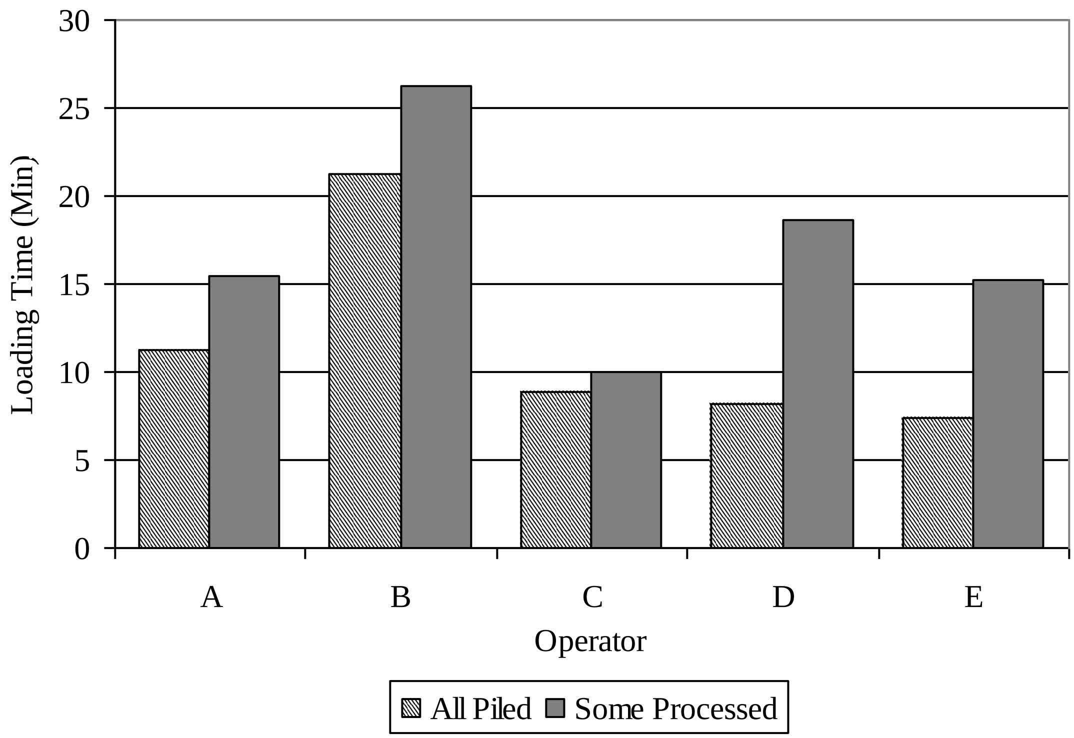

Figure 2. Average loading time per truckload for five operators when loading from fully sorted piles or when some wood required processing from the skidders during loading.

The regularity of truck arrivals at the landing was noted by Williams (1989) as a factor in determining overall loading productivity; however, the relationship was not statistically verified. In our study, the interval between departure of one truck and arrival of the next was assumed to be time available for processing wood. We calculated the average available processing time (time between departure of one truck and arrival of the next), and the variability of that time on a daily basis. Only twelve total days were available for analysis, necessitating nonparametric statistical methods. Average time available for processing was negatively correlated with loading productivity [Spearman's correlation = -0.580 ($p<0.05$) Kendall's tau= -0.667 ($p = 0.001$)]. No reason for this trend was readily apparent. We also found a negative relationship between the variance in truck arrival intervals and loading productivity per PMH [Spearman correlation = -0.510 (p<0.05) Kendall's tau = -0.42 (p=0.031)]. A 10% increase in arrival time standard deviation translated to a 2.26% reduction in tons loaded per productive machine hour (PMH). This agrees with Williams' findings, though the lack of a positive relationship between average available processing time and loading productivity was unexpected.

Detailed processing time data were collected on 748 swings of wood (**Table 5**). Processing productivity was highest for super-pulpwood stems that often required little or no additional processing after the delimbing gate and had a larger average piece size than pulpwood. Both chip-n-saw and tree-length sawtimber stems were processed through the pull-through delimber before sorting, reducing processing productivity compared to tree-length pulpwood that often required no additional processing by the loader after being backed through the delimbing gate. Cut-length sawtimber had significantly lower processing productivity as each piece had to be cut by the ground saw and sorted.

Table 5. Average processing characteristics for main product types investigated.

Product		Function			Productivity
		Sorting	Delimbing	Cutting	(Tons/PMH)
	Seconds per swing	20.5	48.4	n.a.	
Super Pulp	Avg. Weight (tons)	0.97	1.51	n.a.	161
	% of Total Swings	84%	16%	0%	
	Seconds per swing	25.6	55.6	43.3.	
Pulp	Avg. Weight (tons)	0.74	1.51	0.40	104
	% of Total Swings	81%	19%	2%	
	Seconds per swing	18.3	45.5	32.1	
CNS	Avg. Weight (tons)	0.89	0.85	0.79	67
	% of Total Swings	11%	89%	11%	
	Seconds per swing	n.a.	43.7	34.7	
Saw	Avg. Weight (tons)	n.a.	1.11	1.1	73
	% of Total Swings	0%	100%	31%	
	Seconds per swing	30.6	n.a.	29.3	
Pre-Cut Saw	Avg. Weight (tons)	1.04	n.a.	0.40	35
	% of Total Swings	33%	0%	67%	

Using the ground saw to trim damaged butt pieces from the end of tree-length stems added substantial time to the total processing time. Across all tree-length products, end trimming added 32.9 seconds per swing of wood. Average productivity varied based on the volume of wood in each swing. Pulpwood productivity was significantly lower than other tree-length products at 35.2 tons per PMH compared to 102.8 tons per PMH for other tree-length products. When it was necessary to trim pulpwood stems, they were typically handled individually, dropping the average weight handled substantially. However, only 2% of pulpwood stems were processed through the ground saw.

CONCLUSION

Our time study data indicated that productivity, particularly processing productivity, was more sensitive to the type of product being sorted than the absolute number of sorts when dealing with fewer than six separations in a tree-length harvesting system. In particular, handling cut-length products reduced the processing productivity by 48-78%. The reduced piece size and the increase in the number of pieces created when bucking the tree to length had a negative effect on overall productivity. A reduction in loading productivity was also seen with cut-length products, though sample size was insufficient to test statistically. Loading productivity was most sensitive to available processed wood, with all participating contractors reducing truck loading time from 11 to 56% when wood did not need to be delimbed and topped during loading.

ACKNOWLEDGEMENTS

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Potential Impacts of Biomass Harvesting on Forest Resource Sustainability

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ABSTRACT

Due to current woody biomass demand, some loggers have added small chippers to their harvesting operations to produce biomass fuel chips from logging residues such as limbs, tops and otherwise non-merchantable material. Numerous facilities throughout the Southeast and the nation, have announced intentions of converting biomass to energy. Assuming that utilization of biomass increases in the future, additional removals of logging residues will be necessary. Utilizing logging residues for energy has positive benefits for both loggers and landowners. However, there are also some concerns that increased utilization of logging residues will potentially cause negative impacts on the long-term sustainability of forest resources. Concerns over potentially negative effects generally fall into issues regarding removals of nutrient and organic pools or concerns regarding increased erosion losses and water quality effects due to increased bare soil. A review of past studies indicates that nutrient removal rates from biomass harvesting are generally not great enough to cause long term site productivity declines. In instances where the effects on nutrient pools are greater, fertilizer application would be sufficient to ensure future nutrient pools. Nutrient removal rates for a case study site in Virginia that harvested fuel chips indicated that average fuel chip nutrient content of 2.56, 0.27, and 1.33 pounds per green ton of nitrogen, phosphorous, and potassium, respectively. Erosion rates estimated on the case study site ranged from 3.2 to 8.6 tons per acre per year and indicate that additional studies are needed to determine if conventional BMP's are adequate for biomass harvesting operations.

Introduction

The use of woody biomass for the production of energy is expanding rapidly and has the potential to offset a portion of the non-renewable fuels used for energy production in the United States. This can potentially reduce dependence on foreign oil as well as reduce usage of other fossil fuels which are net emitters of carbon dioxide. Utilizing woody biomass from forests to produce energy is generating significant interest in Virginia and throughout the nation. Numerous facilities are already using woody biomass for energy and additional facilities have announced plans to begin construction. Although a variety of positive benefits associated with utilizing woody biomass for energy exist, there are also some concerns. Typical biomass harvesting operations utilize logging residues such as limbs, tops, and otherwise non-merchantable material by adding a chipper to a conventional logging operation (Westbrook et al., 2007). Compared to conventional harvesting, biomass harvesting removes additional branches, foliage, and other logging residues from the site. Removing additional biomass from the site leaves less protective cover on the forest soil which has the potential to increase erosion and sedimentation. Removing limbs and foliage that would have been left on site in conventional harvests is a concern because it removes a disproportionate quantity of nutrients and could potentially decrease long term site productivity by reducing available nutrients.

As interest in biomass utilization intensifies, questions about emerging markets and products have increased and VA Tech Forestry Extension has been actively involved in biomass educational programs throughout the state. In addition to the interest over potential new markets, forestry professionals and others attending these workshops commonly express concern over the potential environmental impacts of utilizing biomass from logging residues. Therefore, the objective of this paper is to provide the forestry community information regarding the concerns of nutrient removal, erosion, and sedimentation when logging residues are utilized for bioenergy. Specifically the goal was to assess current information, determine its relevancy to biomass utilization as practiced in Virginia, and identify areas where future research may be needed.

Study Site and Methods

A 20 acre study site was located in Bedford County, VA in the Piedmont physiographic province. This area has well developed local markets for biomass fuel chips as well as pulpwood and hardwood sawtimber. The market for biomass fuel chips is dominated by an 80 Megawatt wood fired electrical generation facility near Altavista, VA. In addition, two paper mills purchase boiler fuel, including whole tree chips on the open market to produce heat and steam for their manufacturing facilities. The combined consumption of boiler fuel purchased on the open market by these three facilities is approximately one million tons per year, the majority of which is from whole tree chips. The case study site was a pine plantation that involved a clearcut harvest. The harvesting contractor was operating a mechanized logging crew with a feller buncher, 2 grapple skidders, a Morbark Model 22 Chiparvestor disc chipper, and a single loader loading roundwood and feeding the chipper. Products produced on the site were double bunk pine pulpwood and fuel chips. Hardwood stems, small diameter pine stems, tops and branches were chipped for biomass fuel chips.

Chip samples were collected from chip vans on site. Nine chip samples were collected with two subsamples of each for a total of 18 samples analyzed. Samples were sealed in a plastic bag on site then later transferred to a paper bag prior to drying. A green weight was obtained, and then samples were placed in a drying chamber. After dry weight was obtained, moisture content was calculated for each sample. Dried chip samples were ground in a Wiley mill until they passed through a 1 millimeter screen. After grinding, the samples were analyzed for Carbon, Nitrogen, Phosphorous, and Potassium content. Erosion rates on site were estimated using the Universal Soil Loss Equation (USLE) as modified for forests (Dissmeyer and Foster, 1984).

Nutrient Removal

Samples of fuel chips were analyzed to determine nutrient content and if current logging residue utilization standards on this job produced similar nutrient removal rates compared to other previously published studies. Samples were analyzed for moisture content, carbon, Nitrogen (N), Phosphorus (P), and Potassium (K). Pine fuel chips had an average moisture content of 57 percent and contained 53.8 percent carbon. Average nutrient content of the fuel chips indicated nutrient concentrations of 0.297, 0.032, and 0.154 percent N, P, and K respectively as shown in Figure 1.

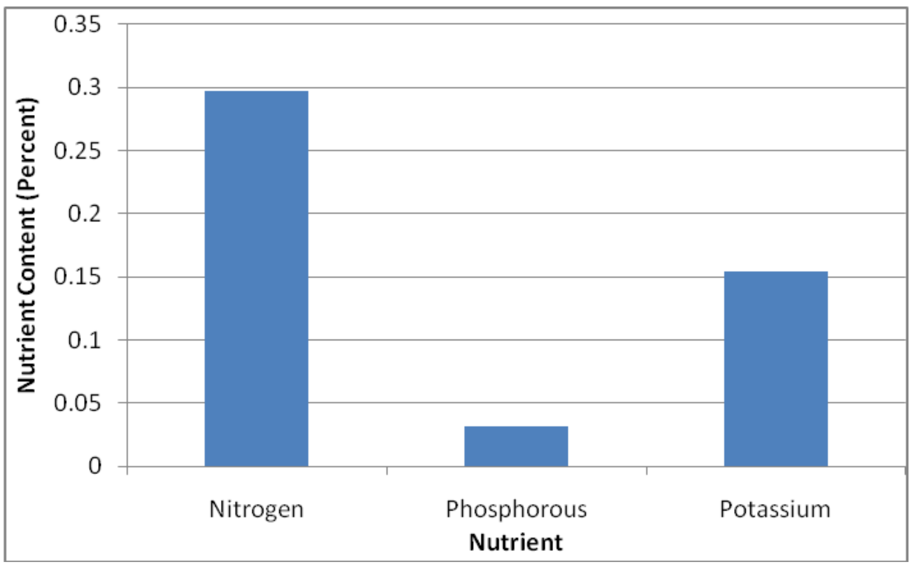

Figure 1. Average percent nutrient content of fuel chips.

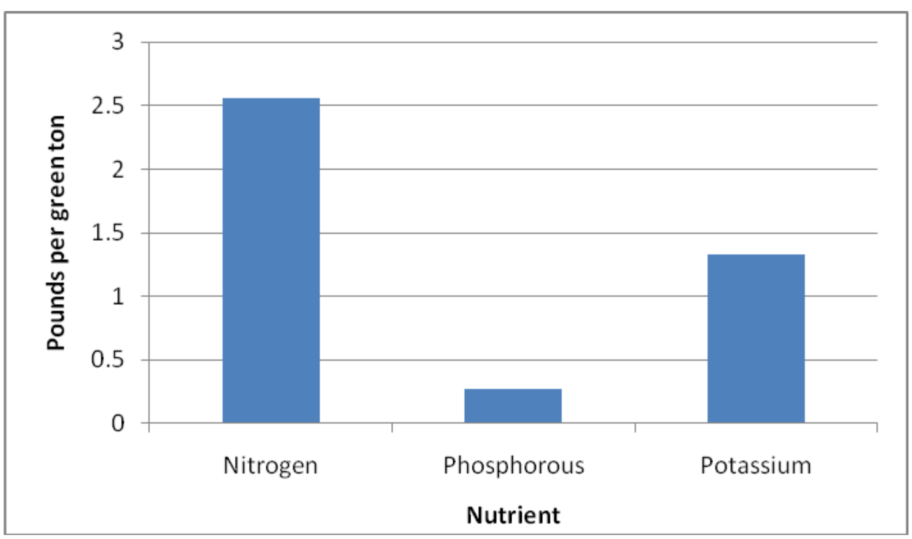

Figure 2. Average pounds of nutrients removed per green ton of fuel chips.

Average quantities of nutrients removed per green ton of biomass were calculated and indicate that for this study site approximately 2.56 pounds of Nitrogen, 0.27 pounds of Phosphorous, and 1.33 pounds of Potassium are removed per green ton of fuel chips removed from the site as shown in Figure 2. Nutrient removals per ton of harvested material may be useful for estimating additional nutrient removals for biomass harvests when compared to conventional harvests. Table 1 provides an example loblolly pine site on a 25 year rotation showing Nitrogen inputs, outputs, and net changes with differing levels of logging residue harvest. Loblolly pine bole only Nitrogen content was estimated at 103 pounds per acre (Pritchett and Fisher, 1987), inputs from natural processes was estimated at 155 pounds of N over the course of a 25 year rotation (Carter and Foster, 2003), and Nitrogen content of residues were based on average values calculated from sample chips in this study. Example residue removal rates were based on reported values of harvest rates for logging residues plus understory material in a pine plantation of 10.8 tons per acre (Westbrook et al., 2007) and a theoretically more intense utilization rate of 20 tons per acre. Inputs and outputs will vary for each site but this example shows the relative quantities of nutrients removed based on our estimates of nutrient content of logging residues and a sample pine plantation system. In this specific example, residue removal rates greater than 20 tons per acre would cause declines in the quantity of available nitrogen over the course of the next rotation. It also serves to illustrate that while it will vary by site, increased residue removal has the potential to decrease site productivity.

Table 1. Nitrogen pools and transfers for 25 year rotation of loblolly pine (pounds/acre).

Treatment	Boles	Residues	Total	Inputs	Net Change
Bole only pulpwood harvest	103	0	103	155	+52
Pulpwood plus 10 tons residues	103	26	129	155	+26
Pulpwood plus 20 tons residues	103	51	154	155	+1

Although nutrient removal associated with biomass harvesting on forest sites can be a concern, nutrient removals from similar whole tree harvests have been researched in the past. Many early whole tree chipping studies date back to the early 1970's when an earlier energy crisis focused research on biomass energy. A recent comprehensive literature review by Eisenbies et al. (in review) on intensive utilization of harvest residues in southern pine plantations concluded that as long as the forest floor remains intact, harvesting logging residues will probably not have long term negative effects, especially on more fertile sites. However, they also noted that even in cases where nutrient removal might cause productivity declines, fertilization could feasibly be used to offset nutrient losses. It should be noted that some studies of whole tree harvesting of hardwood stands revealed additional concerns related to calcium depletion (Boyle et al., 1973; Swank and Reynolds, 1986). As a result, additional research may be warranted for hardwood logging residue utilization and calcium removal.

Erosion and Sedimentation

Compared to conventional harvesting, biomass harvesting removes a higher percentage of above ground biomass including, branches and foliage and therefore could provide less protective cover for the soil. The additional bare soil could potentially result in increased erosion and nutrient loss from the site. In addition to the productivity losses associated with soil erosion, the erosion could reach water bodies and cause water quality concerns. Forestry Best Management Practices

(BMP's) for Water Quality are widely implemented and their effectiveness at preventing erosion and sedimentation is well documented (Aust and Blinn, 2004). However, current BMP guidelines were typically developed for conventional harvesting operations (Shepard, 2006) where logging residues were left on site. Little research has been done to determine what additional impacts there may be from harvesting woody biomass for energy and what additional BMP recommendations may actually be needed for biomass harvesting operations. A number of states have already altered BMP guidelines to reflect additional recommendations for biomass harvesting. However, little research has directly compared water quality impacts from current biomass harvesting operations versus conventional harvesting operations.

We collected preliminary data at the case study site for the Universal Soil Loss Equation (USLE) as modified for forests (Dissmeyer and Foster, 1984). We collected representative samples from the harvested area, deck, and haul road and these data indicated that average erosion rates across this site ranged from 3.2 to 8.6 tons per acre per year immediately following harvesting. These data contrasted with values of < 1 to 5 tons per acre per year for a similar conventional harvest in the piedmont. A visual assessment of the site indicated that the increased removal of logging slash left considerably more bare soil than a typical conventional harvest and indicated that further investigation of the impacts of biomass harvesting on erosion and sedimentation is justified.

Conclusions

Nutrient removal and erosion rates are among the top potential concerns related to biomass harvesting that are voiced by forestry professionals. Significant prior research has been conducted regarding nutrient removals and whole tree harvesting. Based on current utilization standards for biomass and known nutrient removal rates, for most stands, long term productivity will probably not be a wide spread problem. However, there are infertile sites where additional nutrient removals from biomass harvesting could impact productivity. For these potentially nutrient limited sites, standard fertilizer application rates could feasibly offset nutrient removal impacts. Additional research may be needed to identify sensitive sites where nutrient removals from biomass harvesting could potentially decrease productivity.

The other primary concern related to biomass harvesting relates to erosion, sedimentation and water quality. When logging residues are harvested for fuel chips, less protective cover is left on the forest floor and the potential exists for increased soil erosion. Some states have begun to implement additional BMP's for biomass harvesting and other states are considering the possibility of additional BMP's. Implementation of additional BMP's can add significant costs to harvesting operations, yet little research has been conducted to determine if conventional BMP's are effective at protecting water quality on biomass harvesting operations. Before additional BMP's for water quality are recommended for biomass harvesting operations, research should compare and contrast water quality impacts of conventional harvesting versus biomass harvesting operations. These comparisons will determine if current BMP standards are adequate, and if not, what additional BMP's may be necessary.

As with any area of forest operations, sustainability of the resource is a top concern of forest managers. Previous studies indicate that for most sites, utilizing logging residues for bioenergy is a sustainable and desirable use of the forest resource. Additional research in the future should focus on identifying sites of special concern where harvesting logging residues could potentially cause productivity declines, and in determining what if any additional BMP's may be necessary to protect water quality.

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Machine Cost Analysis Using the Traditional Machine-Rate Method and CHARGEOUT!

E.M. (Ted) Bilek[1]

"The aim in developing a machine rate should be to arrive at a figure that, as nearly as possible, represents the cost of the work done under the operating conditions encountered and the accounting system in force."

- Donald Maxwell Matthews, 1942. p.54
Cost control in the logging industry
McGraw-Hill Book Company, Inc.
New York.

ABSTRACT

Forestry operations require ever more use of expensive capital equipment. Mechanization is frequently necessary to perform cost-effective and safe operations. Increased capital should mean more sophisticated capital costing methodologies. However the machine rate method, which is the costing methodology most frequently used, dates back to 1942.

CHARGEOUT!, a recently introduced discounted cash flow methodology is compared with seven machine rate methods using data representing a skidder. I found that use of machine rate methods can lead to either over or under-estimates of machine owning and operating costs, depending on the machine rate model used. CHARGEOUT!'s calculated rate will provide a user-specified rate of return.

The differences between the results calculated by the machine rate methods occur because of different implicit assumptions used within the models' formulas. The differences between CHARGEOUT! and the machine rate models occur largely because of the inability of the machine rate models to properly incorporate the time value of money.

Whereas CHARGEOUT! can be sufficiently constrained so as to more-or-less replicate a machine rate calculation, doing so sacrifices much of CHARGEOUT!'s power and flexibility. Machine rate models cannot be configured to replicate CHARGEOUT!'s calculations. Machine rate models cannot be configured to calculate cash flows, allow for uneven costs or machine hours, incorporate loans that have a different life than the expected machine life, incorporate financing, or perform an after tax analysis. Machine rate models cannot calculate a costing rate that will provide a specified rate of return. CHARGEOUT! is a capital costing model that overcomes these limitations.

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INTRODUCTION

Matthews (1942) published the first methodology to determine how much to charge for logging equipment. This "machine rate" methodology was widely adopted and is still the most common methodology for determining machine charge-out rates for timber harvest operations.

Miyata (1980) produced a machine rate methodology easily adapted for hand calculators. Brinker, et al. (2002) produced a version for spreadsheets. The Caterpillar Tractor Company (2001) and Fight, et al. (2003) use similar methodologies. The USDA Forest Service Forest Operations Research Unit (n.d.) has an on-line version that incorporates a capital cost recovery formula into the capital cost calculation. The FAO's (1992) version is described with examples from machines to oxen. It is incorporated into PACE, a computer program developed to calculate machine rates, road construction costs, and harvesting costs (FAO, n.d.). Virginia Tech (n.d.) also has an on-line edition.

The machine rate method does have advantages. It is simple and produces a single costing rate. It does make sense to have one rate over a machine's life rather than have it change, depending on the machine's age. Matthews (1942, p.55) noted:

> *"The uniform charge thus developed should be adhered to throughout the life of the machine, regardless of its age. ...It would be confusing to change continually the rate charged against a job for a given piece of equipment or to make different charges for pieces of equipment of the same size or type of different ages."*

The traditional machine rate methodology provides charge-out rates out to two (or more) decimal places. However, the methodology can provide answers that differ by dollars. Miyata and Steinhilb (1981. p.1) noted:

> *"Choosing the right cost analysis method has been difficult because of the large number of methods… If an inappropriate method is chosen or incorrect information is used in the calculations, the erroneous results may lead to poor decisions regarding the total logging operation."*

Whereas their observation was astute, Miyata and Steinhilb (1981) did not provide guidelines for selecting an appropriate costing method.

Machine rate models have a number of problems. All machine rate models are based on cost averages. They do not consider the time value of money, do not take into consideration the timing of costs, and are limited with respect to costs that they incorporate. The only rate they calculate is pre-finance and pre-tax. Machine rate models do not do a good job of accounting for financing costs. While the machine rate models can produce cost estimates for new machines, the models are difficult to adapt for used equipment, which may have partially worn replaceable parts. Machine rate models cannot do a good job of incorporating inflation and cannot be used to calculate the rate of return on investment.

Discounted cash flow methods for evaluating forest harvest equipment are not new. Butler and Dykstra (1981), and Tufts and Mills (1982) proposed discounted cash flow methodologies to evaluate machine replacement decisions.

While Butler and Dykstra (1981) propose a practical method to estimate maintenance and repairs costs, they calculate a simple average of the annual net present values, which ignores the time value of money. Tufts and Mills (1982) deal appropriately with the time value of money. However, while they propose the concept of an annual equivalent cost, they do not carry the concept through to calculating a machine charge-out rate.

Burgess and Cubbage (1989) proposed a means of evaluating yearly machine costs using cash flows on a before- and after tax basis using Lotus spreadsheet templates. They also provided comparisons with machine rate methods. However, their methodology produces a different cost rate for each year of the machine's life, which they then average to come up with a comparison with the machine rate. As with traditional machine rate models, this simple averaging of costs over time also ignores the time value of money, unless the discount rate is 0%.

Bilek (2007) introduced CHARGEOUT!, an improved model for determining the charge-out rate for a piece of capital equipment based on discounted cash flows. Like the machine rate models, CHARGEOUT! produces a single rate. Unlike machine rate models, CHARGEOUT!'s rate produces a specified rate of return. CHARGEOUT! offers many additional advantages over the machine rate methods. CHARGEOUT! incorporates options allowing:

- different depreciation rates;
- an economic life that can be different than the depreciable life;
- variable operating hours over time;
- variable repairs and maintenance schedules;
- a loan financing term that can be different than the machine's life;
- automatic inflation adjustments;
- a variable tire replacement schedule that depends on productive machine hours;
- a variable major rebuild schedule;
- the ability to calculate the rate of return on investment if given a charge-out rate;
- the ability to conduct the cost analysis before tax and finance, before tax, or after tax.

Bilek (2008) introduced an improved version of the CHARGEOUT! model that compared CHARGEOUT!'s results with those of four machine rate models. This paper includes comparisons with those models, in addition to three others.

OBJECTIVE

The overall purpose of this paper is to compare CHARGEOUT!'s results with those of traditional machine rate calculations. As a part of this comparison, different machine rate calculations are also compared and contrasted.

METHODS

The analysis was conducted in six stages:

1. Select machine rate models to compare.
2. Enter a common set of input cost and operating data.
3. Place the machine rate models into a common format and adjust their calculations so that they are comparable with each other.
4. Constrain the CHARGEOUT!! model so that its calculation is comparable with a machine rate calculation.
5. Reformulate CHARGEOUT!! so that the machine rate models run automatically within it.
6. Run the models, then use the hourly rates as calculated in the machine rate models as inputs into CHARGEOUT!! to calculate cash flows and financial summary data and to compare with CHARGEOUT!'s break-even hourly rate calculation.

First: Seven readily available machine rate models were selected to compare with CHARGEOUT!.

- "MR Calculator" – a USDA Forest Service model from the Forest Operations Research Unit.
  Available from: www.srs.fs.usda.gov/forestops/downloads/MRCalculator.xls
- Miyata (1980), Appendix B;
- Brinker, Kinard, Rummer, and Lanford (2002), Table 2;[2]
- "Machine Costing Spreadsheet," a machine rate model from Virginia Polytechnic Institute.
  Available from: http://www.cnr.vt.edu/harvestsystems/Costing.htm.
- FAO, 1992. Cost control in forest harvesting and road construction. FAO Forestry Paper 99. Rome. Especially Chapter 3: "Calculation of Machine Rates."
  Available from:
  http://www.fao.org/docrep/t0579e/t0579e05.htm#3.%20calculation%20of%20machine%20rates

[2] A version of Brinker, et al.'s model was initially available to download. However, it contained a number of mathematical errors. The authors were contacted and the downloadable version is no longer available. The version that was evaluated in this paper was constructed directly from Table 2 in their circular.

- Matthews, Donald Maxwell. 1942. Cost control in the logging industry. New York: McGraw-Hill Book Company, Inc. 374 pp. Especially pp. 53-61.
- Caterpillar Tractor Company. Caterpillar Performance Handbook. Edition 32. October. Peoria, Illinois. Especially Chapter 20: "Estimating Owning and Operating Costs."

Second: to compare and contrast the models, a common set of data was used. The data represent the costs of a logging skidder, but are not specific for any one brand or model. The following assumptions were used:

• Purchase price (including tires)	$200,000
• Salvage percentage of total purchase	25%
• Economic life	5 years
• Annual interest rate	10%
• Tire cost	$9,000
• Tire life	4,000 productive machine hours
• Tire installation cost factor	15%
• Insurance and *ad valorem* tax (% of average capital invested)	4%
• Fuel consumption (gal/hp/hour)	0.03
• Fuel cost (off-highway)	$2.75/gallon
• Horsepower	180
• Oil and Lubrication	40% of fuel cost
• Repair and maintenance	100% of straight-line depreciation
• Other consumables	$1,140
• Other consumables life	300 productive hours
• Scheduled machine hours/year	2,000
• Utilization rate	85%

Third: to put all the machine rate models in a common format in Microsoft Excel, modifications needed to be made in the machine rate models to make them comparable with each other. For example, not all the models incorporated a tire installation factor on top of the tire cost. Columns were added to show cost per scheduled machine hour (SMH) and per productive machine hour (PMH) for all models. A variable to account for miscellaneous operating costs was incorporated into all the models. The capital cost factor was modified to account for taxes if the after tax option was chosen. In addition, mathematical corrections to some of the machine rate models had to be made.

Fourth: a new version of CHARGEOUT! was constructed for this analysis.

Fifth: a scenario was constructed so that CHARGEOUT!s cost calculation would not be considering any information that the machine rate models could not incorporate. CHARGEOUT!s constraints follow:

- CHARGEOUT!s cost calculation was set to "Before tax and finance."
- New equipment was assumed (no major overhaul, tire life and cost equal to new tires).
- Loan was ignored.
- Only one compounding period per year for interest charges.

- Inflation was set at 0%.
- State and federal income taxes were ignored.
- Tax loss treatment variable was ignored.
- IRS depreciation rates were ignored.
- Section 179 deduction was ignored.
- Special first-year depreciation allowance was set at 0%
- Ad valorem (property) tax valuation basis was set as average capital invested.
- Maintenance expenses were included with repairs expenses and the maintenance expense variable was set to return $0.
- Repairs expenses were "Estimated" as a constant percentage of straight-line depreciation.
- Engine oil was based on "Fuel cost."
- Other variable costs per scheduled hour were $0.
- Major equipment rebuild cost was set at $0.
- The machine would be scheduled for a constant 2,000 hours/year for five years at a constant utilization rate of 85%.
- All cost and revenue sensitivity factors were set at 100%

Sixth: the hourly rates that were calculated by CHARGEOUT! and the machine rate models were then put into CHARGEOUT! to use its discounted cash flow features to determine the net present values and internal rates of return that would be earned if those machine rates were charged. The results were compared and contrasted.

RESULTS

The results of the calculations in terms of charge-out rates per scheduled machine hour are shown below (Table 1).

Table 1. Summary before tax and finance machine costs per scheduled machine hour ($/SMH) under CHARGEOUT! and seven machine rate models for sample skidder data

		------------------------- Machine rate models -------------------------					
	ChargeOut!	MR Calculator	Miyata (1980)	Virginia Tech	Matthews (1942)	Brinker, et al. and FAO (1992)	Caterpillar (2001)
Ownership and other fixed costs	$ 25.08	$ 25.10	$23.52	$ 24.80	$ 23.39	$ 24.80	$ 22.37
Variable operating costs	36.82	35.28	37.20	35.85	37.07	38.10	38.10
Total $/SMH	$ 61.90	$ 60.38	$60.72	$ 60.65	$ 60.45	$ 62.90	$ 60.47

Points to note:

- If the actual data conform to the assumptions built into the machine rate method (e.g., average costs, constant operating hours, constant repairs and maintenance costs, etc.), then the machine rate methods all provide approximations of hourly costs that are not substantially different than CHARGEOUT!'s rate.
- Although the rates are close to the CHARGEOUT! rate, none of the machine rate methods equal the rate determined using the discounted cash flows.
- Some of the machine rates are shown in red to highlight charge-out rates from methods that would return less than the desired rate of return on investment.
- Brinker, et al. and the FAO (1992) returned the same charge-out rates.

The net present values and internal rates of return that would be earned if the modeled rates were charged are shown below (Table 2):

Table 2. Summary before tax and finance net present values and internal rates of return under CHARGEOUT! and seven machine rate models for sample skidder data

		------------------------- Machine rate models -------------------------					
	ChargeOut!	MR Calculator	Miyata (1980)	Virginia Tech	Matthews (1942)	Brinker, et al. and FAO (1992)	Caterpillar (2001)
NPV @ 10% nominal	$ -	$ (11,229)	$(8,623)	$(9,169)	$(10,670)	$7,890	$(10,571)
IRR	10.0%	7.8%	8.3%	8.2%	7.9%	11.6%	7.9%

As expected, CHARGEOUT!'s net present value was $0 and the internal rate of return was exactly equal to the required rate of return. That was not the case with any of the machine rate models.

If the problem is varied slightly…

- Financial gearing is 40% with a 4-year fixed-rate loan at 7.00%;
- Federal income taxes are 35% and state income taxes are 10% with a flow-through tax treatment;
- Double-declining balance depreciation is used with a Section 179 write-off of $250,000;
- The contractor is subject to self-employment tax;
- Inflation is 3%;
- The salvage value and charge-out rate are both indexed to inflation;
- The desired charge-out rate is one that will make the after tax net present value equal to $0.

…these variables cannot be incorporated into the machine rate calculations. Under these conditions, the break-even charge-out rate, which is the rate that will produce an after tax net present value equal to $0, drops to $58.01.

Increasing maintenance and repairs later in the machine's life, one-off overhaul costs, etc. would also impact the break-even rate but cannot be incorporated into any machine rate method.

CONCLUSIONS

- The machine rate methods all provide reasonable approximations of the cost of running new equipment. However, their rate calculations will not return the specified return on investment. In addition, they are quite limited. They do not incorporate a number of important costs. They are not easily modified to cost out used equipment, and they cannot incorporate factors such as variable operating hours or non-constant maintenance and repairs costs. The machine rate method's use of average costs can lead to misleading answers if those costs represent items that make up a large percentage of the total costs.
- Reliance on the machine rate method can lead to either over- or underestimation of actual machine owing and operating costs.
- CHARGEOUT! is a flexible machine costing methodology that incorporates variable cost schedules, variable operating hours, inflation, financing, and taxes in a discounted cash flow framework that returns a single charge-out rate that will return exactly the specified rate of return. Alternatively, the framework can be used to determine the net present value and internal rate of return that will be earned on any specified charge-out rate.

DISCUSSION

The machine rate method was an innovation in 1942 when Matthews published the method for approximating machine costs, and although there have been advancements, the methodology is still an approximation. However, machine rate methodologies are very limited in terms of the data, types of costs, and types of problems that they can incorporate. In addition, incorporating the rates determined by machine rate models into job bids could lead to over- or underestimates of costs, if the objective is to achieve at least a minimum specified rate of return. CHARGEOUT! provides the power and flexibility needed to calculate accurate machine costs.

If one complicates the costing problem by incorporating inflation, using IRS-approved depreciation rates under the modified accelerated cost recovery system (MACRS) and Section 179 write-offs, purchasing a used piece of equipment with partially used tires and an expected major engine rebuild say in year 2, with a loan that is shorter than the machine's expected economic life, then the machine rate models cannot handle the variables. CHARGEOUT! easily incorporates these complexities. In addition, CHARGEOUT! handles variable scheduled operating hours, productivity rates, and uneven maintenance, and repairs costs.

Machine rate models can easily provide misleading answers to "What-if" questions. For example, if annual scheduled operating hours increase, one would expect maintenance and repairs costs to increase. However, several machine rate models will show repairs and maintenance costs as a set percentage of annual depreciation so as the operating hours increase, the fixed cost per operating hour decreases in these models. Such modeled decreases in maintenance and repairs costs because of increases in operating hours are not likely to be reflected in actual practice.

Although it may not be possible or practical to charge the rates calculated by CHARGEOUT!, the information provided by this model should enable contractors to make better and more informed bids and should help with capital equipment utilization and acquisition decisions.

When Matthews published his machine rate method, a new Caterpillar D6 logging tractor cost $4,100 (June 1939 dollars), which would be worth $62,742 in today's dollars. Today, a used 2008 Caterpillar D6K-XL is being offered at $170,000 (clevelandbrothers.com, n.d.). Logging equipment is expensive. With automated systems, it is becoming more capital intensive. And skyline and high-lead equipment is even more costly. As capital equipment becomes a larger portion of a contractor's total expenses, the accuracy of capital equipment costing models becomes more critical to the operation's total success or failure.

While CHARGEOUT! is more powerful and flexible and its results are superior to those of machine rate models, any financial model is no more than an aid to decision-making, and many other factors (e.g. supply and demand in the marketplace, desire to provide service to a long-term client, the difficulty of the terrain, etc.) will affect a contractor's financial decisions. And while CHARGEOUT! does not guarantee success, it does provide a better benchmark on which to base capital equipment costing decisions.

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Developing a Decision Support System to Optimize Spatial and Temporal Fuel Treatments at a Landscape Scale

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Abstract

There is a recognized need to apply and maintain fuel treatments to reduce catastrophic wildland fires in the United States. Forest managers must establish priorities for where, when, and how to apply hazardous fuel reduction treatments, yet they are faced with limited budgets, narrow prescription-burning days, air quality issues, and effects on other critical forest resources. A number of models and decision support systems have been developed to address different aspects of fuel treatments on a landscape, but no one model adequately handles the strategic scheduling of fuel treatments that simultaneously considers 1) the spatial and temporal changes of fuel treatment effects on a landscape, and 2) the economics of fuel treatments as well as other operational constraints. In order to fill this critical gap, a decision-support system, called OptFuels, is in development that builds linkages between the existing fire behavior, vegetation simulation, and land management planning models. This system is designed to optimize spatial and temporal location of fuel treatments in the way that landscape-level fuel management effects are maximized and maintained over time while satisfying given budget and operational constraints. Upon completion of the system, OptFuels is expected to facilitate analyzing effective spatial and temporal fuel management strategies and provide valuable information to land managers who are searching for the most cost effective way of applying fuel treatments in their forests.

Introduction

There is a recognized need to apply and maintain fuel treatments to reduce catastrophic wildland fires in the United States. The Healthy Forests Restoration Act of 2003 mandates actions to identify and inventory priority areas. Treating all of the 81 million hectares of federal land in the US considered at risk from fire (Schmidt et al. 2002) would be costly and impractical. Forest managers faced with limited budgets, burning windows, air quality issues, and effects on other critical forest resources must establish priorities for where, when, and how to apply new and maintenance fuel treatments. Science-based yet field applicable guidelines to strategically maintain fuel treatments on landscapes should be incorporated into treatment design to reduce catastrophic fire and restore ecosystem health over time.

A number of models and tools have been developed and extensively validated for addressing the effects and effectiveness of fuel treatments from different perspectives and geographic scales. For example, FARSITE (Finney 1998) and FlamMap (Finney 2006) are able to compute fire behavior characteristics at a landscape scale. However, neither temporal effects of treatments nor maintenance scheduling are included in either of these models. FVS-FFE (Reinhardt and Crookston 2003) has the ability to model stand-level fuel and vegetation dynamics, but it does not simulate the spread of fires between stands. As an economic optimization tool, MAGIS (Multiple-resource Analysis and Geographic Information System; Zuuring et al. 1995, Chung et al. 2005) has the ability to optimize forest treatments spatially and temporally in the presence of multiple objectives and constraints, but no fire spread logic exists in the system.

The objective of this ongoing study is to integrate existing fire behavior, vegetation simulation, and land management planning tools into one decision support system that supports long-term fuel management decisions. The system, called OptFuels, builds on the existing land management optimization tool (MAGIS), while incorporating FFE-FVS and FlamMap to analyze spatial and temporal effects of treatment activities. This system is designed to optimize spatial and temporal location of fuel treatments in the way that landscape-level fuel management effects are maximized and maintained over time while satisfying given budget and operational constraints. The release version of OptFuels will be available in 2010. This paper introduces the system design and development methods.

System Development Methods

We used the existing MAGIS framework with proper modifications in the development of OptFuels. The existing MAGIS system has the capacity to set up the vegetative model, incorporate stand and treatment unit GIS data, set up problem parameters (e.g., management objectives and resource constraints), build the matrix of costs and effects of potential treatments, optimize resource schedules and display solution information (Zuuring et al. 1995, Chung et al. 2005). We combined MAGIS with the FFE-FVS to simulate fuel dynamics and stand-level treatment effects over time and FlamMap, a raster-based fire behavior model, to evaluate landscape-level effects of combined fuel treatments in each time period (Figure 1). For this integration, we have developed data transfer interfaces between models and modified the current MAGIS heuristic solver to evaluate spatial and temporal fuel treatment effects and schedule long-term fuel management activities.

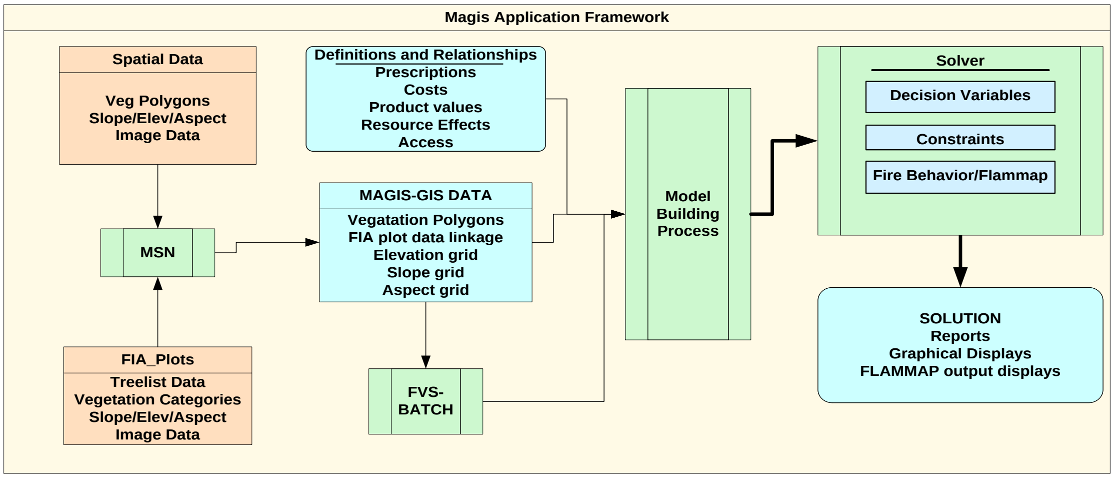

Figure 1. Data transfer interfaces among models

<u>Interface between MAGIS and FFE-FVS</u>

Using the current MAGIS user-interface, stands can be grouped depending on their attributes, such as forest type, region, ownership, slope, current fire hazard, and others. Users can develop different silvicultural prescriptions (fuel treatments) that can be applied to each group of stands. A data transfer interface between MAGIS and FFE-FVS has been developed to 1) identify all the treatment-timing combinations available for each stand, 2) convert silvicultural prescriptions into the FVS readable format, and 3) run FFE-FVS in a batch mode. Using FFE-FVS requires tree list data for individual stands. Using the k–Nearest Neighbor (kNN) imputation process using the Random Forest method as described by Crookston and Finley (2008) can be one way to associate USFS Forest Inventory and Analysis (FIA) stand inventory data with every polygon in the landscape of interest and provide FVS-ready tree lists for each polygon. FFE-FVS are then run for each relevant treatment and timing option on each polygon and the results are stored in a relational database.

<u>MAGIS and FlamMap</u>

In OptFuels, we measure the effectiveness of a fuel treatment in terms of its contribution to the reduction of fire spread rates across a landscape under a specific set of weather conditions. A set of candidate fuel treatment units developed by the MAGIS heuristic solver (described in the following section) collectively form a spatial pattern with diverse fuels and topographic conditions. The effectiveness of the spatial pattern is then measured by the estimated minimum fire arrival time at each pixel on the landscape. With this procedure, a fuel treatment unit, which highly contributes to the reduction of fire travel time across the landscape (e.g. treatment units along the minimum fire travel routes) will receive a higher probability for being selected in the final treatment schedule, while those which contribute little to the landscape-level effects will likely be excluded from the final solution due to other resource constraints. FlamMap (http://fire.org/) is used to compute fire behavior values (e.g. flame length) and minimum travel time (MTT) for each pixel for an entire landscape using data layers consisting of fuels, topography, and weather conditions. An automatic data transfer interface has been developed in the heuristic solver to run FlamMap from MAGIS that 1) reads fuel characteristics developed by

FFE-FVS for each stand for each time period based on a given treatment schedule, 2) mosaic the stand-level fuel characteristics to compose raster-based fuel maps over a landscape for each time period, and 3) transfer fuel maps to FlamMap and run the program with the MTT algorithm option in a batch mode. Fire behavior characteristics developed by FlamMap are then delivered back to MAGIS by the interface and used in evaluating the selected fuel treatment schedule.

Heuristic Solver for OptFuels

Scheduling spatial and temporal fuel treatments involves a large amount of data and an enormous number of solution alternatives, and thus becomes a large combinatorial optimization problem. The current MAGIS heuristic optimizer (Chung et al. 2005) uses the Simulated Annealing (SA) heuristic (Kirkpatrick et al. 1983) to optimize resource management schedules while considering the economics (cost and benefit) of management activities, resource constraints, and operational feasibility. SA is a Monte Carlo search method that uses a local search in which a subset of solutions is explored by moving from one solution to a neighboring solution. In forestry, SA has been widely used to solve large spatial harvest scheduling problems (Öhman and Eriksson 1998, Boyland et al. 2004).

For OptFuels, we have modified the current SA algorithm in MAGIS so that the optimizer automatically 1) develops a variety of fuel management schedules, 2) evaluates each alternative schedule in terms of minimum expected loss values across a landscape, associated costs and revenues, and operational feasibility of treatments, and 3) finally selects the best spatial and temporal arrangement of fuel treatments that produces maximum treatment effects over time while meeting given resource and operational constraints. Specifically, the OptFuels heuristic solver is designed to generate and evaluate alternative fuel management schedules using the following steps.

Step 1: Start with an initial solution that does not include any treatment activities (no action) across a landscape of interest during the entire planning periods (up to 5 time periods).

Step 2: Modify the previous solution by randomly selecting a certain number of management units (polygons) and altering the previously assigned treatment-timing combinations to create a new solution (for example, changing from no action during the planning horizon to mechanical thinning in the first period).

Step 3: Evaluate the solution by 1) running FlamMap and the MTT algorithm suggested by Finney (2002) to compute fire arrival time and flame length at each pixel, and then 2) calculating expected loss values from the landscape using user-defined probability of burn periods and flame length categories.

Step 4: Accept or reject the new solution based on the SA solution acceptance rules.

Step 5: Repeat Steps 2 through 4 until the SA stopping criterion is met.

In this procedure, we assume ignition is placed in user-defined locations and the environmental conditions such as wind speed and direction and spatial arrangement of fuel moistures are constant. The solutions can be also evaluated in terms of management costs, benefits from output products (e.g., timber), and road accessibility. Among alternative solutions (fuel management schedules) evaluated, the solution that maintains the minimum expected loss value from the entire landscape (maximum treatment effects) over time and meets budget and operational constraints is selected.

Concluding Remarks

Development of the data transfer interfaces among the MAGIS, FlamMap, FVS-FFE models and the heuristic solver for OptFuels has been completed. Extensive testing of the system and applications development are currently in progress. Major hurdles we have encountered while applying the system to a large landscape include 1) the lack of polygon-level forest inventory data and spatial information, and 2) a large amount of computation time required by the solver due to the large scale and complexity of the scheduling problem. To substantially reduce computation time, we have been investigating parallel programming techniques and applying them to the heuristic solver. Upon completion of the system, OptFuels is expected to facilitate analyzing effective spatial and temporal fuel management strategies and provide valuable information to land managers who are searching for the most cost effective way of applying fuel treatments in their forests.

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THE BENEFITS AND CONSEQUENCES OF A VIBRANT WOOD-TO-ENERGY MARKET

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ABSTRACT -- Wildfires throughout the US, especially in the West, have led to interest in woody biomass harvesting. Concurrently, the emerging wood-to-energy market has expanded and in some areas provides a market for biomass removed during treatment. As a result, there is concern that wood-to-energy companies will compete with forest industry for roundwood. If this occurs, the southern pulp/paper industry, which has lost 15% of its mills and 10% of its production over the past decade, could be further weakened. Because of the need for a robust forest products industry and a market for small-diameter stems, it is essential that the biomass energy and forest products industries coexist. Therefore, this paper provides examples of how a vibrant wood-to-energy market could improve forest health and management. In addition, through an analysis of price trends in pulpwood and fuel chips as well as a comparison of the price of energy from coal, natural gas, and wood, this paper addresses current competition and the conditions under which future competition may occur between energy companies and forest industry in the South. Results of this study indicate that a vibrant wood-to-energy market can reduce the cost of forest fuel reduction treatments, reduce harmful emissions from power plants, and stimulate rural economies. Currently, widespread competition for resources between forest industry and energy companies is non-existent in the South, but depending on government policies and advances in conversion technologies, future competition is possible.

Introduction

Wood is one of the oldest fuel sources in existence. However, over the past two centuries industrialized countries have increasingly relied on coal, oil, and other hydrocarbons for energy production. In the 1970s and early 1980s it was thought that the use of wood for energy would rapidly expand and energy producers would compete for resources with the forest products industry (Koning and Skog, 1987). This concern proved to be unfounded as low prices for fossil fuels squelched much of the desire to produce energy from wood.

A quarter century later, the same concerns have resurfaced. The price of fossil fuels has increased recently and the Energy Information Administration predicts that global demand for energy will increase by 50% between 2005 and 2030 (EIA, 2008). This fact, along with concerns about greenhouse gas emissions and energy security, has renewed interest in producing energy from wood. Biomass is already the largest source of renewable energy in America, and 75% of the biomass used for energy comes from forests (Perlack et al., 2005). In 2005, 142 million dry tons of woody biomass was converted to energy and it is estimated that an additional 226 million dry tons of woody biomass could be produced sustainably.

Benefits of using wood for energy include: reduced emissions of heavy metals and CO_2 (Bergman and Zerbe, 2004), improved energy security (Zerbe, 2006), and stimulation of rural economies (Gan and Smith, 2007; Perez-Verdin et al., 2008). In addition, the wood-to-energy market may provide a market for small-diameter and other currently non-commercial stems which will reduce the cost of site preparation and fuel treatments (LeVan-Green and Livingston, 2001; Polagye et al., 2007). However, there are concerns that a large scale expansion of the wood-to-energy market may increase raw material costs for the forest products industry (Bowyer, 2008). Therefore, the objectives of this study are to examine the potential benefits of a vibrant wood-to-energy market, determine the extent of current competition between energy companies and forest industry in the South, and identify the circumstances under which competition may occur in the future.

Benefits of Wood-to-Energy

Forest Health Benefits

Between 1960 and 1998, there were only six years in which wildfires burned more than five million acres (Figure 1). However, more than five million acres have burned in eight of the past ten years. In fact, the average acreage burned over the past five years has been over 8 million acres. Suppression costs have risen to the point that the U.S. Forest Service now spends nearly half of its discretionary budget on wildland fire management (Kashdan, 2009). Recent trends in wildfire acreage, along with increasing suppression costs, underscore the need for treatments which reduce hazardous fuels.

In 2001, more than 73 million acres of land managed by the U.S. Forest Service had lost ecological integrity because of changes in vegetative structure and composition (LeVan-Green and Livingston, 2001). Since that time all federal land agencies combined have treated 29 million acres nationwide (HFR, 2009), meaning there is still a substantial area in need of treatment. A major impediment to fuels treatments is the high cost, especially in areas requiring mechanical treatments (Bolding and Lanford 2005; Bolding et al. 2009). For example, Arriagada et al. (2009) found the average per acre harvesting cost for fuel treatments in 12 western states varies from $620 to $3,535 per acre depending on the equipment used. These estimates are significantly higher than the estimates provided by LeVan–Green and Livingston (2001) who suggest the cost of thinning to be $150-$550 per acre, or $70 per dry ton. Rummer et al. (2003) estimate the cost of mechanical treatment can vary between $35 and $1,000 per acre. Of course, if there were a market for the biomass removed by fuel treatments, some of these costs could be offset.

An expansion of the wood-to-energy industry could provide such a market. Polagye et al. (2007) examined using biomass removed during fuel treatments for 1) wood chips, 2) wood pellets, 3) bio-oil, and 4) methanol. This study found that none of these options allowed the fuels treatments to pay for themselves. However, under most circumstances, each of these options reduced the cost of treatment with the production of wood chips for co-firing in power plants the most economical option followed by pellet production.

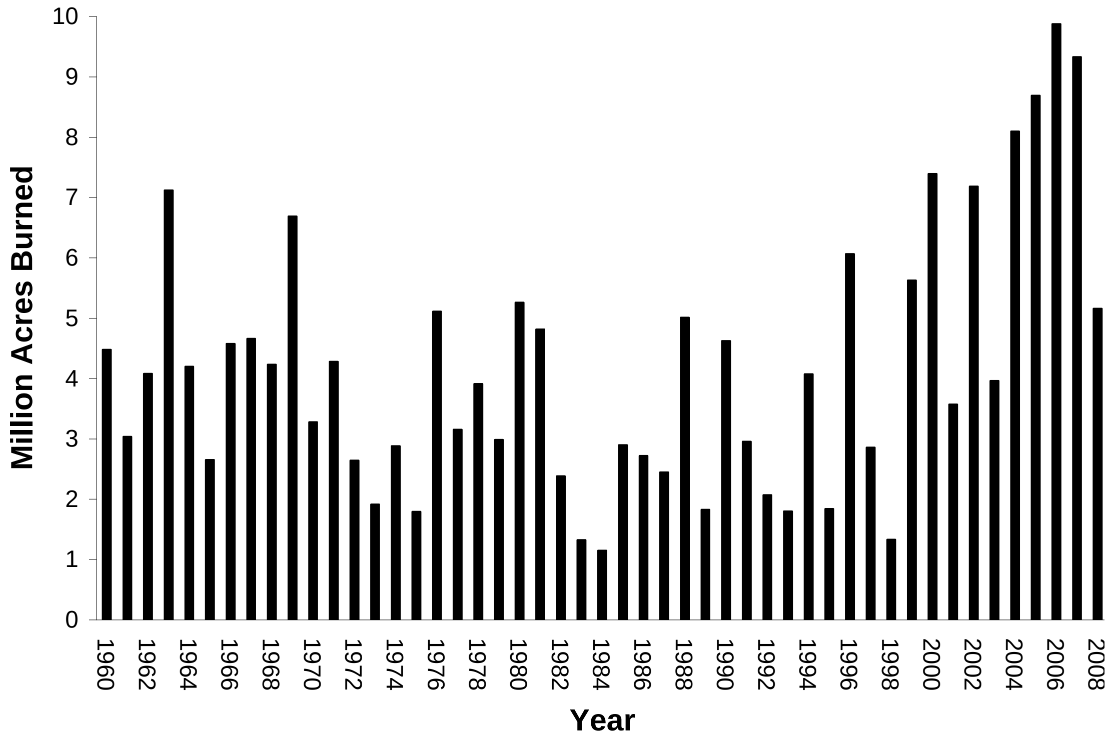

Figure 1: Acres burned by wildfire in the United States from 1960-2008 (NIFC, 2009; NOAA and NCDC, 2009).

Socioeconomic Benefits

Studies show that the use of wood for energy can have a significant positive impact on rural economies. This is of particular importance in the South and West which have a large proportion of rural counties. In Mississippi, the construction and operation of a cellulosic ethanol plant producing 52 million gallons per year would create 908 jobs and generate $150 million in gross economic output (Perez-Verdin et al., 2008). Likewise, the conversion of a 100 MW coal-fired power plant to a wood-fired facility would create 281 jobs and generate $64 million of gross economic output. Similarly, in East Texas, utilizing 1.3 Mt of harvesting residues would create 150 jobs associated with electricity generation and 260 jobs associated with residue procurement (Gan and Smith, 2007). Electricity generation would create $183 million in gross economic output and residue procurement would generate another $63 million. In addition, the recovery of these residues would decrease site preparation costs by $81-$101 per acre, for an annual savings of $7.3-$9.1 million. The displaced carbon as a result of this recovery is valued at $9 million.

In addition to stimulating rural economies and improving forest health, using wood to produce electricity could allow the South to displace coal and other non-renewable fuels. Currently, the South produces 75% of its electricity from coal and natural gas (Figure 2), and replacing some of this capacity with wood could reduce harmful emissions in the case of coal and perhaps reduce energy costs in the case of natural gas.

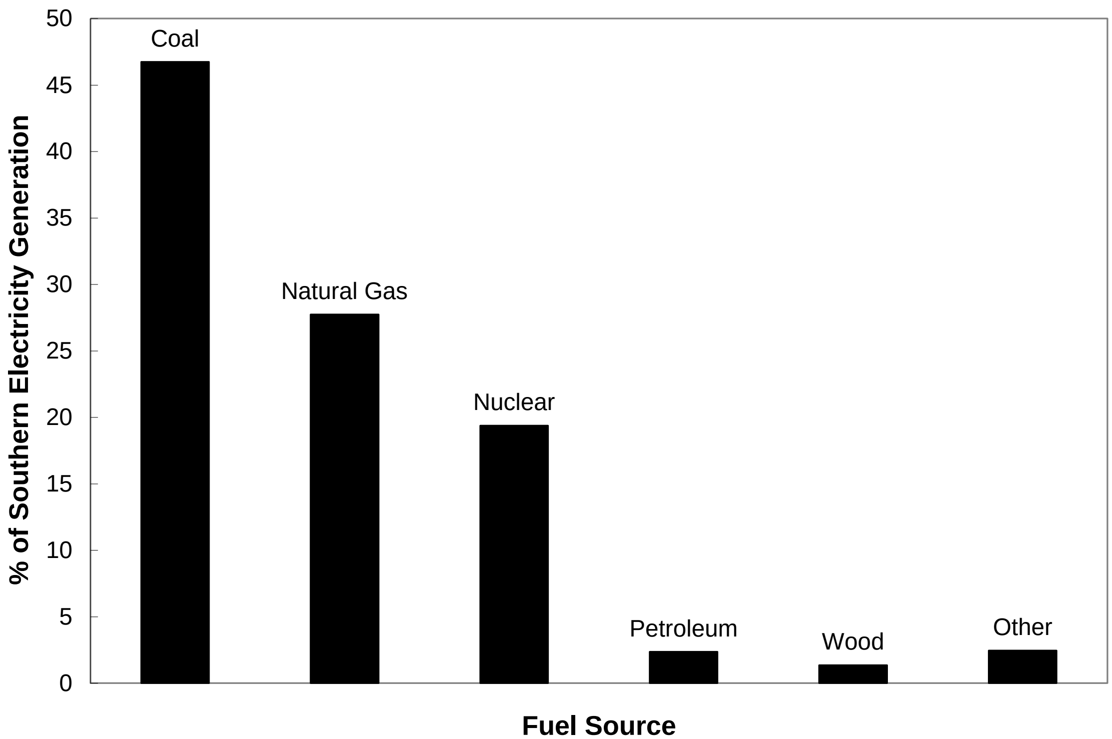

Figure 2: Percentage of electricity produced from coal, natural gas, nuclear power, petroleum, wood, and other sources in the thirteen southern states in 2007 (EIA, 2009).

Consequences of a Vibrant Wood-to-Energy Market

Using wood for energy at a small scale benefits the entire wood supply chain. Landowners benefit as site preparation costs are reduced through greater utilization. Loggers profit from an additional product to harvest and transport. Wood-to-energy at a small scale benefits forest industry by providing a market for the by-products of manufacturing such as sawdust and black liquor. On the other hand, an expansion of the wood-to-energy market could have adverse consequences for the pulp and paper industry.

Several recent studies suggest that a large expansion of the wood-to-energy market could put upward pressure on raw material prices. Perlack et al. (2005) suggest that at high oil prices and low pulp prices, pulpwood and other small diameter materials may become available for energy production. Others suggest that the use of roundwood by energy companies would drive up the price, making it impractical for energy production, unless there is a significant decline in the pulp and paper industry (La Capra Associates, 2006). In Sweden, there is a wood energy demand level at which it becomes more economical to produce energy from roundwood than from residues, and if this demand level is reached it will put upward pressure on stumpage prices (Lundmark, 2006). In North Carolina, South Carolina, and Virginia if forest residues are exhausted there is likely to be a subsequent spike in roundwood prices which may eliminate marginal wood users (Galik et al., 2009). Likewise, expansion of the wood-to-energy market in the northeast is likely to create competition between energy companies and pulpmills (Benjamin et al., 2009).

Current Competition

In order to determine whether or not competition is currently occurring between the forest products and wood-to-energy industries in the U.S. South, we investigated three factors which serve as indicators of competition: the relative cost of fuel chips and pulpwood, recent pulpwood prices, and the relative energy cost of wood, coal, and natural gas. These three variables were analyzed using data from Timber Mart-South and the Energy Information Administration.

In order for a logger to profit by chipping pulp-sized material and delivering it to an energy facility rather than a pulpmill, the price of fuel chips must equal the price of roundwood pulpwood minus the difference in harvesting and transportation costs. A logger's costs are reduced when chipping whole trees compared to producing roundwood because chipping requires less material handling and processing. Chipping whole trees eliminates the need for sorting, topping, delimbing, and bucking at the landing which reduces operating costs. In addition, labor costs are reduced because fewer machines are operated and less time is spent processing at the landing. For example, assume it costs $2 per ton less to chip whole trees than it does to produce roundwood. In this case, a logger could accept up to $2 per ton less from an energy facility than a pulpmill assuming equal hauling costs. In order to determine whether or not such conditions exist, fuel chip prices and roundwood pulpwood price averages for the southeastern US were compared from the second quarter of 2006 through the second quarter of 2008 using data from Timber Mart-South (TMS, 2006-2008) (Table 1). We chose this period for comparison because fuel chip price data was available for multiple states during this period.

To date, the price of roundwood pulpwood has remained well above the price of fuel chips, indicating that energy facilities are not competing with forest industry. The average difference in price between pine pulpwood and fuel chips between the second quarter of 2006 and the second quarter of 2008 was $8.25 and ranged from $4.45 to $12.56 (Table 1). For hardwood, the average difference was $6.57, ranging from $3.23 to $8.49. The difference may be slightly less because fuel chip prices were reported as FOB mill/woods, meaning the price is an average calculated using both delivered and on-board truck costs. Nonetheless, it is apparent that presently there is not widespread competition between wood-to-energy companies and forest industry.

If energy companies were competing with forest industry for roundwood, one would expect to see a spike in roundwood pulpwood prices. Delivered pulpwood prices have been on a generally upward trend, at least until recently (Figure 1); however, a portion of the increase can be explained by rising transportation costs due to high fuel costs. When transportation costs are taken into account, pulpwood prices appear to be on a stable upward trend, without the spike in prices one would expect if energy companies were competing for roundwood (Galik et al., 2009)

A factor which may influence whether or not energy companies compete with forest industry for roundwood is the relative price of coal, wood, and natural gas. The delivered price of coal varies considerably, even within the Southeast, and therefore some states may be more willing to produce electricity from wood than others (Table 2).

Table 1: Pine and hardwood pulpwood delivered price averages ($/ton) for the Southeast, fuel chip price averages ($/ton) for the Southeast, and the price difference between pulpwood and

fuel chips from the second quarter of 2006 through the second quarter of 2008 (TMS, 2006-2008).

Quarter	Pine pulpwood ($/ton)	Pine fuel chips[1] ($/ton)	Difference ($/ton)	Hardwood pulpwood ($/ton)	Hardwood fuel chips[1] ($/ton)	Difference ($/ton)
Q2 2008	26.48	19.62	6.86	26.25	20.45	5.80
Q1 2008	27.49	18.69	8.80	26.08	20.02	6.06
Q4 2007	26.97	16.14	10.83	24.88	16.39	8.49
Q3 2007	24.66	17.69	6.97	24.18	17.70	6.48
Q2 2007	24.56	15.33	9.23	23.47	15.37	8.10
Q1 2007	25.47	12.91	12.56	23.35	16.08	7.27
Q4 2006	24.79	17.56	7.23	23.22	17.75	5.47
Q3 2006	23.65	16.34	7.31	23.12	14.90	8.22
Q2 2006	22.91	18.46	4.45	21.98	18.75	3.23
Average	25.22	16.97	8.25	24.06	17.49	6.57

[1] Fuel chip prices are reported as FOB Mill/Woods, meaning these prices are averages calculated using both delivered and on-board truck prices.

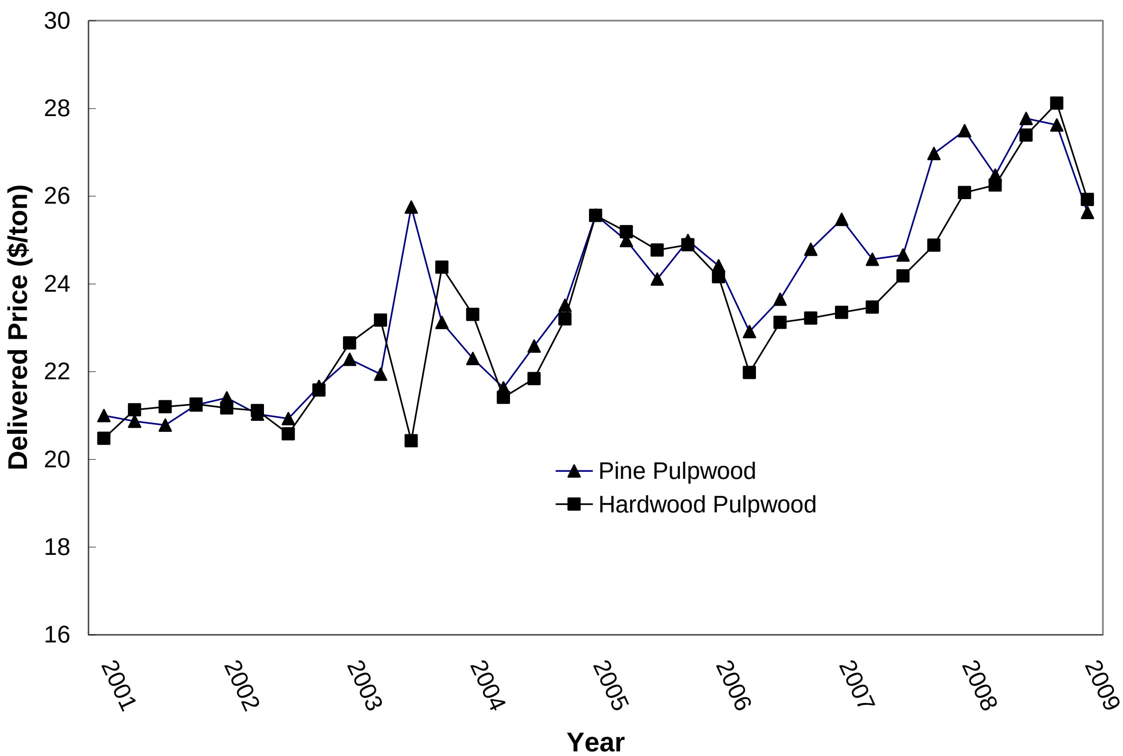

Figure 3: Pine and hardwood pulpwood delivered prices for the Southeast from the first quarter of 2001 through the first quarter of 2009 (TMS, 2001-2009).

Wood fuel chips are cost-competitive with natural gas, but only competitive with coal in the South Atlantic region (Table 2). In order for wood to be competitive with coal, wood will need to cost between $18 and $19 per ton in the South Atlantic region, between $14 and $15 in the East South Central region, and between $8 and $9 in the West South Central region, assuming coal prices remain near their 2006-2007 levels. Obviously, energy companies in the South Central region will not compete with forest industry for wood while wood is three times as expensive as coal on an energy basis. However, government mandates such as renewable portfolio standards (RPS) which require utilities to produce a certain percentage of electricity from renewable sources may force utilities to use energy sources which are more expensive than coal. Currently, Virginia, North Carolina, and Texas are the only southern states with renewable portfolio standards (DSIRE, 2009).

Based on current market prices for coal and the current conversion technologies for cellulosic ethanol, it is unlikely than energy companies will compete on a broad scale with forest industry for wood in the near future. However, localized markets may experience inter-industry competition (Bowyer, 2008).

Table 2: Comparison of the delivered price of coal (public utilities), wood, and natural gas on an energy basis (EIA, 2009; TMS, 2006-2007). Coal prices are the average for the said region, wood prices are the average yearly price for the southeast, and natural gas prices are the average for the U.S. The following conversion factors were used in our calculations: coal contains 11,500 Btu/lb, natural gas contains 930 Btu/ft^3, and bone dry wood fuel contains 7,600 Btu/lb (assumed 50% moisture content for delivered wood) (ORNL, 2009).

Fuel Source	Delivered Price ($/million Btu)	
	2006	2007
Coal (South Atlantic[1])	2.44	2.52
Coal (East South Central[2])	1.81	1.92
Coal (West South Central[3])	1.02	1.13
Pine pulpwood	3.15	3.34
Pine fuel chips[4]	2.27	2.04
Hardwood pulpwood	3.04	3.15
Hardwood fuel chips[4]	2.15	2.16
Natural gas	7.65	7.86

[1] South Atlantic region includes DE, DC, FL, GA, MD, NC, SC, VA, and WV.
[2] East South Central region includes AL, KY, MS, and TN.
[3] West South Central region includes AR, LA, OK, and TX.
[4] Fuel chip prices are reported as FOB Mill/Woods, meaning these prices are averages calculated using both delivered and on-board truck prices.

Future Competition

The conversion of wood to cellulosic ethanol has yet to be demonstrated on a commercial scale and cellulosic ethanol may never be cost-competitive with fossil fuels (Hamelinck et al., 2005). Wood pellets are, for the most part, produced from industrial wood waste such as sawdust, shavings, or ground wood chips (Peksa-Blanchard et al., 2007). Therefore, the most likely source of competition for forest industry is electricity generating companies in states with renewable portfolio standards, or perhaps nationally if a national RPS is instated. However, there is considerable debate over the definition of woody biomass as it relates to renewable portfolio standards. For example, the Virginia legislature capped the amount of wood which can count toward its renewable portfolio goal at 1.5 million dry tons (Public Law VA HB 1994). In this case, beyond 1.5 million dry tons, wood must be cost-competitive with non-renewable energy sources for facilities to consider its use.

Another factor which may encourage competition between energy companies and forest industry companies are tax incentives and subsidies for renewable energy production which may or may not be available to forest industry companies. For example, Virginia has a $0.10 per gallon incentive for locating a biofuels plant in Virginia (VAMME, 2007). If a wood using cellulosic ethanol plant were built in Virginia this incentive would equate to a $4 per ton subsidy on delivered wood, enabling the energy company to pay 15% less than a pulpmill for its raw material.

Conclusion

If the wood-to-energy market expands it could reduce the cost of fuel treatments (Polagye et al., 2007), stimulate rural economies (Perez-Verdin et al., 2008), and provide a new product class for forest industry (Winandy et al., 2008). On the other hand, a large scale expansion of the wood-to-energy market could increase raw material costs thereby further weakening the southern pulp and paper industry which has lost 15% of its mills and 10% of its production since the mid 1990s (Johnson and Steppleton, 2008). However, large quantities of forest and urban residues indicate there is room for wood-to-energy expansion without competion with the forest products industry (Perlack et al., 2005; Galik et al., 2009).

This research indicates that widespread competition between forest industry and energy companies is currently non-existent in the Southeast. There is a substantial difference in price between fuel chips and roundwood pulpwood, and increases in pulpwood prices appear unrelated to the wood-to-energy market. The relative prices of coal, wood, and natural gas suggest that fuel chips are competitive with natural gas and coal in the South Atlantic region. However, in the deep South, coal is significantly cheaper than wood and natural gas on an energy basis, and apart from government mandates coal is likely to remain the electricity feedstock of choice.

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Transportation of Woody Biomass Using Roll-Off Containers

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Abstract
One of several factors limiting the utilization of woody biomass produced during forest operations is the on-road transportation of slash or hog fuel over rough woods roads. The poor horizontal and vertical alignment of most woods roads in the western US limits the types of vehicles that can traverse these roads to smaller, more maneuverable vehicle configurations. One option is the use of roll-off containers in conjunction with hook-lift equipped trucks and trailers. This paper will review the use of roll-off containers in two production-scale trials in and around West Yellowstone, Montana and North Bend, Oregon.

Introduction

As we look toward greater utilization of forest residues for energy production, questions of supply, harvest, and transport arise. In the western US, a large volume of woody biomass is produced as slash created during forest treatments. However with current technology and markets much of this volume is uneconomical to remove from the forest and is left on site or is piled and burned. Many efforts are underway to examine the economics, efficiencies, and technical applications of various woody biomass harvesting and transportation options. The series of field trials discussed here deal with the on-road transportation of woody biomass.

Transportation of woody biomass is primarily limited by the horizontal and vertical alignment of forest roads typically encountered in the western US (Rawlings et al. 2004). Historically woody biomass has been transported in ground form (hog fuel) in standard on-highway chip vans which are limited to high-standard roads. Therefore other, more maneuverable means of transporting this material is needed. Options include short chip vans (eg. 35-foot long containers as opposed to the standard 55-foot containers), stinger-steered vans, and two-stage transportation.

The goal of a two-stage transportation option is two-fold: first, to transport woody biomass in the form of slash from the landing to a concentration yard using a vehicle suited to lower-standard roads with poor horizontal and vertical alignment, and second to increase the efficiency of the grinding operation by concentrating a large volume of slash from multiple landings in one area accessible to both a grinder and high-capacity vehicles (eg. chip vans) for the transportation of hog fuel to market.

This paper examines the use of roll-off bins coupled with a truck equipped with a hook-lift system to transport these bins. "Roll-off" refers to modular containers that are rolled onto and off of the haul truck by a hydraulic arm on the hook-lift (Han 2008), shown in Figure 1. This paper will discuss two field trials of the roll-off system for forest biomass transportation in the western US and will conclude with a discussion of how this system can be utilized to provide economical transportation of woody biomass.

Figure 1: Hook-lift truck unloading a roll-off bin of slash at the concentration site used in the Hebgen Lake study

Trial Sites

Production-level trials of the hook-lift system occurred near Hebgen Lake in southwest Montana during the summer of 2008 and are ongoing near North Bend, on the central Oregon coast. Both trials used the same 1989 Peterbilt Class 8 truck equipped with a Stellar 52,000 lb.-capacity hydraulic hook-lift. Roll-off bins measuring 24 feet long, 8 feet tall, and 8 feet wide (capacity of 54 cubic yards) were fabricated with a taper allowing up to three empty bins to be stacked and moved at once. While the equipment was constant between the two trials, the owner of the hook-lift truck and the lessee of the bins changed.

Hebgen Lake

At Hebgen Lake, the hook-lift truck was paired with a harwarder (forwarder modified to allow for the use of cutting heads) equipped with a hook-lift system (see Kash 2009). By utilizing a harwarder equipped with a hook-lift, slash could be picked up in the woods and placed immediately into a bin. Once back to the landing, the full bin could be offloaded, an empty bin picked up, and the cycle repeated without the harwarder having to either wait for the haul truck or unload slash onto the ground to await grinding or reload into a haul truck. The bins, therefore, eliminated the need to handle slash multiple times and the additional costs associated with this handling. With a sufficient number of bins it was hypothesized that down time would be transferred from the high cost equipment (harwarder and haul truck) to the low cost bins. Roll-off bunks were also available for the contractor to use in order to facilitate the collection and transportation of roundwood (primarily pulp and post-and-poles).

Slash from this fuel hazard reduction project was hauled by the hook-lift truck seven miles from the project site to a waste transfer site that served as a concentration yard. Here slash was unloaded from the bins by tipping the front end of the bin until the slash was in contact with the ground then driving away from the load of slash. The loads of slash remained in compact loaf-shaped piles once on the ground. With this method of unloading slash from bins there was no way to stack one load on top of another. Once the concentration yard was full, a Vemeer HG6000 (horizontal-feed grinder) was called in to grind slash directly into full-sized (55-foot containers, 30 ton capacity) chip vans. From here, hog fuel was trucked 85 miles to Rexburg, Idaho.

North Bend

At the ongoing trial outside of North Bend, Oregon, a different configuration of the same hook-lift system is used. The initial idea was to use the roll-off bins as set-out containers on the landings of whole-tree commercial logging operations as in Rawlings et al. (2004). It was found, however, that landings were generally too small for the bins to be used in this way. Instead, the hook-lift truck gets into the rotation of log trucks and, in turn, backs into the landing, unloads the roll-off bin for loading, the bin is loaded with slash and cull logs by the log loader, the bin is reloaded on the haul truck, and the slash is driven to a concentration yard with ready highway access. At least two harvest units are serviced in this way by a single hook-lift truck with one bin. Once the concentration yard is full, accumulated slash in the yard is ground into a pile. Hog fuel is loaded into chip vans using a front-end loader, taking advantage of a previously empty backhaul.

Results and Discussion

At Hebgen Lake, several inefficiencies meant that the hyphothesized benefits of the roll-off system were not realized. For one, the contractor only had two bins on site. While, on average, one cycle with the harwarder to fill one bin with slash was approximately equal to the amount of time required for the haul truck to take one full bin to the concentration yard and return to the harvest site with the empty bin, it was always the case that either the haul truck or the harwarder was left waiting at the landing. Additional bins would have helped to eliminate these delays.

In order to compare grinding efficiencies between grinding at a concentration yard versus moving a grinder in between landing piles, limited detailed time-and-motion study data was collected in November 2007 near Frenchtown, Montana. This operation utilized the same grinder as at Hebgen Lake but used short (35-foot) 20 ton capacity vans to traverse woods roads. One day of grinding yielded six loads of hog fuel from dispersed landing piles created during harvesting activities the previous summer. On average, each van took 41.7 minutes to load (range 35.8 – 48.4 minutes) for 27.3 green tons per hour ($8.19/green ton at $300/hour). At Hebgen Lake one day of grinding yielded seven loads of hog fuel, averaging 41.9 minutes per load (range 34.0 – 47.6 minutes) for 37.3 green tons per hour ($11.19/green ton). In this limited comparison, grinding efficiency increased 37% in a concentration yard versus grinding dispersed landing piles, saving $3/green ton.

During the Hebgen Lake trial, the 54-cubic yard bins hauled an average of 5.5 tons of green slash. At $80.23/hour for the truck and bins, the cost to transport slash from the harvest unit to the concentration yard in roll-off containers via the hook-lift truck averaged $9.63 per green ton (Kash 2009). For this case, the cost to transport biomass from the woods to the concentration yard was likely greater than the increased efficiency of grinding biomass from a central concentration yard.

To avoid double-handling hog fuel, the grinder loaded ground biomass directly into chip vans. This system, however, depends on a constant flow of chip vans for efficient operation. Unfortunately, this did not always occur, leaving the grinder idle for hours at a time.

The grinding operation did not utilize truck scales at the transfer facility utilized as a concentration yard. As a consequence, van loads of hog fuel leaving the concentration yard averaged 23.8 green tons in a van with a 30-ton capacity for a total of 585 tons hauled in 25 loads. By running trucks at an average capacity of 78% (range 52% – 106%) and a haul rate of $390/trip, this inefficiency added $1.00 per green ton to the transportation cost over fully-loaded vans.

By contrast, initial results indicate the North Bend trial is meeting expectations. By inserting the hook-lift truck into the log truck rotation instead of using the bins as set-out containers, the hook-lift truck spends 5-15 minutes at the landing on average. The time spent by the loader operator dealing with slash is no greater with the hook-lift bins than if the loader were instead piling slash off to the side of the landing for later burning.

As seen at the trial at Hebgen Lake, avoiding double-handling of hog fuel by grinding directly into haul trucks is efficient only when there is a constant stream of chip vans available. In the North Bend trial, chip vans delivering chips to North Bend are able to pick up hog fuel at the trial's concentration yard on their way back to Roseburg, OR. Therefore the decision was made to grind biomass in the concentration yard at one time and to grind into a pile. As trucks become available to haul hog fuel to market, a front-end loader located at the concentration yard loads hog fuel for transportation. The first round of grinding occurred late March, 2009.

Conclusions

Based on the experience of these two trials, the following recommendations can be made for future study and implementation of hook-lift technology for the transportation of woody biomass:

- The cost of transporting unconsolidated (unground) slash in roll-off bins is significant and therefore should only be undertaken when larger vehicles such as chip vans cannot access the site.
- In the limited study presented here, increase in grinding efficiency was found to be 37% by grinding at a centralized landing as compared to grinding dispersed landing piles.
- Including the hook-lift truck in the log truck rotation allowed the log loader operator to clear the landing of slash by loading the roll-off bin instead of placing slash into a slash pile off to the side of the landing. This system did not cost the logging contractor any additional time (therefore money) and served as a benefit by removing the need for a slash pile at the landing.
- The choice of grinding woody biomass directly into chip vans or into a pile for later loading and transportation must be made in light of truck availability.

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Developing Managerial Behaviours and the Indispensable Information to Do So: a Double Challenge for Forest Entrepreneurs

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Abstract

We have recently collected the hard data required to support the hypothesis that a majority of logging contractors in eastern Canada are true entrepreneurs managing complex businesses. Nevertheless, we believe that only a minority of them could be considered to be paying attention to all key business functions, which are often viewed as important criteria of performance. Not surprisingly, most of them focus primarily on the operations function. However in spite of this narrow focus, few entrepreneurs have on hand, in a timely fashion, the data and information required to conduct the analyses that would assist them in their decision-making process. Poor data collection practices contribute to this shortcoming.

The above issues were addressed within the PREFORT project at Laval University. First, a profile of the entrepreneur was obtained and used to understand why a large proportion is reluctant to assert the managerial behaviours likely to contribute to enhancing performance. Second, as long as the entrepreneur is inclined to develop his/her managerial skills, he/she will require field information that is useful, accurate, and easily analyzable so that the "right" decisions can be made. In the present context, this information, while indispensable to performance monitoring and improvement, remains elusive for entrepreneurs. Using field data from a site study and machine utilization rate, involving five entrepreneurs, each equipped with a datalogger (FERIC's MultiDAT), we describe to what extent this kind of data can be useful. The ever-present challenge of collecting valid field information in a North American context is discussed.

Key words: Forest Entrepreneur Performance – Machine utilization rate – SME management – Data collection

1. Introduction: The Forest Entrepreneur as an SME owner-manager

Despite multiple responsibilities, business risks incurred (St-Pierre, 2004), and numerous work hours, many actors in the forest products supply network question the status of the real

SME owner-manager applied to the forestry entrepreneur (FE) (Lidén, 1995a, 1995b; Bernier, 1999; Furness-Lindén, 2009). Certain FE managerial behaviours favour the arguments of those who question this status. For example, recent research in entrepreneurial performance shows that all SME owner-managers should pay attention to the functioning of their enterprise as a whole and to the multiple performance-determining factors (i.e. financing, customers, internal processes, organizational learning) (Rantanen et al., 2001). For the FE, as for several forestry researchers, the concentration of efforts at the production level (mainly productivity and reduction of operating costs) could partly explain the doubt that remains as to this status of the SME owner-manager.

From the point of view of forest harvesting operations, the special environment in which the FE evolves seems to influence this reality as well, and provide munitions to those who question it. Among the significant elements characterizing a good number of FE, we can mention dependence on a sole customer (client), lack of choice of harvesting process, limited choice of operators and weak negotiating power (Lidén, 1995b; Mäkinen, 1997).

However, a literature review combined with the results of a scientific survey conducted with 336 forestry harvesting entrepreneurs (FHE) (estimated population = 1500) (PREFoRT, 2007) confirms that the typical characteristics of SME owner-managers well apply to this kind of entrepreneur (Table 1) (Drolet, 2009).

Table 1: Common features shared by SME owner-managers (from literature review) and FHEs (from survey) for four anlaysis elements

Analysis Element	Observations
Motivations to be in business	Strong desire for independence Love of the work Need for flexibility in course of action options Monetary factor a low priority
Managerial characteristics	Low FHE ability to engage in management behaviours outside the production function FHE manager profile similar to that of other SME owner-managers FHE predisposition to experience the same difficulties as other business people
Influences and strategies	Short-term SME owner-manager planning horizon (2-3 years) FHE strategic choices poorly or not defined SME owner-manager business strategies mostly based on opportunism and business opportunities
Organizational and entrepreneurial performance	One-dimensional FHE notion of performance (productivity) FHE performance focused on production New performance models seek coherence of strategy, goals and performance indicators

As a result, despite the particular environment of the FE, these entrepreneurial and managerial imperatives cannot be ignored, whatever the context may be. This is why this study has been conducted from a perspective that resolutely defines the FE as an SME owner-manager, a title that integrates and transcends that of owner-operator of forest machinery and that allows a more integrated approach to the management of the affairs of the FE in which access to, quality and management of information play a central role in improving performance.

2. SME owner-manager and information

For the SME owner-manager, whether at the level of financing, human resources or yet at production, obtaining useful, reliable data, both in sufficient quality and quantity within the time required is vital for the manager of a productive enterprise. Performance follow-up, measuring and management take place by means of performance indicators themselves conceived using data from diverse sources. These data, where pertinent, are used for operational and strategic follow-up of enterprise activities as well as to manage risks and react at the opportune time in order to stay focused on the established objectives (Bergeron, 2000).

2.1 Machine Utilization rate and operational efficiency

In forest operations, among the data potentially available to assist the FE in follow-up and performance management, are found the number of hours per period during which his machinery has accomplished the task for which it has been conceived. By associating this data to the total number of hours planned (scheduled) for this period, it is possible to generate an important performance indicator frequently used in harvest operations, the machine utilization rate (Thompson, 2001).

According to Rolston (1972), utilization rate is the ratio of Productive Machine Hours (p.m.h.) to scheduled machine hours (s.m.h.). Utilization rate is represented by Equation 1. It stands for the proportion of planned work time that the machine accomplishes its main function. This factor demonstrates as a whole the mechanical dependability of the machine and the efficiency of the harvesting operations, maintenance and repairs (LeBel et al., 2009)

For Silversides and Sundberg (1989:34): "*Productive Machine Hours (p.m.h.) are those hours of scheduled time that a machine actually works [and] Scheduled Machine Hours (s.m.h.) are those that a machine is scheduled to work".* Under uniform operating conditions, in addition to productive machine hours, the productivity of equipment (Kurelek, 1976) depends on the production that is effective per unit of productive time (Equation 2) (McDonagh et al., 2004). Equation 3 shows how productivity (operational efficiency) is influenced both by hourly production and utilization rate.

Equation 1: $$\textit{Utilization rate}\,(\%) = \left(\frac{\textit{productive machine hours}}{\textit{scheduled machine hours}}\right)\times 100 \text{ or } \left(\frac{p.m.h.}{s.m.h.}\right)\times 100$$

Equation 2: $$\textit{Machine production} = \left(\frac{\textit{cubic meters harvested}}{\textit{productive machine hours}}\right) \text{ or } \left(\frac{m^3}{p.m.h.}\right)$$

Equation 3: $$\textit{Productivity}\,(\textit{operational efficiency}) = \left(\frac{p.m.h.}{s.m.h.}\right)\times\left(\frac{m^3}{p.m.h.}\right) = \left(\frac{m^3}{s.m.h.}\right)$$

Under perfect and uniform operating conditions, the higher the utilization rate is, the more periodic production must increase, and thus, productivity. However, in forest harvesting operations, *in situ,* several parameters vary, and there exist many sources of possible variation (season, type and state of equipment, operators, shifts, field conditions, quality of forest stand, etc.) This variability complicates the analysis as well as the interpretation of the different factors made available to the FE to improve operational performance. For the proactive FE seeking to profit from useful data enabling continuous enhancement of his enterprise's performance, the moment when the data become available constitutes an additional constraint that amplifies the difficulty of making an analysis. Faced with all these constraints, entrepreneurs wonder about the pertinence of gathering and treating such data and to what extent they ensure a satisfactory return on investment for the time allotted and other resources expended on the management of the enterprise.

2.2 Data collection for utilization rate measurement

MultiDAT datalogger, developed by FPInnovation, FERIC division, is an electronic device for collecting data related to the use of equipment (Turcotte, 1999). Its functioning is based on the levels of movement (i.e. motor vibrations) registered by the device. The minimal thresholds that indicate to the tool that its engine "is working" are adjustable, and the time scheduled according to a periodic basis (week, shift) is also adjustable from the treatment and analysis software program developed along with the device. The data possible to obtain from the basic device (MultiDAT Junior) mainly concern hours scheduled and productive machine-hours. With the exception of periodic data transfer to a central computer by means of a manual computer, or by automated transfer, no manipulation of the device is required. In particular, no keyboarding by the operator of the machine is necessary. As for the MultiDAT Senior, it is furnished with a keyboard that allows indicating manually to the device the kinds of stops (repairs, upkeep, pause, etc.) or even the sort of work effectuated (harvesting, moving, waiting, selective cutting, etc.) As concerns data transfer, its functions are identical to the Junior model. In both cases, if the device is equipped with the proper peripheral it can serve as an interface making possible the collection of GPS data related to the harvest area.

3. Methods

Source: MRNF

Figure 1: Location of study

The project involved the collaboration of five forest harvesting entrepreneurs working in the forest region of Northern Quebec. Three entrepreneurs were located north of the Lac St-Jean region (around 50° 19' N; 70° 23' W) and two entrepreneurs were located in the North Shore administrative region (around 51° 28' N: 65° 43' W) (Figure 1).

The study used production data and utilization rate available weekly for the 2007-2008 forestry year and concern solely the harvesting activities of eight harvesters, (two entrepreneurs operating two machines each for the entire forest year, and a third acquired a second during the course of the year.

The data from the study are taken from the harvesting activities that took place simultaneously on two territories located in the boreal forest, where the "topography is uniform enough and the forest cover is chiefly black spruce forming a good number of monospecific stands" (our translation) (MRNF, 2003).

Figure 2 illustrates the sequence of preparatory stages to the data analysis. Firstly, the estimated weekly volume harvested per entrepreneur and per sector and the final scaling reports have been combined. The actual volumes from the official scaling system were distributed in proportion to the volumes estimated in each sector and for each period when volumes harvested appeared on estimated weekly volumes sheet provided by the client. Next, the GIS intersection of GPS shape files data from each cutover on the corresponding ecoforestry map has permitted characterization of the harvesting sectors and consideration of harvested volumes according to characteristics found in the field. This treatment has allowed considering the unavailability of real (scaled) volumes per cutover area, with the goal of eventually making a closer analysis of obtained results. The table obtained from the first two treatments has been joined to the utilization rate database per period and entrepreneur. The last step consisted in the final integration of the four distinct databases (estimated volumes, GPS shape files (cutover), utilization rate) into one with the goal of statistical analysis by linear regression by means of the SAS© statistical analysis software.

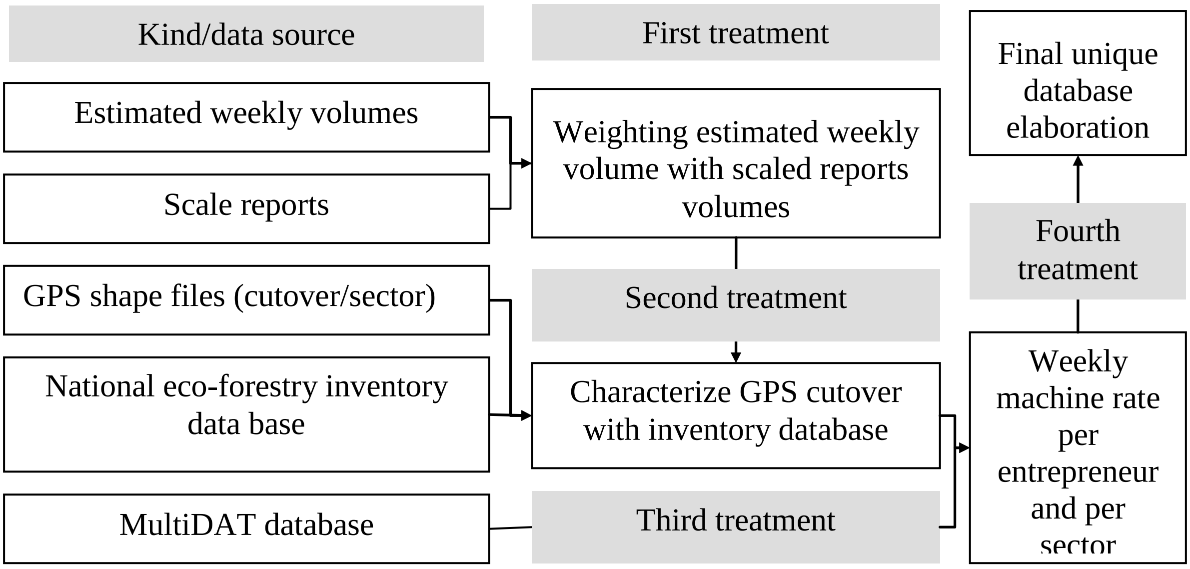

Figure 2: Final single database elaboration process

Following the first analyses, due to the gap between the estimated weekly volumes, and the final scaled volumes provided, the analyses had to be limited to estimated volumes. Table 2 indicates available information for all entrepreneurs.

Table 2: Descriptive information for five pooled entrepreneurs

Variable	Weeks of data	Mean	Standard error	Min	Max	Sum (for the year)
Estimated weekly volume	137	1766,53 cu. meters	969,15	149,29	6517,53	242 014
Machine rate	134	75 %	17,0%	18,0%	101,0%	-

4. Results

According to the available data, which are the same as those used by FE on a weekly basis, a linear regression between the utilization rate and the total volume does not allow concluding that a statistically significant relationship exists ($p=0,16$, $R^2=0,017$) (Figure 3). This result is surprising a priori, since there should be a direct link between production and the utilization rate. The absence of a significant regression may be caused by the presence of factors outside this relationship, which conceal the possibility of a relationship existing in reality. We will come back to this point further along in the discussion. In order to explore this possibility, a complementary study has been done taking into account the volume available per hectare at the sites visited by the entrepreneurs for each week considered. The volume per hectare was determined by finding the mean of the values of volume class available in the data base, balanced with the area of each sector. A mean value of volume by hectare by week and by entrepreneur is thus obtained. Finally, the values obtained for the volume per hectare are grouped into two categories (less or equal to 105 and higher than105). This initial attempt to recodify aims at having a first idea of the possible effect of volume per hectare on the relation between the volume and the utilization rate. Figure 4 presents the relation between the volume and the utilization rate, however this time by identifying the point by class and volume per hectare for all five pooled entrepreneurs. This figure shows that points identified with a heavy volume per hectare are found to be homogeneously distributed across the graph, indicating that a heavy volume per hectare is not directly associated to situations with the heaviest volumes produced for a given utilization rate.

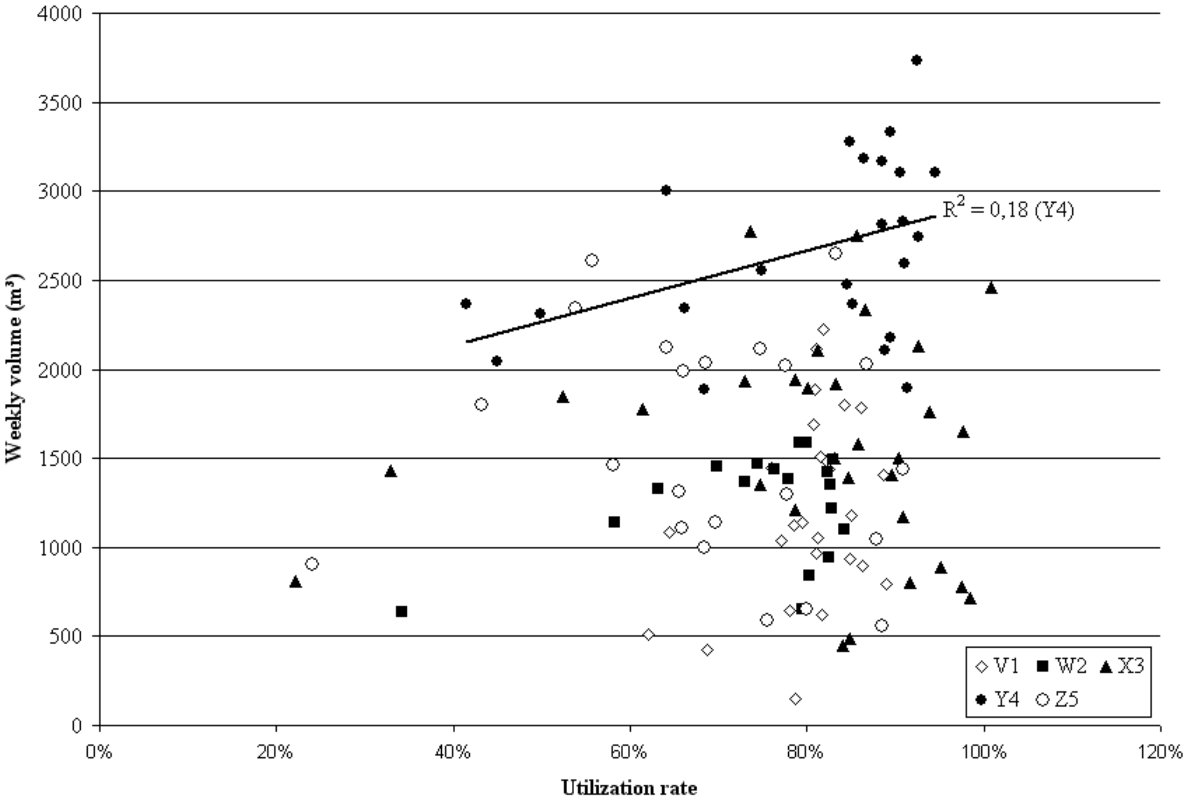

Figure 3: Relation between the utilization rate and weekly volume for each entrepreneur

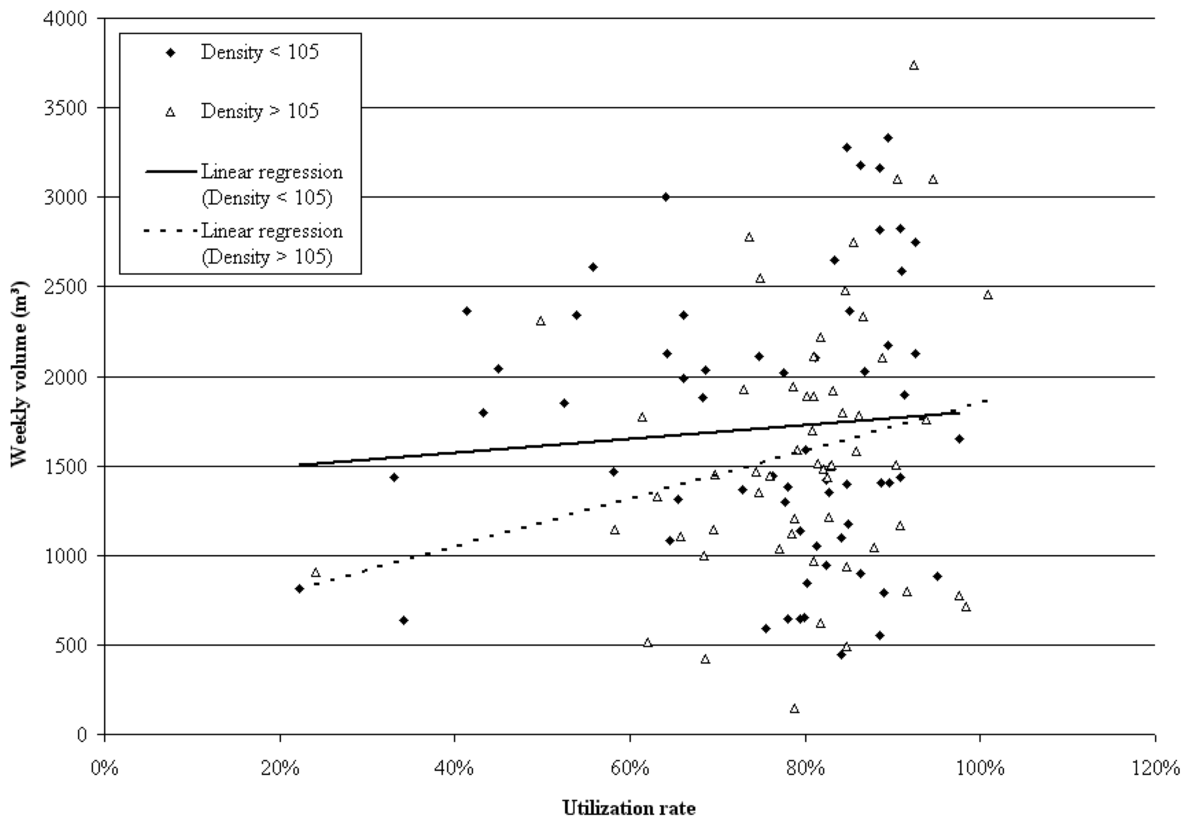

Figure 4: Relation between the utilization rate and weekly volume/ha for all five pooled entrepreneurs

When analyzing the relation per entrepreneur (Table 3), only two relations were statistically significant. In the first case (Y4) the linear regression gives a statistically significant relation (p=0,0435, R^2=0,18) between the utilization rate and the total volume. In the second case (V1), the relation between the utilization rate and the total volume produced from heavy volumes per hectare (> 105) is statistically significant (p=0,028, R^2=0,24), but not statistically significant with weak volumes per hectare (p=0,99, R^2=0,00). However, working with volume group per hectare, it cannot be concluded that the relation (utilization rate vs. volume) is significant and this, as much with the presence of heavy volumes per hectare (p=0,23, R^2=0,27), as with the presence of weak volumes per hectare (p=0,15, R^2=0,14). As for the rest of the relations measured (8/10), no relation proved to be statistically significant using the available data.

Table 3: Relation level between utilization rate and two parameters

FE	**Total volume**		**High vol/ha**		**Low vol/ha**	
Relation	R^2	*P*<	R^2	*P*<	R^2	*P*<
All	0,017	0,16	0,056	0,07	0,01	0,54
V1	0,13	0,076	0,24	0,028	0,00	0,99
W2	0,13	0,14	0,25	0,25	0,20	0,17
X3	0,00	0,91	0,02	0,24	0,03	0,64
Y4	0,18	0,0435	0,27	0,23	0,14	0,15
Z5	0,01	0,64	0,46	0,21	0,12	0,17

5. Discussion

The forestry entrepreneur has been defined as a SME owner-manager for whom the pertinence and quality of available information are necessary to manage his enterprise adequately and improve its performance. On this subject, Lepage and LeBel (2007) mention that: *"Even though in an era of information technology many firms are weighed down by data of all kinds, little of it is converted into useful information".* The results of the present exercise of relating two basic parameters, utilization rate and volume harvested, constitute an example of this reality. Results demonstrate the whole difficulty that multiple variables to be considered can engender when analyzing production data. With the means of analysis presently available to them, forestry entrepreneurs would be justified in being little interested in information of this kind since, from the results obtained it would be of little use.

The study aimed above all to verify whether a significant linear relation exists between the volumes harvested on a weekly basis and the utilization rate measured with the help of data collectors could be established in a simple way, i.e. from the daily perspective of the FE who wishes to profit from a non-negligible sum of data that have been made available to him. The analyses made have not allowed establishing such a statistical relation. As already stated, several factors both internal and external for the entrepreneur including technical, physical and technological constraints, influence and vary the results. However within the normal operating context, the FE ceaselessly aim at maximizing the utilization rate, a goal they pursue without looking at these multiple parameters.

Although the utilization rate of harvesting equipment is an indicator of an organization's technical efficiency in "making equipment work", the study confirms that an initial interpretation of its value alone can lead to a simplified analysis which conceals the conditions of variability that prevail during the hours worked. The utilization rate is a relative indicator of performance. In the same manner as the measure of total volume produced, the utilization rate alone is not a systematic gauge of productivity nor of profitability. That said, it remains by definition an important indicator of efficiency in management operations. In the context of follow-up of performance of daily harvesting activities, where external conditions are known and recent, measuring utilization rate proves to be an essential indicator. This short-term horizon more easily allows considering several variables when analyzing variables (operators, field conditions, break-downs…) and thus adjusting resources and efforts. On the other hand, over a longer period of time, (week, month, year) the number of external variables that influence the value and validity of the utilization rate obtained turn out to be too great to assure the FE that the results obtained are dependable.

6. Limits

The 2007-2008 forest year was an example of a standard forestry year for Quebec forestry harvesting entrepreneurs. Harvesting took place from the end of April 2007 to the end of February 2008. Thus the study used data covering a period of ten months and involved the collaboration of five forestry harvesting contractors. Throughout the study, one of the challenges was to ensure that the MultiDAT dataloggers operated continuously. If a break-down took place, the contractor was never – or rarely – in a position to repair it without help from an external source. With the resources available, it was impossible for a research team to be constantly present and assure permanent back-up at the harvesting operations site in order to take care of technical problems caused by the use of dataloggers (electrical current cuts, internal configuration, etc.). Under these conditions, a few hours' or weeks' data could be lost for each of the devices. In the event of this happening, the weeks were withdrawn from the database and were not included within the scope of the analysis.

Moreover, a closer analysis of the utilization rate per operator could not take place. Despite the FE's acceptance to do so, a certain reticence on the part of the operators was present throughout the whole project, even though information sessions on the nature and objectives of the project were held periodically. The request to key in the operator's number in the datalogger at each shift change was followed by a minority of operators. Davis and Kellogg (2005) also underlined the extreme importance but sometimes the difficulty in maintaining cooperation from operators to assure MultiDAT data reliability.

Finally, although the data analysis occurred separately for each entrepreneur, it did not take into consideration the technical characteristics specific to each type of harvesting equipment used (Plamondon, 1998; Gingras and Favreau, 2007). However, the analysis for each entrepreneur taken separately did not reveal any notable tendency.

Conclusion

The absence of a clear statistical relationship in the results presented raises the double challenge to which the scientific forestry community and the FE must respond by collaborating. On the one hand, a great deal of research and technological development remains to be accomplished with a view to furnishing the FE with data that is valid, pertinent and reliable, and available at the right moment. From a practical point of view, the FE who is presently attempting to analyze production and who comes to the same conclusions regarding results, risks being little motivated to further the acquisition and analysis of data and especially questions the pertinence even of the statistical follow-up of his activities. The study has necessitated physical and computer databases manipulations that few FE are equipped to accomplish in addition to their usual tasks. While important technological advances are taking place to facilitate the acquisition and transmission of data of all kinds, principally in production (volume, fuel consumption, utilization rate, travelling optimization, etc.), it is essential that research and development of management tools accelerates with the goal of assuring adequate precision of these data transmitted to forest entrepreneurs as well as models of performance management that enable analysis and decision-making. Better data precision making use of performance models specific to forestry harvesting enterprises is an important catalyst for innovative change in management behaviours of forest entrepreneurs.

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Updating FRCS, the Fuel Reduction Cost Simulator, for National Biomass Assessments

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Abstract

In 2005 the USDA and DOE jointly published a report (Perlack et al. 2005) concluding that it would be technically feasible to supply a billion dry tons of biomass annually from farms and forests throughout the United States in support of an emerging bioenergy and bioproducts industry. The report was criticized because it defined "supply" largely in terms of physical availability without a formal evaluation of economic feasibility. As a result, during 2008 and early 2009 the two agencies conducted a follow-up study in an effort to assess the potential biomass supply economically by deriving county-level supply curves for farm and forest biomass. This paper describes the forest harvesting model that was used to estimate the costs associated with collecting and preparing forest biomass for transport to processing facilities. The model was updated from an earlier version that was limited to forest conditions in the Interior West. The revised model has been designed for use in all regions of the contiguous United States. Actual results from the study are not provided in this paper because they have not yet been cleared for release by the USDA and DOE.

Introduction

In 2007 the US Congress passed the Energy Independence and Security Act (EISA), which revised the 2005 Renewable Fuel Standard (RFS) upward to specify that, by 2015, the US as a whole is mandated to produce 20.5 billion gallons of biofuels annually from renewable sources, and that by 2022 this should grow to 36 billion gallons per year (Renewable Energy World 2008). At the current average yield of 67 gallons of ethanol per dry ton of biomass (DOE 2009), these targets imply the need for biomass supplies of around 305 million tons by 2015 and 540 million tons by 2022. Such quantities represent ambitious targets, and it seems unlikely that they could be met solely from crop-based biomass. Additional biomass sources could include logging and mill residues, small trees from thinnings, wood from energy plantations, urban wood waste, and possibly even repurposing of conventional forest products such as pulpwood.

In an effort to estimate the technical feasibility of supplying the large quantities of biomass needed to meet the RFS mandates, in 2005 the Departments of Energy and Agriculture jointly published a report on potential biomass supplies from both agriculture and forestry (Perlack et al. 2005). The report concluded that more than a billion tons of biomass are "potentially available" each year from US farms and forests. However, the study was criticized because it relied heavily on data related to physical availability without comprehensively evaluating biomass supply in an economic context. As a result, a new study was commissioned in late 2007 to derive county-level supply curves, using economic data, for both farm and forest biomass. Counties were selected as the basic unit of area for the assessment because that is the level at which the Agricultural Research Service collects agricultural data. Both the farm and forestry components were to be modeled at that level in order to facilitate aggregation of supply curves. The county-level supplies can then be aggregated at the state level and summarized according to regional groupings that are commonly used in assessments of this type. For this study, "supply" refers not to a fixed quantity but rather to an economic supply curve indicating the estimated quantity of biomass that might be made available at a given price. In general, as the price of biomass increases, the quantity made available by landowners should increase as well, up to some limit imposed by the long-term productivity of the land and the propensity of landowners to sell biomass.

Acknowledgments

Overall coordination of the Forest Service contribution to the biomass supply study was managed by Bryce Stokes, then at the Forest Service Washington Office. The forest biomass supply assessment was led by Kenneth Skog at the Forest Products Lab in Madison, Wisconsin, with programming and statistical assistance from Patricia Lebow, who is also at the Lab. Consultation on data from the Forest Inventory and Analysis Program of the Forest Service was provided by Patrick Miles, an FIA scientist at the Northern Research Station in St. Paul, Minnesota. Estimation of biomass harvesting and collection costs was the responsibility of Dennis Dykstra at the Pacific Northwest Research Station in Portland, Oregon, who updated and revised a simulation software package developed originally by Bruce Hartsough at the University of California, Davis (Hartsough et al. 2001).

Methodology

The procedure used in this study involved estimating biomass stumpage prices and harvesting costs nationwide on a county-by-county basis. The assessment relied on data from the Forest Service's permanent Forest Inventory and Analysis (FIA) plots located throughout the US. For this study, Alaska and Hawaii were excluded. Forest biomass supply curves were determined by simulating thinning operations on each FIA plot to estimate the costs of:

a) Felling and extracting whole trees to a roadside landing.

b) Chipping or grinding the limbs and unmerchantable tops of pulpwood and sawlog trees. The merchantable stems of such trees would be utilized in the normal way as pulpwood or sawlogs and would not form part of the biomass supply.

c) Chipping or grinding whole trees that are too small to be used for conventional forest products but are scheduled to be removed in the thinning. Larger unmerchantable trees that are scheduled to be removed may also be processed in this way.

d) Loading the biomass chips or ground particles onto trucks in preparation for transport to a processing facility. We assume that the particles are blown or conveyed into a chip van directly from the chipper or grinder. Transportation costs are not included so that we can combine supply curves for forest biomass with those for agricultural biomass, which is modeled as being supplied at the farm gate without accounting for road transport cost.

e) Paying landowners a stumpage price for small biomass trees and the limbs and tops of larger trees. We used a base stumpage price of $4/dry ton as a rough national average, derived from an informal national assessment of biomass stumpage prices. We recognize that stumpage prices tend to be dynamic and location-specific, so we regard this only as a starting point. We assume that as the biomass stumpage price increases in a locality, the amount of biomass offered for sale would also increase. We model the biomass stumpage price as increasing to a maximum of 90% of the pulpwood stumpage price when the total biomass harvest reaches its maximum level as limited by the level of harvest for conventional forest products. Limiting biomass collection according to the level of conventional harvest is described under point 4 of the assumptions below.

f) We do not include the cost of moving logging equipment to and from each harvesting site. Because our forestry data are taken from the FIA database, including moving costs would require us to make assumptions about both the moving distance and the physical area of each harvesting operation. Using assumed averages for these values would shift the supply curves upward slightly but the effect would be the same for the entire country.

Assumptions

To develop the supply curves for forest biomass, we made the following assumptions:

1. Forest biomass is considered to be supplied at the point where it is loaded onto trucks or other vehicles for transport from the farm gate or forest roadside to a processing facility. Thus, road transportation costs are not considered in the analysis. This is consistent with the treatment of farm biomass in the analysis.

2. Forest biomass is assumed to come from thinning treatments on overstocked timberland as described in point 3 below, except that federally managed forests are not considered as contributing to the renewable biomass supply as mandated under the RFS. The thinning treatments simulated are consistent with those used for the West-wide reports by Rummer et al. (2003) and Western Governors' Association (2008).

3. Simulated thinnings to recover biomass are devised so that they remove trees across all size classes, based on the stand density index (SDI) of the timber stand. The simulation methodology assumes that stands will be treated only if their SDI exceeds 30% of the maximum SDI for their forest type and ecoregion. The methodology used to identify the fraction of trees within each size class to be removed in a simulated thinning is described in Shepperd (2007). In short, beginning with 1-inch dbh trees, the simulated treatment removes successively fewer trees from each larger diameter class. The removals in aggregate reduce the stand density to 30% of the maximum SDI. Thinning operations are assumed to be scheduled so that they occur over a 30-year period, with 1/30th of the total SDI reduction across the US being removed each year.

4. Unmerchantable, small-diameter trees (1-5 inches dbh) and larger cull trees are considered available for potential use as biomass feedstocks for energy or biofuels. Trees 5-7 inches dbh in the East and 5-9 inches dbh in the West are considered pulpwood trees, and larger trees are considered sawlog trees. The biomass supply is assumed to come from the unmerchantable trees and from the limbs and unmerchantable tops of pulpwood and sawlog trees. The harvest of all raw materials is assumed to be integrated, so the supply of limbs and unmerchantable tops is limited by the level of sawlog harvest for conventional forest products, and by a recovery factor recognizing that not all limbs and tops can be recovered (see point 6 below). We also assume that the supply of non-merchantable trees is limited by the level of conventional harvest; i.e., we assume that most biomass harvesting will be done in conjunction with conventional harvesting operations.

5. We assume that there is a slight cost premium for harvesting hardwoods as compared to softwoods. For the West this differential is 20% and for the North Central/Northeast and South it is assumed to be 5%. The figure for the West is a default that has been programmed into the simulation model and was based on experience with poorly formed hardwoods such as oak, tanoak, and madrone in California. The 5% figure for other regions is based on a suggestion from Greene (2008).

6. Not all limbs and unmerchantable tops of pulpwood and sawlog trees will make it to the landing in a whole-tree harvesting operation. One study (Stokes 1992) reported a wide range of recovery percentages averaging about 60% for biomass recovery in association with conventional harvesting operations. Currently we are using a recovery percentage of 65%, which is constant for all regions.

7. We assume that the cost of harvesting pulpwood and sawlog trees is fully allocated to the pulpwood and sawlogs that are recovered. Thus the limbs and unmerchantable tops of those trees are free at the landing except for the stumpage cost, and only the additional costs of chipping and loading are allocated to them. Unmerchantable trees that are harvested, however, bear all costs of felling, extraction, chipping, and loading in addition to the stumpage cost.

8. We separate the unmerchantable trees from pulpwood and sawlog trees only by dbh, without considering species. This is a recognized oversimplification in situations where larger trees of certain species, such as basswood in Wisconsin, might be used for biomass but not for conventional products.

Operations Simulated

We are not attempting to simulate all possible types of harvesting operations that might be used to collect biomass. Instead we consider only the following:

- Manual felling and whole-tree extraction, either with conventional skidders or with cable systems. The simulator uses cable systems if the average ground slope on the FIA plot is 40% or more.

- Mechanized felling and whole-tree skidding or forwarding. We assume that mechanized felling is not used with cable yarding even though we recognize that this is not a fully accurate assumption.

For ground-based logging, the simulation model calculates the production rates and costs for both of the possible alternatives (manual felling and mechanized felling). It then selects the lower-cost alternative for use in deriving the supply curve.

We recognize that harvesting systems other than these are likely to be used for biomass collection, such as harvesters and forwarders, slash bundlers, mobile chippers or grinders, or yet-to-be-developed technologies that could offer financial advantages in this type of operation. At present we have not identified publications providing production rates and related information for these other systems when they are used for collecting biomass, and therefore simulating them would involve more guesswork than we were willing to accept in doing this assessment.

Cost Estimation

The harvesting-cost simulation model used for this study is an adaptation of the Fuel Reduction Cost Simulator, or FRCS (Fight et al. 2006), which in turn was based on an earlier model called STHARVEST, for Small-Tree Harvest (Hartsough et al. 2001). FRCS is a Microsoft® Excel® application with auxiliary modules written in Visual Basic for Applications (VBA). It was originally designed to simulate fuel-reduction treatments in the Interior West, where wildfire is a significant problem. The model was substantially revised for this study, including the development of new procedures to simulate harvests in the North (North Central and Northeast), the South, and the coastal West as well as the Interior West. Cost data used in the original FRCS had several baselines: December 2000 for wages, December 2002 for equipment costs, and December 2004 for fuel costs. We updated all costs to December 2007 for this assessment. This represents the latest month for which all data were available when we were beginning to make production runs in early 2008. Furthermore, we have disaggregated the costs regionally, as described below.

Logging wages differ for each state, and are taken from the Bureau of Labor Statistics (2008), which publishes an online census of employment and wages by state and county for a wide variety of occupations, including logging (NAICS code 1133). We assume a nationwide average of 35% for benefits and other payroll costs because the BLS series do not include these costs.

Fuel prices differ by subregion (New England, Central Atlantic, Lower Atlantic, Midwest, Gulf Coast, Rocky Mountain, West Coast, California) and are taken from the diesel price series published by the Energy Information Administration (2008). We have not attempted to account for wholesale prices or off-highway savings in fuel costs because these vary widely and we have not identified a reliable source from which we could obtain the necessary information for all states. In any case, fuel prices are extremely volatile.

Equipment costs have been updated from the December 2002 base by using the producer price index for construction machinery manufacturing (Bureau of Labor Statistics 2008). We use a single national average cost for each category of equipment. The costs include estimates for all of the standard categories such as depreciation, repair and maintenance, interest, insurance, and taxes, but do not include an allowance for profit. Utilization rates are assumed to vary from 50% to 75% depending on the type of equipment but are constant throughout the country for any particular type of equipment.

No doubt the cost data could be improved if information were available for specific locations. However, the goal is to provide reasonable cost estimates for the country as a whole. Our assessment involves projections to 2022, and for simplicity we assume that different types of costs will remain about the same relative to each other as they are now.

Simulated production rates. To simulate harvesting operations, FRCS uses published production rates that typically vary according to the size of the trees being harvested and other factors such as slope and skidding distance. Most of the published studies are specific to a particular area of the country; hence, the simulated production rate for whole-tree harvesting with ground skidding in Alabama would differ from the simulated production rates for the same type of operation in Massachusetts or Wisconsin. In part this is due to different timber types and conditions, but also the published production rates for skidding operations in Alabama differ from those in Massachusetts and Wisconsin. A major part of the effort in this project was developing three new variants for FRCS that could be used to estimate logging and biomass collection costs in the West, North, and South respectively. More than 40 new production-rate equations were identified and implemented in the different variants of FRCS in order to support this effort.

FIA data. Parameters used to drive the simulation are taken from the 2007 Resource Planning Act database available from the Forest Inventory and Analysis National Program at http://www.fia.fs.fed.us/program-features/rpa/. This database includes all types and ownerships of forests in the United States. Each plot in the database represents a certain area of land that varies in different parts of the country and is influenced by local ownerships and other factors. Plots are identified in the database by county and state so it is possible to assign the harvesting operation simulated on each plot to a particular county.

Simulation results. The harvesting simulation runs involve calculations for about 125,000 permanent field plots located throughout the United States that have been established and are maintained by the FIA. For each plot, one of the following types of results is provided:

a) **No treatment**—the trees on the plot do not meet the requirements for thinning. Such plots do not contribute to the biomass supply curves. This is true also of plots on federally managed forest land due to restrictions in the EISA related to the RFS mandates.

b) **Treatment scheduled but inoperable**—if the average plot slope is greater than 40% and the distance to the nearest road as recorded in the FIA database is greater than 1,300 feet (the simulation limit for cable yarding), the plot is considered inoperable. For such plots, a harvesting cost of $100/green ton of biomass is recorded, indicating that the costs associated with collecting biomass from the plot are so high that it is very unlikely the trees on the plot will contribute to the biomass supply. No such limitation is imposed on ground-skidding or forwarding operations, although those with very long operating distances will inevitably enter the biomass supply at an extremely high cost.

c) **Treatment scheduled and feasible**—the simulation model was able to calculate estimated harvesting costs for the site. The following are recorded for use in putting together the biomass supply curves:

   (i) Estimated total harvesting cost (the sum of felling, yarding/skidding, chipping, and loading costs) for all unmerchantable trees, pulpwood trees, and sawlog trees, expressed in $/CCF of logs recovered, $/green ton of logs and chips recovered, and $/acre of treatment area.

   (ii) Estimated volume of chips recovered from unmerchantable trees, in green tons/acre.

   (iii) Estimated volume of residue chips recovered (from the limbs and tops of pulpwood and sawlog trees), in green tons/acre.

   (iv) Estimated volume of pulpwood logs recovered, in CCF/acre.

   (v) Estimated volume of sawlogs recovered, in CCF/acre.

   (vi) Estimated total collection cost for unmerchantable trees (the sum of felling, yarding/skidding, chipping, and loading costs), expressed in $/green ton of chips recovered.

   (vii) Estimated total chipping and loading cost for residue chips produced from the limbs and unmerchantable tops of pulpwood trees and sawlog trees, expressed in $/green ton of residue chips recovered. Felling and yarding/skidding costs are not included for these trees because those costs are allocated to the production of logs from pulpwood and sawlog trees.

Limitations of the Model

One of the major difficulties in undertaking this type of analysis is the fact that FIA plot data do not include a robust measure that can be used as a surrogate for average skidding distance. The only plot-based measure related to distance is the estimated distance to the nearest road. Although we used this measure in our analysis, it is a poor surrogate for average skidding distance. A better approach, given sufficient time, would be to develop average skidding distance values for each county or group of counties.

Another limitation of the model is that it makes no effort to incorporate the cost of building or upgrading roads where that might be necessary in order to harvest forest biomass. The importance of this limitation would differ by region, but the general result is that our estimates of biomass supply are probably optimistic.

As mentioned earlier, our approach assumes that the thinning operations from which the forest biomass supply would be drawn are to be spread out evenly over a 30-year period. However, we use FIA data from the most recent measurement so the anticipated treatments are based on these data without incorporating future growth or other changes in forest area or timber conditions that might occur over the 30 years.

Concluding Remarks

Forest harvesting simulators are imperfect predictors at best, and we make no claim that the Fuel Reduction Cost Simulator is the best of all possible models to use for estimating harvesting costs throughout the United States. Even so, given the very short amount of time that was available to adapt the model for national use, the flexibility and robustness of FRCS permitted us to make the necessary adaptations and to successfully complete the analysis on time. On average, the general shapes of the supply curves derived from the analysis appear to be reasonable and at levels that are consistent with those independently derived for agricultural biomass.

The three regional FRCS variants and documentation for the original FRCS model can be obtained from a Forest Service website, http://www.fs.fed.us/pnw/data/soft.htm. Notes on formatting and methodological changes that were needed to accommodate the national assessment are also available on the website.

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A Methodology for Implementing Best Management Practices using WEPP:Road Erosion Modeling and a Simulated Annealing Algorithm

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Abstract

Forest road erosion causes problems for downstream water bodies, with these problems being readily evident in the Lake Tahoe Basin. To minimize erosion from roads, managers install and maintain physical Best Management Practices (BMPs). BMP installation on a watershed scale is a difficult task because of the need to account for multiple constraints and issues. We present a methodology for addressing this challenge through combining WEPP: Road erosion modeling and Simulated Annealing Optimization. Field surveys provided inputs for WEPP: Road and subsequent identification of erosion risk potential. Appropriate BMPs were identified for segments posing an erosion risk. These BMPs, along with their associated costs and maintenance frequencies, were input into a Simulated Annealing algorithm. The algorithm minimized sediment leaving the road buffer over the course of the planning horizon by comparing potential BMP installation and maintenance scenarios. Preexisting BMP maintenance costs, new BMP installation costs and maintenance regimens, and spatial adjacency were accounted for within the algorithm framework. In the solution presented here, of the 37 segments where applicable BMPs could be installed, 30 were installed in period zero. Sediment leaving the buffer over the course of the planning horizon was reduced by 40%. We note that this methodology can be applied to any watershed, but relies heavily on the perceived accuracy of WEPP: Road.

Introduction

Forest roads, when imposed on the landscape, often become the most prominent source of erosion in mountainous watersheds (Burroughs 1990). Roads can magnify erosion rates by multiple orders of magnitude (e.g. Megahan and Ketcheson 1996, Megahan and Kidd 1972). Frequently, roads increase sediment delivery to streams in a given watershed and alter geomorphic processes both in and out of the stream channel (e.g. Montgomery 1994, Jones et al. 2000, Wemple et al. 1996). Impacts of road-generated fine sediment entering streams include increased turbidity (Forman and Alexander 1998) and impairment of fish habitat (FPAC 2000). Roads become a chronic source of fine sediment to downstream water bodies (Luce 2002).

It could be argued that few places in the Western United States, or the world, for that matter, are as aware of the consequences of downstream impacts from upstream management actions as the Lake Tahoe Basin (LTB). Lake Tahoe has been declared an Outstanding Natural Resource Water by the U.S. Environmental Protection Agency. As a result of precipitous losses in water clarity over the past 25 years, Lake Tahoe is currently designated as an impaired water body under

Section 303(d) of the Clean Water Act (Roberts and Reuter, 2007). In order to stem this decline in water clarity, it is imperative that innovative solutions for mitigating fine sediment inputs to Lake Tahoe be conceived.

To minimize road erosion, managers frequently implement Best Management Practices (BMPs). In practice, physical BMPs (e.g. drain dips, cross-draining culverts, rip rap) are installed based on professional judgment in the field. Often, no data on sediment leaving the road surface or sediment leaving the buffer- thereby entering a stream- is used to guide judgment. One way to mitigate this issue is to apply a road erosion model such as WEPP: Road (Elliot et al. 1999). WEPP: Road provides a user-friendly process-based model via web interface for managers to evaluate erosion from forest roads.

While WEPP: Road provides a highly cost-effective means of evaluating road erosion using relatively few measurements made in the field, new BMP implementation on a watershed scale is a daunting task. Given budget constraints, managers must evaluate which sites stand to benefit most from BMP implementation right now as well as planning future BMP implementation. In addition, existing BMPs must be maintained to ensure continued effectiveness, along with any new BMPs. Further complications stem from the logistics associated with project planning for BMP installation because it would be cheaper to install and maintain BMPs in near proximity in the same time period.

Here, we present a solution to this problem through combining WEPP: Road-derived erosion data with a Simulated Annealing algorithm to spatially optimize BMP placement across the road network. In doing so, we have produced a methodology for minimizing road-related sediment entering streams in a given watershed while taking into account budget constraints and spatial adjacency considerations over the course of a planning horizon.

Study Site:

Lake Tahoe, on the California-Nevada border, is nestled between the Sierra Nevada Range to the west and the Carson Range to the east. The Lake Tahoe Basin receives hundreds of inches of annual snowfall but receives little precipitation during the summer months. Because weather tends to track west to east across the basin, the east side of the basin is much drier.

The Glenbrook Creek Watershed encompassed the majority of the study area (Figure 1). Glenbrook Creek, on the east side of the LTB, lies approximately 15 miles west of Carson City, NV and 20 miles north of South Lake Tahoe, CA. The watershed ranges in elevation from approximately 6200 feet (1899 m) to 8800 feet (2686 m) at its furthest upslope extent. Soils are both volcanic and granitic in origin (Grismer and Hogan 2004).

A gated housing development near the mouth of Glenbrook Creek was excluded from the study area. The portion of Forest Road 14N32 connecting with Highway 50 at Spooner Summit was also included in the study area since it served as a major access point to the watershed. The gated road segment to the west of Highway 50, known as the "Old Lincoln Highway," was initially surveyed using GPS but never modeled for road erosion since it only is used for administrative access.

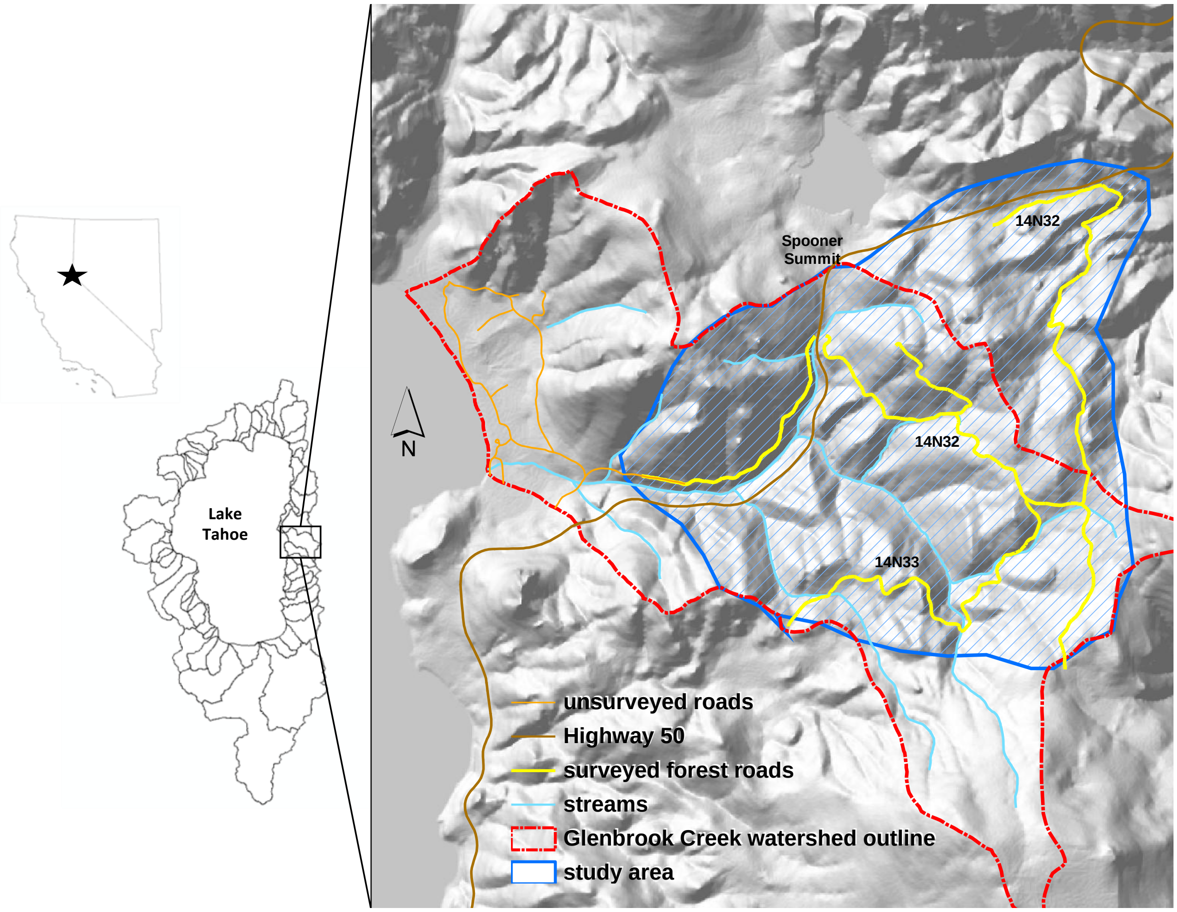

Figure 1. Map of study area.

Data acquisition and processing

Field data collection:

Field data collection was conducted in July 2008. Of the 7.6 miles of road surveyed (5.6 miles of those roads being in the LTB), 173 hydraulically contiguous road segments were identified. WEPP: Road input parameters determined or measured in the field for each of these segments included:

- Identification of road segment from nodes and to nodes
- GPS coordinates for from and to nodes
- Road gradient
- Road surface type
- Coarse rock content

- Fillslope gradient
- Fillslope length
- Soil texture
- Road width
- Road design (insloped or outsloped, rutted or unrutted, bare or vegetated ditch)

From nodes and to nodes were identified for each road segment. To nodes were always delivery points, or the perceived segment outlet for runoff and sediment. From nodes comprised the entrance or beginning segment locations for runoff and sediment entrainment. Segments were delineated between two existing drainage structures, from a slope break or high point to a drainage structure, from a high point to a low point, or between a drainage structure and a low point.

Data acquisition/processing using GIS:

For GIS derived input parameters, vector data was provided by the Tahoe Regional Planning Agency (TRPA) and the 10 m Digital Elevation Model (DEM) was obtained from the Lake Tahoe GIS Data Clearinghouse.

WEPP: Road parameters derived from GIS data or from Lake Tahoe Basin Management Unit (LTBMU) data included segment length, buffer slope, buffer length, and road traffic level. Segment length was found by first reprocessing the GPS-derived road layer into segments based on hydraulic connectivity observed on the ground, then using a GIS to calculate the length of those segments. Buffer slope and buffer length were found using a software program developed by the Forest Operations Research and Management Sciences Group at the University of Montana. Following suit with a 2006 application of WEPP: Road in the basin by the LTBMU (Briebart et al. 2006), road traffic level was held constant at "low" for all segments.

Delivery points for insloped segments were always assumed to be to nodes. Since sediment delivery from outsloped segments occurs along the entire length of the sediment, delivery points for these segments were designated at the middle of the segment. Buffer length and slope for each segment were then calculated from these delivery points to the nearest point on streams. Since WEPP: Road will not accept slopes exceeding 100% and road lengths exceeding 1000 feet, values exceeding these thresholds were replaced with 99 and 999, respectively. In locations where there was no fill slope, WEPP defaults of .3% slope and 1 foot were used.

Road segments were processed in WEPP: Road Batch according to soil texture. Sandy clay loam and silty clay loam were grouped together and processed as being "clay loam" soil type (J. Rhee 2008 personal communication). Climate was derived using the PRISM climate generator in WEPP: Road Batch. "TAHOE CA" was chosen for the climate, being the closest available climate base station and was modified using coordinates from a central location in the watershed.

"Hot spot" identification and verification

Following WEPP: Road Batch processing, results were reviewed to identify which segments had the greatest amount of sediment leaving the buffer (entering LTB streams). Natural breaks in a histogram were used to determine "hot spots", or those segments that were contributing disparate amounts of sediment to Glenbrook's streams. Those segments that were not classified as high risk segments were classified as moderate or low risk segments. The LTBMU supported our risk rating criteria (C. Shoen 2008, personal communication). The breakdown is shown in Table 1.

We conducted field verification of the high risk road segments within the Glenbrook Watershed in September 2008. A LTBMU roads engineer accompanied us during the field verification. During this process, we assessed the legitimacy of the hot spot by identifying the overriding characteristic causing the segment to be high risk. These segments were deemed legitimate hot spots for reasons ranging from steepness of the segment to length of segment to lack of surface durability. In addition to validating erosion risk from modeled road segments, applicable treatments were assigned to the road segments visited.

Table 1. Classification of road segments with greater than 0 T/yr sediment leaving buffer into risk rating classes.

Risk rating	**Number of segments in class**	**Low bound (lbs/yr sediment leaving buffer)**	**High bound for class (lbs/yr sediment leaving buffer)**	**Miles of road in risk class**	**Percent of total road mileage surveyed**
High risk	9	134	1292	0.94	12
Moderate risk	30	12	134	1.45	19
Low risk	35	0	11	1.58	21

Selection of applicable BMPs for problem road segments:

Due to time constraints, we were unable visit every road segment on the network generating sediment; accordingly, we couldn't identify the most appropriate BMP for each segment in the field. We were, however, able to identify patterns in treatment of problem BMPs. From these patterns, we constructed a simple hierarchy of appropriate BMPs used to treat problem road segments in the Glenbrook watershed (Table 2). WEPP: Road outputs confirmed the benefits of applying a given BMP on a road segment and the applicability of our decision hierarchy in the Glenbrook watershed.

Using those site-specific BMP options identified in the field and expanding on them, all segments within the Glenbrook Watershed producing greater than 0 T/yr sediment leaving buffer were assigned potential BMPs.

Table 2. Hierarchy used to assign BMPs to problem road segments.

Problem	BMP	Comment
Buffer slope > fill slope	Outslope	
Road slope > 17%	Pave	
Road length > 300 feet	Drain dip	Segment length reduced by one third

Simulated Annealing algorithm problem formulation:

Those designated BMPs became one of several inputs into a Simulated Annealing algorithm. This algorithm, originally developed by Metropolis et al. (1953), uses a modified Monte Carlo simulation that loosely resembles metal cooling after leaving a forge. A flowchart explaining the adaptation of Simulated Annealing algorithm framework to this planning problem is in Figure 2.

An initial budget per period was specified, as was the length of the planning horizon (in this case, 20 years), the number of total segments, and the number of segments on which BMPs can be installed. The algorithm first calculated the cost of maintaining pre-existing BMPs over the course of a planning horizon. This cost per period of existing BMP maintenance was subtracted from the initial budget for each period. Costs of new BMP installation, maintenance and associated frequencies presented in Table 3 were compiled through a combination of personal communication with Lake Tahoe Basin Management Unit personnel and the Region 4 Cost Estimating Guide for Road Construction (USDA 2008).

Table 3. BMPs applied to forest road network for Glenbrook Creek watershed using Simulated Annealing algorithm.

Category/treatment	Low-end cost($)	High-end cost($)	Necessary equipment	Maintenance cost	Frequency (years)
Drain dips	95/each	130/each	Cat D7	150/each	5
Outsloping	820/mile	1220/mile	Cat D7	same as installation	3
Asphalt paving	200000/mile	290000/mile	contracted	15000/mile	7
Graded aggregate base	150000/mile	220000/mile	contracted	4400/mile	3

*in Lake Tahoe Basin, aggregate base is always used under paved segments.
*Asphalt paving costs are for a project less than 1 mile that does not include aggregate base.

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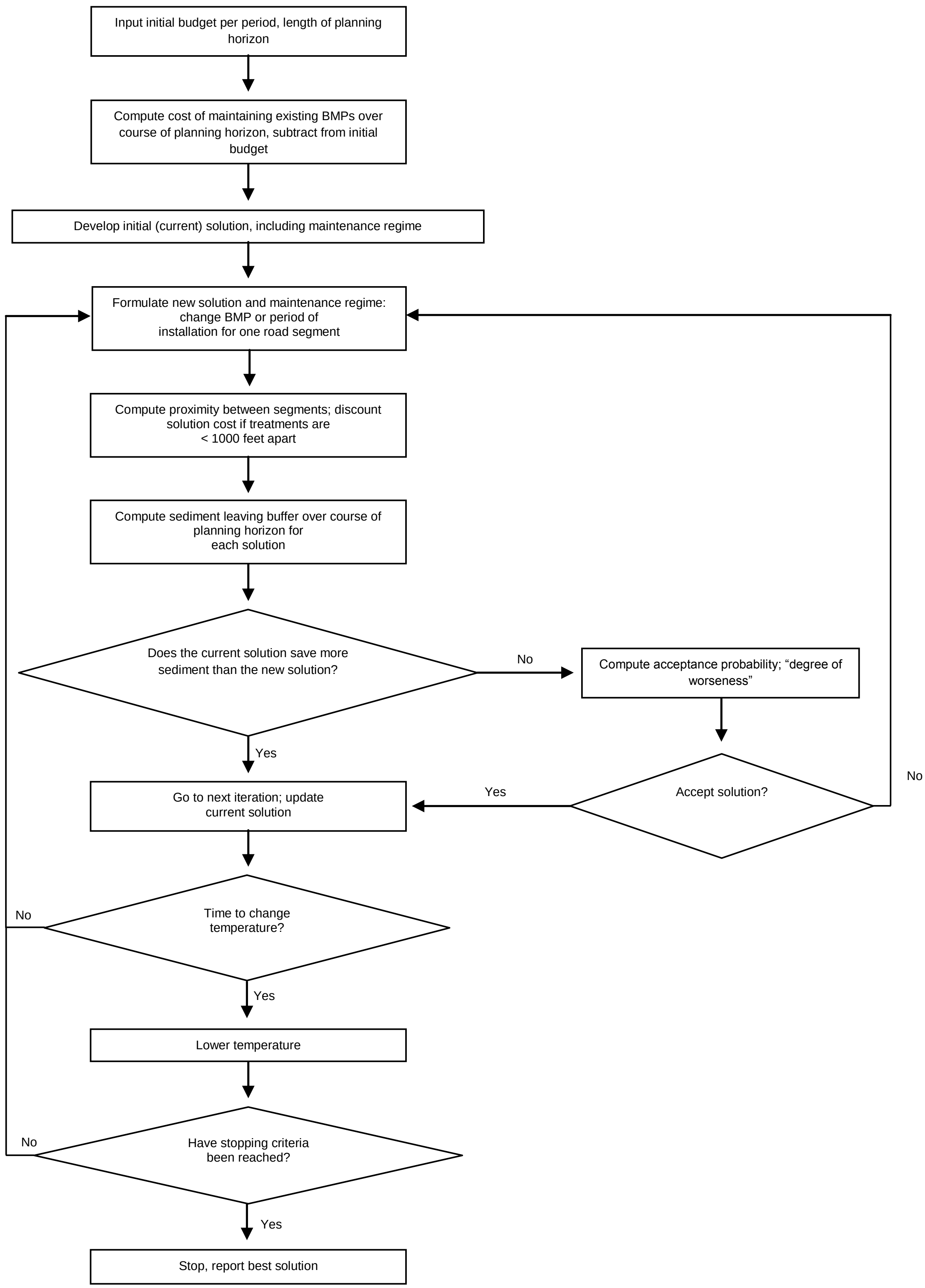

Figure 2. Flowchart describing adapted Simulated Annealing algorithm.

The algorithm generated a scenario where, starting with planning period zero, one BMP option (including “no treatment”) was installed on an individual road segment and maintained through the course of the planning horizon. Individual BMP treatments were installed on individual road segments until the budget for period zero was exceeded or until every segment had one BMP installed on it. As another component of this initial solution formulation, any BMP treatments installed less than 1000 feet from one another in the same period were discounted by 10% to reflect savings on equipment move-in costs. From this initial solution, a new solution was formulated such that either the BMP installed on a given road segment was changed or the period in which the BMP was installed was randomly changed. The maintenance regimen for the new solution was then formulated and the solution was checked for feasibility. BMPs installed in close proximity (less than 1000 feet) were discounted, just as with the initial solution.

The algorithm next calculated sediment leaving the road buffer (entering a stream) for the initial and new solutions using the following formula:

$$Total\ sediment = \sum_{i=1}^{n} [\mathrm{H} \times \mathrm{Sed_i} + (\mathrm{H} - \mathrm{q}) \times \mathrm{Sed\_Saved_i}]$$

Where n is the total number of segments in the study area, Sed_i is annual sediment leaving the road buffer produced by road segment i without a new BMP, Sed_Saved_i is the difference between annual sediment leaving the buffer from a single road segment with and without the applied BMP treatment, H is the length of the planning horizon (H = 20 years in this study), q equals the time period (year) in which a BMP is installed on a given road segment. When no new BMP is selected for a segment, the *Sed_Saved* term becomes zero.

This total amount of sediment leaving the road buffer was compared for the two solutions. If the new solution produced less sediment over the course of the planning horizon, it replaced the existing solution and a new solution was formulated according to those criteria outlined above. If the new solution was worse than the existing solution, an acceptance probability (*p(new)*) was calculated and compared to a random number to decide solution acceptance:

$$p(new) = e^{\frac{new-current}{temp}}$$

The algorithm repeated the solution procedures described above until the stopping criterion (final temperature) was met. For this modeling exercise, initial temperature was set at 10 degrees and final temperature was set at .0005 degrees with a cooling rate of 1%. Number of iterations performed at a given temperature level was 15, making for a total of approximately 18,000 iterations before reaching the final temperature. Initial budget per period was 30,000 dollars.

Results and Discussion:

WEPP: Road Analysis:

Of the 173 segments analyzed in the study area, 99 of them (accounting for 3.6 miles of the study area) produced zero erosion over the 30-year modeling period. WEPP: Road found a total of 54.96 tons per year of sediment leaving the road and 2.95 tons of sediment leaving the buffer -

theoretically entering a waterway- per year (Table 4). Rates of erosion were lower within Glenbrook than across the entire study area.

Overall, our WEPP: Road Batch results fall within the range of empirical results found in other studies. Megahan and Kidd (1972) measured .09 ton/yr of background erosion in granitics of the Idaho Batholith, which are less erodible than the volcanic substrates frequently found in the Lake Tahoe Basin (Grismer and Hogan, 2004). In terms of erosion rates from forest roads, active logging operations can produce 15 ton/ha/yr, including erosion from the associated roads (Brooks et al. 2003). In a 2003 study, Simon and others found 8.90 tons/yr of fine sediment leaving Glenbrook Creek. Evaluated against WEPP: Road outputs, forest roads in this watershed are responsible for approximately 17% of all sediment in Glenbrook Creek.

Table 4. Sediment leaving road and sediment leaving buffer in t/yr and t/ha/yr. Average road width across the entire study area was used to calculate t/ha/yr values.

Study Area	**Sediment Leaving Road**		**Sediment Leaving Buffer**	
	ton/yr	ton/ha/yr	ton/yr	ton/ha/yr
Entire Study Area	54.96	14.99	2.95	0.80
Glenbrook Watershed	22.66	8.40	1.55	0.59

Note: tons are English short tons (1 short ton = 2000 pounds).

Simulated Annealing Algorithm results:

Of the 37 segments where BMPs were assigned, 30 were installed in period zero (Figure 3). Since sediment leaving the road network over the course of the planning horizon would be minimized if every possible BMP was installed in period zero, these results are appropriate. Six segments had no BMPs assigned because of budget limitations in later planning periods. 35 preexisting BMPs had to be maintained in period 12, making this period the most limiting in terms of available initial budget (Figure 4). Pavement was never chosen as an applicable BMP because of its high implementation cost as well as the fact that pavement, in several cases, increased sediment leaving the road buffer.

As the result of new BMP installation, sediment was reduced from the maximum possible output of 59.0 tons over the course of the planning horizon (should no new BMPs be installed) to 35.5 tons, creating a 40% reduction in sediment.

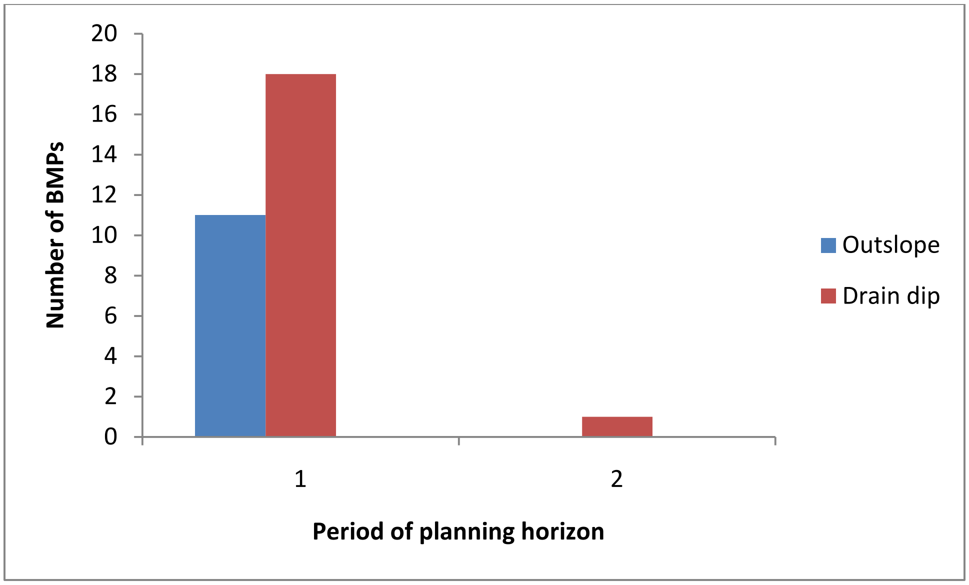

Figure 3. Simulated Annealing result for BMP installation in Glenbrook Creek. No new BMPs were installed later than the second year.

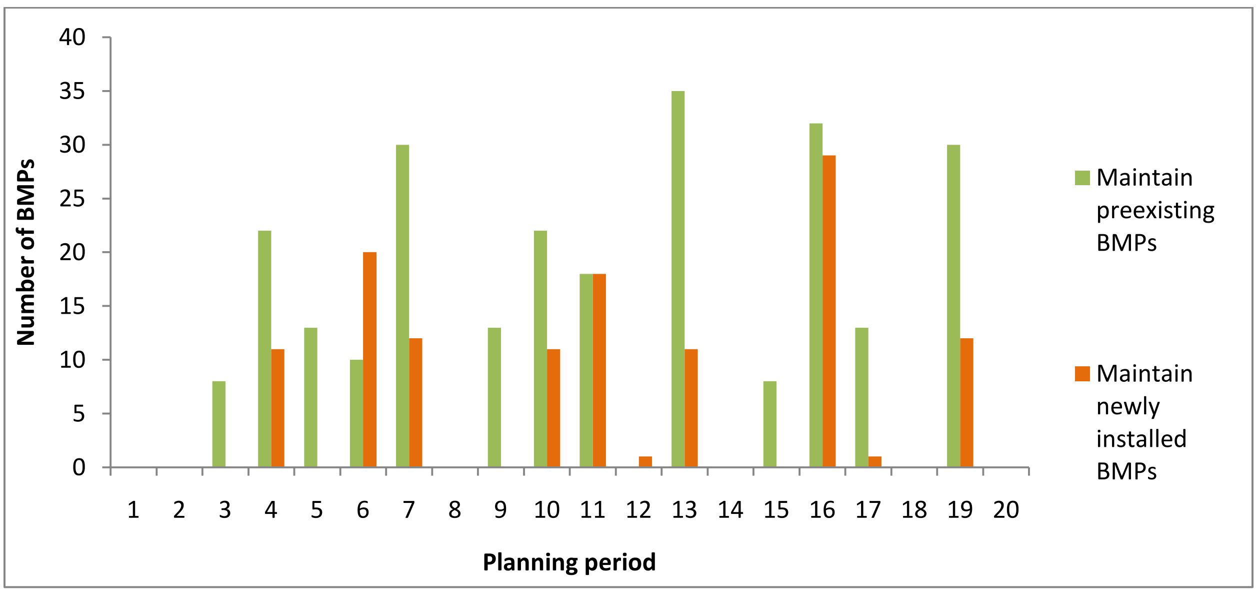

Figure 4. Number of BMPs maintained in each planning period over the course of the planning horizon.

Conclusion:

We have presented a method for increasing efficiency of BMP implementation on a forest road network. Road-related sediment leaving the forest buffer is minimized over the course of a planning horizon while accounting for budget constraints as well as spatial adjacency considerations. The solution presented here used modeled road erosion data from a high-density road survey as well as a hierarchy for establishing which BMPs are appropriate for a given road segment. While the data used here is from the Lake Tahoe Basin, this methodology can be applied to any watershed.

A critical assumption of this modeling exercise is that BMPs must be maintained at appropriate intervals in perpetuity, otherwise money spent installing BMPs is not worthwhile. Currently, this algorithm does not account for adjacent BMPs with identical maintenance frequencies. A logical continuation of this research would be to incorporate this important planning consideration into the optimization process, such as through cost discounting of nearby BMPs with identical maintenance frequencies.

Also of note is the fact that this modeling process relies on the accuracy of WEPP: Road to determine problematic road segments. Validation of WEPP: Road through any means beyond our on-the-ground verification was out of the scope of this project. While on-the-ground verification is not unwarranted, we have left that task to other researchers.

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Forest Road Pavement Design in New Zealand

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Abstract

The New Zealand forest industry currently has an annual cut of 19 million m^3 that is expected to increase over the next decade to 30 million m^3 per year. Much of the new production is situated in first-rotation forests that are located on steep terrain and have minimal existing forest road networks. A survey conducted as part of this study identified that current road engineering practices vary widely between forest owners and that forest road construction owes more to the experience of roading supervisors than to formal design methods, qualifications and training. While the economical design of forest roads is affected by many factors, including: road location and surveying, geometric design, and construction and maintenance, the acquisition and placement of aggregates for pavement can contribute 60-70% of forest road cost.

The majority of forest owners use a single 'improved' aggregate layer to complete their forest road, as opposed to a multi-layered approach used for most public roads. This paper focuses on reviewing the aggregate grading standards available for forest road design, and notes there is considerable variation between standards. A series of eight aggregates actually used for East Cape forest road construction were analysed by sieve test and compared to the standards. It found that the aggregates had widely varied gradation and were dissimilar to the gradation envelopes of the reviewed standards. Further research is required to determine an aggregate grading standard that will best suit East Cape aggregate sources and conditions.

Background

The New Zealand commercial forest estate is currently estimated at 1.8 million hectares, with an annual cut of 19 million m^3 (MAF 2008). The annual harvest is predicted to increase by 50% over the next decade (MAF 2000). Much of this new harvest area is situated in first-rotation forests that are located on steep terrain and have minimal existing forest road networks. A significant investment in forest road design and construction is required in order to provide access for harvesting in these new areas. This investment will call for the application of sound technical engineering knowledge and capability. Anecdotal evidence obtained through discussions with forest managers has identified that forest road engineering practices vary widely across the industry, and that many forestry regions struggle with developing and maintaining a cost-effective forest road network. The current level of forest road engineering capability in New Zealand, and the specific nature of deficiencies, is not well understood.

Figure 1 – Examples of forest roads in the East Cape region of New Zealand. The left picture shows a prepared subgrade awaiting placement of aggregate. The right picture shows a road constructed with log corduroy after failure of the original road pavement.

The purpose of this paper is to outline the forest road engineering research programme being implemented at the School of Forestry. Specifically, we review forest road pavement design considerations and aggregate grading standards, before presenting gradation curves for a selection of East Cape aggregates that have been tested.

Road Engineering Research Programme

The School of Forestry has committed to a programme of forest road engineering research. The objective of the research is to examine current New Zealand forest road engineering practices and identify opportunities to improve the design and construction of economical forest road pavements. To achieve this objective, the research programme will:

- Formally evaluate current forest road engineering practices in New Zealand in order to define current industry capability,

- Identify opportunities for improvement in pavement design that could be applied to New Zealand forest roads, and

- Test alternative pavement design methods to determine the applicability, and potential economic benefits, of these opportunities.

The research commenced at the end of 2008 and is in its early stages. The formal survey of industry capability is underway. While conducting the survey, the author has had the opportunity to observe many forest roads and to collect soil and aggregate samples for lab testing to determine material engineering properties. It was during these visits that forest owners expressed conflicting views of what aggregate grading should be used for surfacing unsealed forest roads.

Gradation of Forest Road Aggregates

Forest Road Pavement Design Considerations

In New Zealand, and in many other parts of the world, public low-volume roads are constructed using unbound flexible pavements – an arrangement that uses layers of unbound granular material that may be unsealed, or capped by a thin asphalt or chip-sealed layer. The typical structure of flexible pavement for a low-volume road is illustrated in Figure 2.

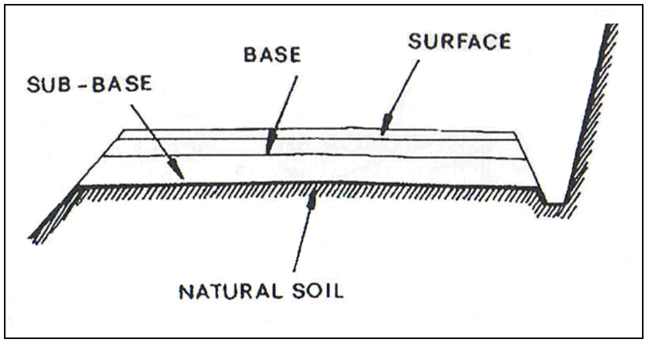

Figure 2 – Typical design of a public low-volume road (Sessions, 2007)

Pavements for forest roads often differ from public low-volume roads in that they commonly will not have multiple pavement layers or a sealed running course, but will consist of a single improved layer placed over the compacted natural soil, as illustrated in Figure 3. These two different design approaches have a significant impact on the gradation of aggregate required for the road pavement.

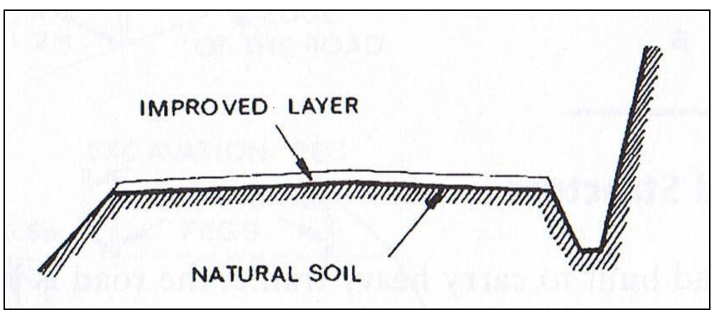

Figure 3 – Typical design of a forest road (Sessions, 2007)

Aggregate Gradation Standards

The difficulty faced by forest road engineers is that most aggregate gradation standards have been designed for the multi-layered pavement approach. A multi-layer pavement incorporates a surface layer that uses smaller aggregate and increased fines content to provide a smooth running surface that is water and abrasion resistant. By comparison, the base layer uses larger aggregates and reduced fines content to maximise structural strength and to provide resistance against capillary action. The improved layer approach is more problematic, as the single layer needs to have a gradation that concurrently satisfies the requirements of both the base and surface layers.

A review of a selection of existing aggregate gradation standards identified two broad categories of grading envelopes, namely: base course specifications and surface course specifications. These specifications relate to the base layer and the surface layer respectively. In all cases, aggregate gradation was specified via a gradation envelope in order to allow for variability of aggregate size, shape, texture and mechanical properties.

The base course specifications that were reviewed and compared in more detail are listed below in Table 1 and the surface course specifications in Table 2. Note that a number of entities and texts, including the USDA (1979), the FHWA (1996), and Giummarra (2000) list multiple gradation standards – but only one has been selected from each for the purpose of this comparison. These tables describe the maximum permitted aggregate size, the range for percentage of fines (fines are particles passing the 0.075mm sieve) and the coefficient of uniformity at the mid-range of each gradation envelope. The coefficient of uniformity (C_U) describes the uniformity of the aggregate. A higher C_U value indicates that the aggregate is less porous and is consequently less permeable (Forrester 2001). Low permeability is desirable for a surface course to provide water-resistance, but is less desirable for a base course, as the smaller pore spaces encourage water entry to the pavement by capillary action.

$$C_U = \frac{D_{60}}{D_{10}} \qquad \text{Eqn. 1}$$

Where: D_{10} *is the particle diameter corresponding to 10% passing*
D_{60} *is the particle diameter corresponding to 60% passing*

Table 1 – Aggregate gradation characteristics for base course specifications

Gradation type	**Source**	**Max. particle size**	**Percent fines**	C_U
Base course	Keller and Sherar 2003	37.5 mm	2 – 9%	75
Base course AP40	TransitNZ 2006a	37.5 mm	0 – 7%	35
Base course H	USDA 1979	38 mm	0 – 15%	43
Base course D	FHWA 1996	50 mm	4 – 8%	65
Base course 40a	Giummarra 2000	53 mm	4 – 10%	50
Base course No.1	Ryan *et al.* 2004	75 mm	0 – 10%	60

Table 2 – Aggregate gradation characteristics for surface course specifications

Gradation type	Source	Max. particle size	Percent fines	C_U
Surface course AP20	Main Highways Board 1938	19 mm	10 – 20%	240
Surface course	FHWA 1996	25 mm	9 – 16%	110
Surface course	Keller and Sherar 2003	25 mm	9 – 17%	80
Surface course D	USDA 1979	25 mm	3 – 15%	107
Surface course DSA	PSU 2006	37.5 mm	10 – 15%	160
Surface course 2	TransitNZ 2006b	37.5 mm	0 – 8%	67

The base course gradation specifications produce an average maximum particle size of 49mm, an average fines content of 2–10% and an average coefficient of uniformity of 55. By comparison, the surface course specifications produce an average maximum particle size of 28mm, an average fines content of 7–15% and an average coefficient of uniformity of 127. These results fit with the expectation that a base course should have larger aggregates and less fines, thus producing a layer that has high structural strength and resistance to capillary action. Similarly, the surface course specifications support the need for smaller particles and increased fines to help develop the required water and abrasion resistance.

The average characteristics from Tables 1 and 2 highlight the expected differences between base and surface course aggregate specifications. However, examining each specification in isolation shows a picture that is much less clear. Regardless of the parameters that are compared within the different gradation standards, we can see quite a range a values – indicating that even across the different standards, both between countries and within a country, there is very little consistency. Comparing these standards side-by-side produces a much wider 'combined' gradation envelope. This combined envelope is demonstrated below for both the base course aggregates and the surface course aggregates in Figures 4 and 5 respectively. For emphasis, the combined envelope is outlined in bold.

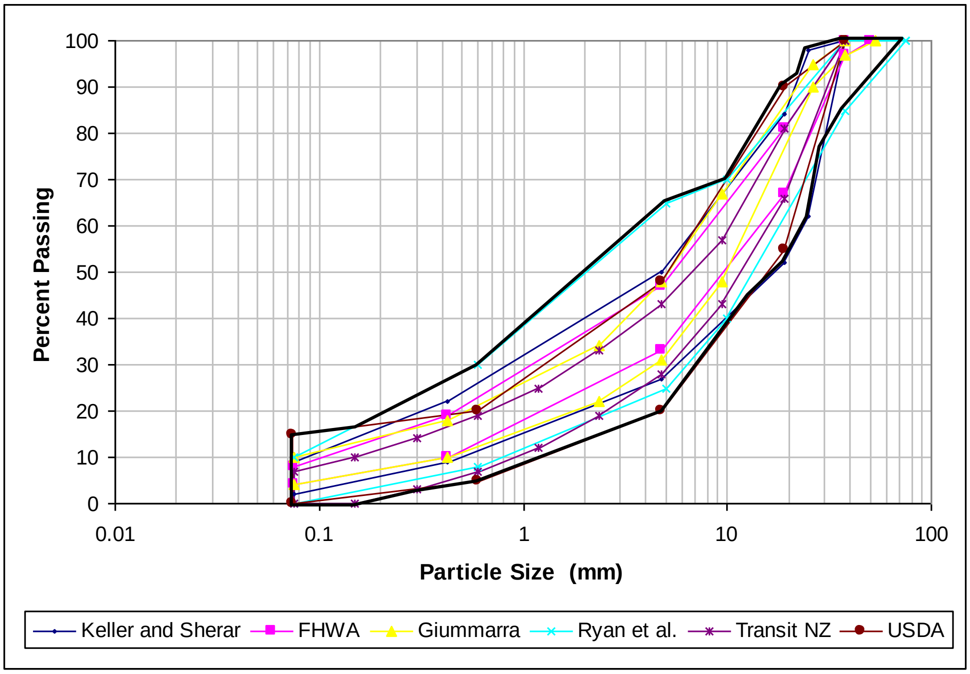

Figure 4 – Aggregate grading envelopes for selected base course standards

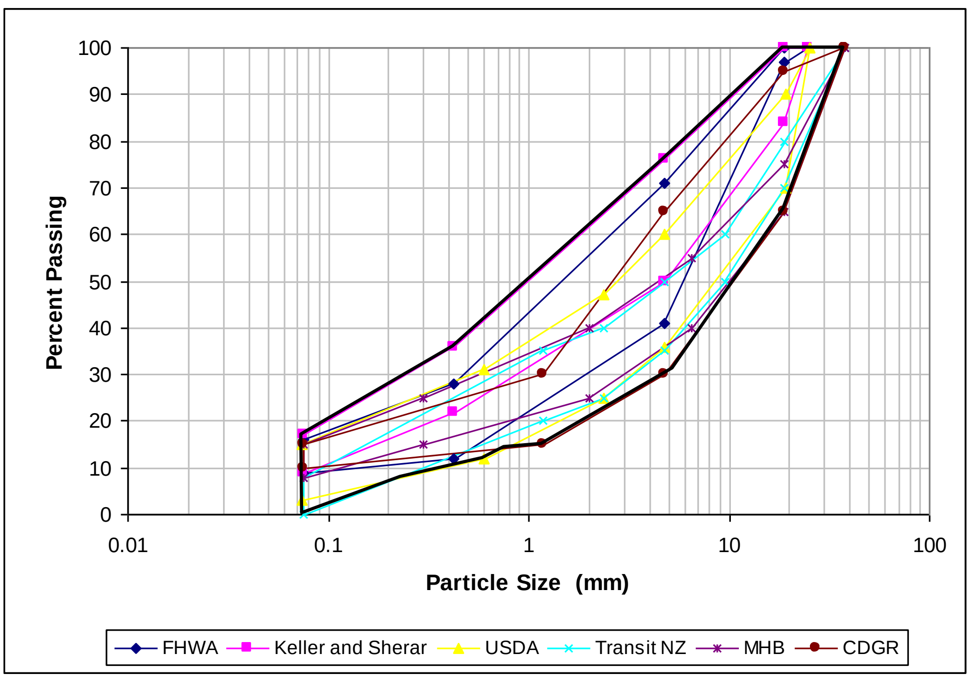

Figure 5 – Aggregate grading envelopes for selected surface course standards

The combined grading envelopes in Figures 4 and 5 appear, at first glance, to not be appreciably different to each other. Comparison of these two combined envelops, as shown in Figure 6, reinforces that the difference between surface course and base course grading specifications is not as apparent as the average characteristics extracted from Table 1 and 2 might suggest.

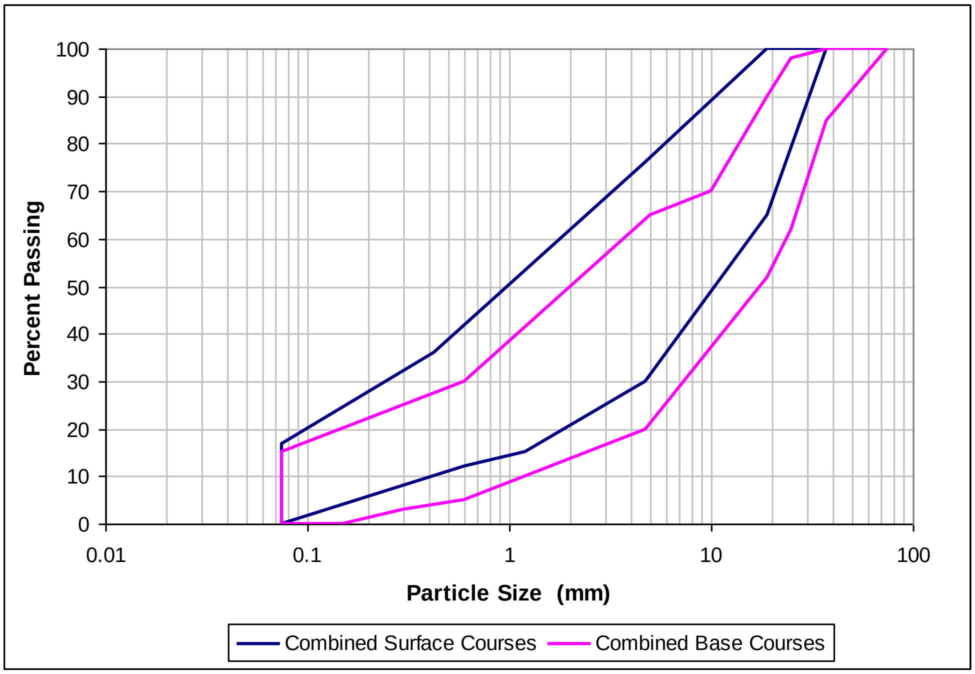

Figure 6 –Combined grading envelopes for surface course and base course aggregates

The considerable overlap between surface course and base course grading specifications highlights the difficulty facing forest managers when attempting to determine the most appropriate aggregate grading standard for their unique aggregate sources and forest road conditions.

Results from Testing of Aggregate Samples

Testing of eight forest road aggregates sourced from in-forest quarries and in-forest stockpiles in the East Cape region has been completed. The sampled aggregates were representative of materials being used during summer 2008/09 by three different forest managers as a combined base and surface course on East Cape forest roads (i.e. the East Cape forest managers were foregoing the traditional multi-layered pavement approach and had adopted the single improved layer approach). Minimum sample sizes of 25kg were collected for each aggregate and then reduced to sieving samples of not less than 5kg. Samples were wet sieved in accordance with NZS 4407 Test 3.8.1:1991 (Standards New Zealand 1991). The results from these tests are presented below as Figure 7. The combined envelope for surface course aggregates has been added as a grey shaded outline to provide reference to the reviewed standards.

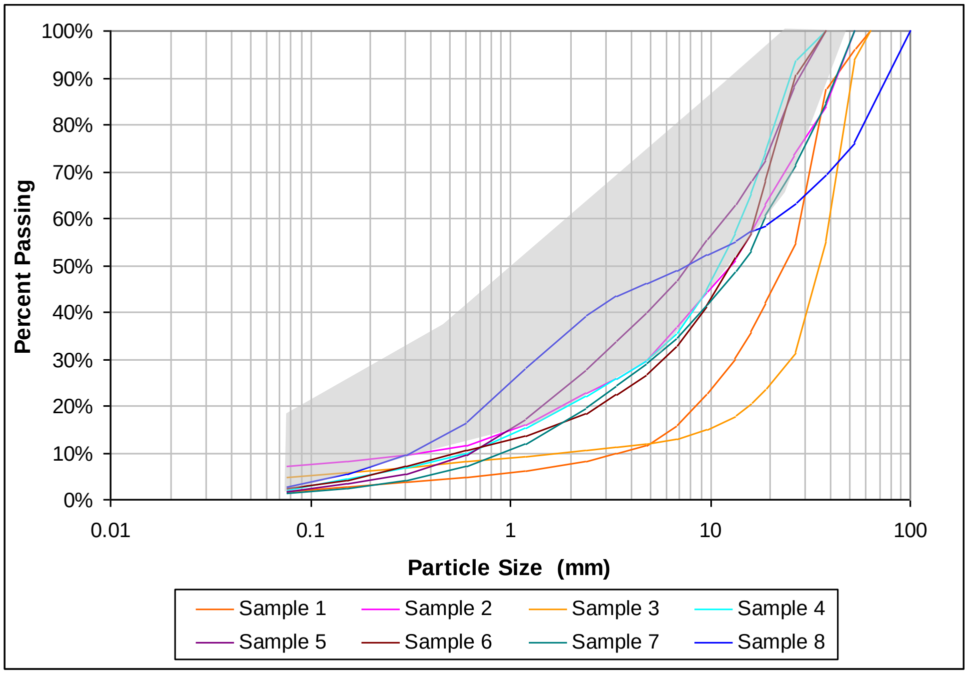

Figure 7 – Results from sieve analysis of east cape forest road aggregates

Analysis of the sieve test data shows that maximum permitted aggregate size ranged from 37.5mm to 100mm. The range of fines was from 1.4% to 7.2%. The coefficient of uniformity ranged from 8 to 73. These results show that a great variation exists in the grading of aggregates used on East Cape forest roads. Furthermore, most of the tested aggregates fall outside of the combined envelope for surface course aggregates – suggesting that the aggregates currently used in the East Cape region tend to use material that is too large and has insufficient fines to produce an effective surface layer.

However, the natural soil on which the roads are being built on the East Cape are predominately silty clays, dominated by fines. In most cases the natural soil is only lightly compacted, and very rarely are geotextiles or stabilisers, such as lime or cement, used to improve pavement engineering properties. The forestry companies recognise that over time the surface aggregates will be 'pushed in to' the natural soil to produce an aggregate/natural soil mix that acts as an improved layer. Further research is required to determine whether an existing aggregate grading specification, or a hybrid of several specifications, can produce a pavement that better meets the needs of an improved layer than the current aggregate does.

Conclusion

A formal survey of New Zealand forest roading engineers has commenced to determine the extent of current forest road engineering capability and deficiencies in New Zealand. Early results from this survey have identified conflicting views of what aggregate grading should be used for surfacing unsealed forest roads. A subsequent examination of a selection of aggregate grading standards demonstrated that the standards vary widely within and between countries. Furthermore, there is a considerable overlap between the specifications for surface course and base course aggregates. This variation and overlap between standards highlights the difficulty facing forest managers when attempting to determine the most appropriate aggregate grading standard for their unique aggregate sources and forest road conditions.

A range of East Cape aggregates was tested and found to have widely varied gradation. Furthermore, the tested aggregates fell outside of the envelope for surface course aggregates and, in some cases, also fell out of the envelope for base course aggregates. Further research is required to determine an aggregate grading standard that will best suit East Cape aggregate sources and conditions. This research will be conducted as part of the forest road engineering research programme underway at the School of Forestry, University of Canterbury.

Acknowledgements

We would like to acknowledge Hikurangi Farm Forests, Ernslaw One, Juken NZ for their support in this project.

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Understanding the Hazards of Thrown Objects: Incidents, Research and Resolutions

Dr. John J. Garland, PE[1] and Dr. Robert Rummer[2]

Abstract: Improved rotating cutting devices (teeth on a disk/drum or cutters on a chain) for forest operations have produced hazards for operators and others from thrown objects. Anecdotes and actual incidents show fatalities and serious injuries are possible and likely under certain circumstances. Some mechanisms for thrown objects are clear (thrown cutting teeth) while others are less obvious and need explanation (chain shot, thrown spears and stubs). Research on thrown objects and protective materials provides insights on the problems. Resolutions to the problems come from improved guarding, protecting operators and others, and changing operating practices. The effectiveness of a specific no-entry force field around the machine is questioned. Safety standards at the state, national, and international levels address the issues. Authors discuss implications for anyone working in the vicinity of cutting machines.

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Introduction

Rotating cutting devices used in woods work have improved the efficiency of forest operations immensely since their development. Chains on saws can travel 15,000 revolutions per minute (rpm) and heavy disks or drums over 1,700 rpm. The rotational energy coupled with cutting edges provides tools for cutting trees; masticating, chipping or grinding vegetation and debris; and even chewing up forest road surfaces. But what happens when the rotational energy is converted to translational energy in the form of thrown objects? What hazards are faced by operators and other workers? What are the actual mechanisms that throw objects? What does research tell us about the phenomenon? What can be done to protect people from these hazards? What are the implications for anyone working around cutting machines? These questions need assessment and response.

Incidents and Anecdotes

Forestry folks know there are hazards from thrown objects from some of the anecdotes circulating in the industry. There is the story about a saw tooth from a disc saw being retrieved from halfway through a skidder's engine block. How about the logging contractor walking the unit toward his operation and seeing something moving along the ground and hitting his steel-toed boot? He picked it up and recognized it as a saw tooth from his disk saw—an operation nearly a half mile away. There is an oak firewood section in a Texas saw shop that is split down the middle showing a disk saw tooth imbedded at least 10 inches into it (author observation).

There are also documented incidents that resulted in fatalities or injuries. Some are documented in the lawsuits where one of the authors served as an expert. For example, a Mississippi timber cutter walking to his vehicle past the landing where a wheeled feller-buncher was clearing hardwood saplings was struck by a blunt spear thrown from 40-50 feet away. The object did not penetrate the cutter but did internal injuries resulting in his death at the landing. In another case, a landing sawyer was limbing and topping a tree when he was knocked to the ground. He reached to his back and pulled out a four foot long, ~three inch diameter stick. He survived but lost his spleen and suffered other internal injuries. The stick had distinctive saw marks at the same spacing as the teeth on the disk saw that threw the object from ninety four feet (94') away. Similarly, a Texas sawyer was limbing and topping near the landing when he was struck in the head by an eight inch (8") long, five inch (5") diameter sweetgum stub from over three hundred thirteen feet (313') away from where the feller buncher was working. Other similar stubs were found some distance from where the sweetgums were growing. The sawyer was wearing a hard hat.

The Workers Compensation Board of British Columbia documented severe injuries to a harvester operator struck by a chain link (chain shot) that passed through a half inch (1/2") polycarbonate cab window. In another legal matter, a worker was struck in the abdomen by a chain link (chain shot) from a manual chainsaw operated about thirty five feet (35') away. Another worker was cutting a dead stump of a tree broken off by wind (~10-12' tall) when his chain broke. The section of broken chain flew through the air and impacted the nearby worker. The chain piece removed in life-saving surgery caused injuries similar to being shot by a bullet. A different incident caused injuries to a bystander at a demonstration of a forestry mulcher when a six foot (~5-6'), four inch (4") slab shot out from beneath the machine. The slab traveled just above the ground and then went vertical before striking the bystander standing with his colleagues eighty-five feet (85') away. While he survived, damage from the object was made worse by infections received during hospital treatment (MRSA). Other anecdotes and incidents demonstrate the hazards of thrown objects.

Mechanisms of Thrown Objects

Circular Cutting disks and drums can throw teeth that break or come loose along a tangent line from the circle at the point of release. There is little published information about the actual failure modes of disk saw teeth. Anecdotal reports suggest that loosening of mounting bolts may lead to detachment. Teeth may also fracture on impact with rocks or other debris. Operators report missing teeth or noting excessive vibration while cutting. In general, the assumption is that if a mounting bolt fails, the tooth would separate from the holder and be carried in the debris stream around the inside of the saw shroud. At the discharge point the tooth could be moving at the tip speed velocity. The rotational velocity in revolutions per minute (RPM) varies by machine type but many use the stored inertial energy of heavy rotating drums or disks operating from 1000 to about 1500 RPM. The rotating velocity may drop to half its original (or much more) during the cutting cycle and then recover as mechanical energy is added to bring the RPM up to a pre-set level. Typically operators stop the inertial rotating cutters by "grounding" the cutter in a stump or into the ground.

A survey of high-speed sawhead specifications identified over 40 models in current production. Older designs are still in use, but specifications were unavailable. Most of the designs (68%) rotated at 1300 RPM or greater, although the speeds ranged from 600 to 1650 RPM. Combining rotation with disk diameter reveals a narrower distribution with almost all designs (88%) working at a tip velocity that exceeds 85 m/s (~254 ft/s). The highest tip speed was 102 m/s (~316 ft/s). These survey data (Fig. 1) provide an indication of design trends, but are not comprehensive or weighted by numbers in service.

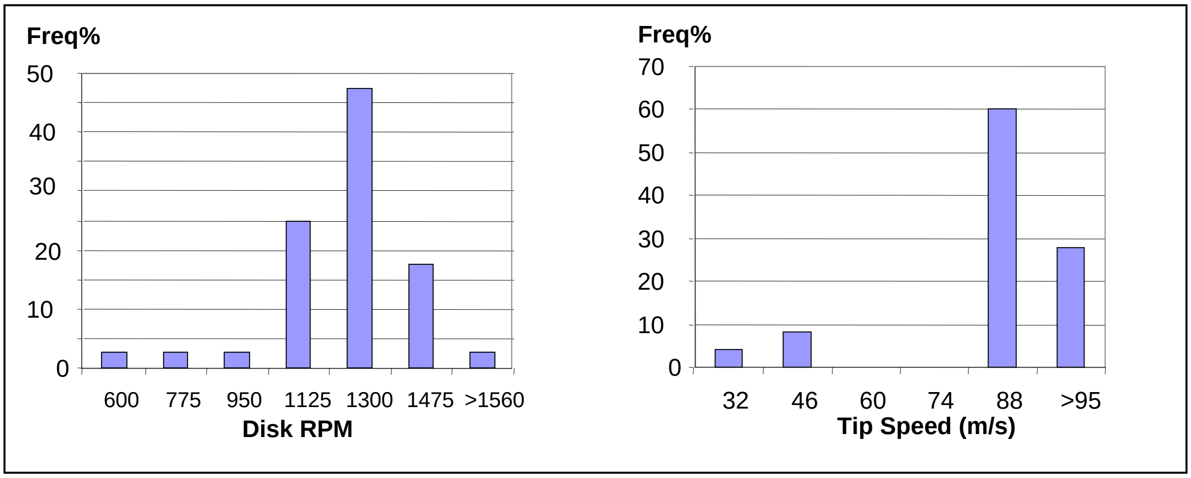

Figure 1. Comparison of high-speed sawhead designs.

Ballistic equations from high school physics provide a first look at how far rotating cutters can throw compact objects like saw teeth. Recall that the range (X) of a projectile does not depend on its mass and follows the equation:

$X_{max} = v^2 \sin(2\,\theta) / g$ where v=velocity, θ= flight angle from horizontal, g=gravitational constant (est. 32.2 ft/sec^2)

Thus, a tooth from a disk saw about two and a quarter pounds (2.25) leaving a fifty-five inch diameter disk (55") rotating at thirteen hundred (1300) RPM at an angle of forty-five (45) degrees might travel over three thousand feet (~3023').

Spear-like objects thrown from rotating cutting heads are more difficult to describe. Their flight trajectories take on aerodynamic characteristics making them unpredictable once they leave the machine. Initially, some rejected the idea that disk saws could throw spears. However, home woodworkers may have experienced a similar phenomenon when their tablesaw catches a scrap that comes against the rotating teeth and is thrown violently. One of the authors duplicated the mechanism by throwing three foot (3') long and one inch diameter (1") dowels into hay bales. The mechanism involves one tooth just catching (but not cutting) the spear and each successive tooth adding similar translational energy for a few teeth until the spear moves away. The energy transferred by this mechanism was impressive in that the dowels would be driven fourteen (14") inches into the hay bale. Once understood, the throwing mechanism could be predictably replicated. One manufacturer was unsuccessful at throwing 2x4's full scale with a disk saw on an excavator until a fellow added some liquid soap that mimicked sap and moisture to overcome friction. The reduced friction was more like woods conditions and they were able to throw 2x4's over two hundred (~214') feet across the gravel pit.

Stubs (small chunks of saplings/hardwoods) can be thrown some distance (>300') and injure unprotected workers. The throwing mechanism is apparently a vertical version of when a tablesaw nearly cuts off a segment and then barely touches the small cut section with the saw teeth. The small section is not cut but rather broken away and thrown violently in the direction the saw is turning. The documented Texas case of a thrown stub described earlier came from the practice of first clearing away saplings or hardwoods at about a foot off the ground. The machine could then access the larger trees for cutting nearer ground level. However, when the disk saw would return and pass through the cut stubs, several teeth would nearly cut off the stub while the following teeth would strike the stub, break it away, and throw it in the tangential direction from the saw. Examination of the stubs distant from where they were grown showed a small strap of wood/bark still attached. Attempts to simulate the thrown stubs by tossing samples against a turning disk saw were not successful. Some operators acknowledge the thrown stubs but cannot see what causes them.

Chain shot is the term used to describe when a piece of a saw chain is thrown into the operating area creating a hazard to workers. Manufacturers demonstrated chain shot by intentionally weakening chain and using high speed photography to see what happened. Not all broken chain ends up with a chain shot. When the loose end of the chain comes free and cracks like a whip, chain shot can often be seen in the high speed photos. There may be other conditions that produce chain shot--like the chain hitting something but they have not been replicated. Chain shot can occur both on chainsaws and cutting bars using chains on mechanized equipment. The first step is for the chain to break and a number of causes produce a break:

- Improper tension—chain too loose
- Improper chain maintenance or repair (hammered rivets)
- Damaged sprocket, bar and/or chain
- Improper bar and chain lubrication
- Defective chain
- Excessive chain speed—new chainsaws can drive chains faster than their design and harvesters can be adjusted to push chain to excessive speeds

Swedish researchers have estimated that a chain shot might occur within the frequency of about once every fifty (50) chains replaced during operations (Hallonborg 2002).

Research

Testing conducted by the US Forest Service examined how properties of polycarbonate glazing panels may affect the ability to resist penetration by saw teeth (Veal et al. 2003). Projectile size, type, impact angle, and velocity were varied. Alternative polycarbonate panels were tested to examine effects of panel size, thickness, construction, curvature, and temperature. The principle findings were that 0.5" monolithic polycarbonate was not sufficient to stop penetration of large sawteeth at high velocity. It was also determined that curved windows and larger openings were not more likely to fail than smaller openings. Panel temperature, however, was the most significant factor affecting performance of polycarbonate. All tests of monolithic material below 0°F resulted in brittle failure. This testing program serves as the basis for the development of new equipment standards described below.

Resolution and Results

Not surprisingly, when incidents occur and legal issues arise, there are responses to the perceived problem. Manufacturers, safety agencies, operators and others try various approaches to reduce the hazards of thrown objects. Safety professionals recognize the abbreviated hierarchy of hazard mitigation:

- Design/engineering modifications to eliminate the hazard
- Operating modifications to avoid human exposure
- Personal/machine protection with safety apparatus (clothing, protective structures, etc.)
- Warnings, labels, training, and signage

Industry responses include the approaches below.

<u>Guarding of Circular Disk Saws</u>—For some inertial saw types, the saw felling disk extends forward beyond the side guards or is about even with them. These saws present the most opportunities to throw objects. Additional length of the saw guards can minimize the chance for spear like objects to be thrown. In reality, only the guard on the side of the direction of disk rotation need be of sufficient length (right side facing a clockwise rotating disk). The length of the guard can be estimated by the tangential line from the disk extending past the guard. Using a reference of a clock face with 12 o'clock designated the direction of the straightforward line of the saw, only the tangential lines from about 10:00 to about 12:00 o'clock provide the need for guarding. Practically, to reduce the hazard of thrown spears, the length of the guard in the direction of disk rotation need only extend to a point where the tangential line from a likely thrown object would not strike the guard. The geometry of curves, middle ordinates, and deflection angles (δ) for such a guard where the cutting opening for the disk saw is half its diameter (the radius r) yields a guard of a length **G** beyond the leading edge of the saw as $\mathbf{G} = r/\sqrt{3} - r + (\sqrt{3}/2)r$ Where the saw diameter is a 2r=55 inch disk, then the guard length is **G**=~12 inches (12.19'')

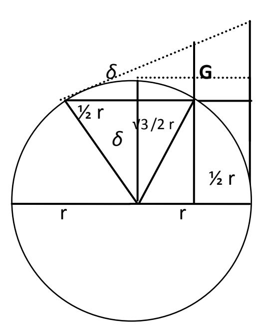

Figure 2. Geometry of disk saw and thrown objects.

Some disk saws have guards meeting this rough criteria while others fall short providing various hazards.

Guarding Rotating Drums – Cutting/mulching drums typically rotate forward in the direction of machine travel. Objects may be thrown forward as the cutting teeth strike the object or ejected from the bottom of the drum under the machine. Traveling forward the strike point of the rotating drum is most likely from the horizontal plane to the ground level, and pusher bars and head controls facilitate this geometry. Some machines lack any barriers to thrown objects ejected beneath the machine. Others use vertical chain links or strips of conveyor belting to impede the discharge of thrown objects. A hanging "bang plate" has also been suggested as a stopping barrier but is not evident on machines seen by the authors. Whatever barrier is used, it must extend to the ground level of the machine as the spears thrown by cutting heads may be less than 2 inches (2") in depth. The design of such barriers under the machine is beyond the scope of this paper but testing of such designs seems in order.

Improved Chains, Maintenance, Control of Chain Speed and Chain Catchers may reduce hazards of chain shot. Some saw chain may not be designed for the speed of the current saws and improperly maintained chain will have a point of weakness. The first step is to keep the chain from breaking. Some harvester operators have been known to increase the cutting speed beyond manufacturers' recommendations for their cutting heads. Chain manufacturers have adapted chains for higher speeds, harvester heads, and difficult operating circumstances. It is unclear whether the chain speed needed to eliminate chain shot would render the saw cutting features useless. In addition, some chain saws and harvester heads have "chain catchers" which may reduce the whip like action that produces chain shot. This is the approach proposed in the committee draft International Standard 11837.

Operating Modifications to reduce human exposure provide some immediate hazard reduction. For example, earlier training instructions often directed harvester operators to cross cut the stems immediately in front of them to see that cuts were made properly. Current guidelines call for avoiding the chance of chain shot directly at the operator by repositioning the stems for crosscutting where a chance breakage would not be in line with the operator. Operating modifications for disk felling heads have some practical problems. It may be possible to separate workers on the ground from cutting operations using space and timing of operations, especially when cutting saplings/hardwoods near the landing. However, other machines that operate nearer cutting operations and operations in the urban fringe put cutting heads proximate to people. Workers on the ground approaching a disk saw can recognize the direction of rotation and approach such machines from the opposite side. Discharge from cutting/mulching drums is typically rearward, leaving the machine approachable from the sides. However, such machines move and turn quickly in relation to the work ahead of them.

Personal/machine protection from thrown objects is under consideration. Workers on the ground probably cannot be protected from thrown objects with personal protective equipment. Operators of machines doing the actual cutting may benefit by sufficient protection to stop thrown objects with metal and polycarbonate materials. This is the subject of the new Draft International Standard 11839 "Test method for classification of panel material for thrown objects." However, other operators in machines that work near the cutting action may not have the protection against thrown objects, eg, skidding machines, trucks, loaders, and so forth. Adjacent roadways, structures/housing, and bystanders also present difficulties if exposure and likely thrown objects combine in worst case scenarios.

Warnings, labels, training, and signage are used when other approaches are not feasible or in combination with other approaches. It also depends on who these measures are intended to influence. Warnings, labels, signage and training can influence operators and others who can see, read and understand them. When a sign on the machine reads "Stay back 500 feet" yet you have to be within a hundred feet (~100') to see it on a moving machine, the warning value is limited. Large warning signs with letters over two feet (2') high are impractical to maintain on forest machines. It is extremely difficult to maintain lettering in a woods environment by typical painted warnings. Likewise, an operator's manual is unrealistic when it suggests the operator stop the machine when anyone is within a five hundred foot (500') radius and has violated the "no entry zone." Operator visibility and the need to attend to the work at hand limit what can be expected of an operator. Nonetheless, when operators do see someone trying to contact them or in harm's way, they will stop the machine to avoid injury. Some manufacturers or distributors apparently think such a "force field" relieves them of liability for thrown objects. It is difficult to even specify a distance that would eliminate hazards of all thrown objects given that some can fly great distances, e.g., saw teeth. Wood chips may not be dangerous beyond fifty feet (50') while chunks fly over three hundred feet (300'). The use of an advisory warning of a distance around a machine where there should be no exposure to thrown objects comes far down the list of mitigation efforts needed to prevent injuries. Relying on a distance warning rather than providing appropriate guarding seems a vulnerable position for manufacturers. Who should specify such a warning distance is also a problem when a base machine manufacturer supplies a carrier to an attachment provider who uses cutting components from two or more suppliers. Further complications arise when domestic and foreign companies are involved. The reality is that the best approach seems to be avoiding throwing objects from the machine itself.

Safety Standards

Safety standards for operator protection and machine guarding are applied at the state level (where they exist), the federal level for logging operations, and international standards that are referenced in both state and federal standards. Furthermore, manufacturers of forestry equipment sell in an international market and generally adhere to international guidelines. It is important to recognize that the various standards apply to different stakeholders in the forestry safety picture. OSHA and state safety standards generally apply to employers and include a mandated enforcement component. Equipment manufacturers, on the other hand, are guided by consensus standards. In the US, forestry equipment standards are developed by the Society of Automotive Engineers (SAE) and define generally accepted practices. At the international level, the International Organization for Standardization (ISO) develops global consensus standards. Consensus standards are voluntary and compliance is at the manufacturer's discretion. The forest equipment industry further complicates the issue as multiple manufacturers may be involved. For example, the base machine may be built by an excavator manufacturer and then converted into a forestry application by a third party company or even the end-user.

Federal Occupational Safety and Health Administration (OSHA) standards apply to all employers in the US unless superseded by approved state-level safety codes. OSHA addresses general machine guarding: "One or more methods of machine guarding shall be provided to protect the operator and other employees in the machine area from hazards such as those created by point of operation, ingoing nip points, rotating parts, flying chips and sparks."(1910.212(a)(1)). Furthermore, "The point of operation of machines whose operation exposes an employee to injury, shall be guarded." (1910.212(a)(3)(ii)). The logging operation codes on guarding require: "Each machine used for debarking, limbing and chipping shall be equipped with guarding to protect employees from flying wood chunks, logs, chips, bark, limbs and other material in accordance with the requirements of subpart O of part 1910"(1910.266(f)(8)(ii)). Subpart O refers to shop and plant industrial processes that are difficult to relate to logging operations but employers have the general obligation cited above. In the federal codes covering logging operations, protective structures address the hazards of material falling, dropping or jill-poking into the cab area rather than thrown objects. The basic content of the federal code covering logging operations comes from the mid 1990's when machine cutting/mulching was much less than now.

Oregon has adopted a more definitive Logging Safety code. The Oregon Forest Activities Code has had three major revisions since 1980 with latest rule changes affecting operator protection current to 2008. Unlike most states, Oregon's code not only covers logging operations but many other forest operations where cutting/mulching machines are used: site preparation, fuels reduction, silvicultural treatments, and so forth. However, the definition of "Operator Protective Structure" lists "whipping saplings, branches, jill-poking and snapping winch lines….and other hazards" (437-007-0025 Definitions). Later standards specify when the need for protection is required: "**(1)** Cabs and protective structures for machine operators must be: **(a)** Provided when machine use exposes an operator to hazardous conditions.(437-007-0770 Protective Structures for Operators, General Requirements)**.** The federal requirement for enclosed cabs for forest machines is more specific in Oregon standards: "**(7)** Each machine used in forest activities that is manufactured on or after July 1, 2004, must have a fully enclosed cab for the operator which prevents objects from entering the cab."(437-007-0775 Protective Structures For Operators, Machines Manufactured On Or After July 1, 2004). Many of the Oregon standards reference national or international standards of performance (SAE or ISO) for guarding and protection. Oregon standards do not specifically address the hazards of thrown objects as discussed above. The Oregon code advisory committee is aware of the hazards of thrown objects but has not suggested standards changes as of this date.

International safety standards for forestry machines are found in ISO 11850 “Machinery for forestry—self-propelled machinery—safety requirements.” In section 5.2.2.3 it states that, “operators shall be protected from hazards caused by failed saw chains, teeth and similar failures using polycarbonate or equivalent glazing, or other appropriate guards or shields, or both.” Two further documents are under development. ISO 11839 specifies a test method to classify panel material that may be applied to protect machine operators from thrown saw teeth. The intent is to provide manufacturers with quantitative information about the ability of materials to resist impact failures. The problem of chain shot protection is different and the ISO committee has determined that the preferred approach is to catch broken chain in a way that minimizes the whiplash effect. This is being specified in ISO 11837 “Machinery for forestry – Saw chain shot guarding systems – Test method and performance criteria”. The scope of the ISO forestry committee limits work to the design of the equipment itself and thus does not address worksite management or other safety approaches noted above.

Summary

Thrown objects are a relatively new hazard in forest operations. As described in this paper, there are many potential incident scenarios that present unique challenges to engineers and safety professionals. In the international arena, work is underway (though not complete) to establish standards to protect operators of cutting and mulching machines. Equipment manufacturers and material suppliers are working on developing improved glazing materials and cab enclosures based on current research. State and federal logging safety codes must develop appropriate worksite direction for appropriate machine guarding and work practices to alert operators and others to the hazards. The Federal Logging Safety section of OSHA does not adequately address this new hazard and should be revised. The concept of a “no entry zone” of a specified distance, e.g. 500 feet, is unrealistic for many forest operations. Cooperative efforts from all involved to improve machine design followed by enforcement, training and warnings would seem to be the most effective.

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FPInnovations - Maximizing value from the forest

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Abstract

FPInnovations is the merger of FERIC, Forintek and Paprican and a partnership with the Canadian Wood Fibre Centre, which is part of Natural Resources Canada. FPInnovations works towards optimizing the forest sector value chain by capitalizing on Canada's fibre attributes and developing new products and markets. The presentation provides an overview on FPInnovations and describes the main focus of its research and development activities. More particularly, it presents the pivotal role that Forest Operations plays within that structure and the linkages that have been developed with both the upstream side (forest management and genetics) and the downstream side (manufacturing and marketing). Initial results from this integrated approach to forestry research are also being presented.

What is FPInnovations?

FPInnovations was created in 2007 through the merger of FERIC, Forintek, Paprican, and the Canadian Wood Fibre Centre of Natural Resources Canada, to create the world's largest private, not-for-profit forest research institute. With over 600 employees located throughout Canada, FPInnovations unites the individual strengths of each of these forest research and development institutes into a single entity.

The main goal of FPInnovations is to strengthen the Canadian forest sector's global competitiveness through research, knowledge transfer and implementation, in the context of a changing marketplace. Its activities span from genetics and harvesting operations to wood and paper products and beyond, all based on marketplace realities.

Some of the current research priorities include:

- Forestry and forest operations
  - identify and inventory desirable fibre quality attributes
  - develop solutions for a bioeconomy
  - improve forest productivity and maximize fibre delivery and value
  - apply precision forestry techniques to optimize operation and management processes
  - deliver solutions to suppress and manage wildland fires
  - promote environmental sustainability

- Wood products

  - apply advanced technology to reduce production costs and improve manufacturing processes
  - create innovative solutions to increase the quality and variety of specialty, wood-based products
  - provide solutions to optimize fibre usage
  - develop the next generation of wood construction products and system solutions
  - collaborate internationally to strengthen building codes and standards

- Pulp, paper and beyond
  - optimize pulp and paper processes and enhance traditional paper products
  - conceive revolutionary paper products
  - identify new product streams by extracting chemicals and energy from forest biomass
  - build cellulose-based nanomaterials to produce high-performance paper and packaging
  - promote environmentally sustainable mill practices

FPInnovations' mission is: *To work towards optimizing the forest sector value chain by capitalizing on Canada's fibre attributes and in developing new products and market opportunities within a framework of environmental sustainability.*

This aspect of FPInnovations' mission is delivered through a program called "Value Chain Optimization" which is one of four Flagship Innovation Programs.

What is value chain optimization?

Value chain optimization means…
....understanding customer needs, leveraging suppliers' skills and managing to optimize the overall process, not just its discrete pieces.

The idea of value chain optimization is based on the concept of supply chain management, with the notion of product value added to that of costs. A value creation network is simply a virtual business based on information sharing and joint planning. Suppliers are an important element to consider since they are network partners. The main competitive advantages for a company implementing value chain optimization are cost and net product value, which translate into the highest margin possible on sales.

The network can improve a chain's performance by strengthening its connections or links. The decision-making and steering system must be flexible so as to react rapidly to change. The decisive competitive advantage is the prime consideration to ensure good coordination and integration between chain links. It can be further improved by optimizing the network overall. The following table compares the differences between the "traditional" and the "value chain" business model.

Table. Comparison between the "traditional" and the "value chain" business model.

	Traditional	Value chain
Sharing of information	Little or none	Extensive
Value focus	Cost/price	Value/quality
Direction	Raw material	Differentiated product
Main perspective	Supply push	Demand pull
Organizational structure	Independent	Interdependent
Philosophy	Self optimization	Chain optimization
Business relations	Opponents, seeking to maximize individual profits	Co-operators, seeking a win-win situation

<u>Why is the Canadian forest sector interested in value creation networks?</u>

Traditionally focused on cutting costs in isolated business units, the Canadian forest industry is now under much stress, and for many reasons. The industry must get away from commodity products by concentrating on the inherent advantages of its forests and developing new products that are not only easier to trace, but that are also certified and highlight Canadian wood and expertise. Simply put, the Canadian forest industry can no longer compete on price alone with many countries that enjoy lower cost structures; it must also capitalize on the variety and quality of its extensive forest resources and compete by offering higher quality and value products that the competition can't produce for lack of the same quality raw material and knowhow.

To achieve this goal, the Canadian forest sector must embrace value chain optimization networks as a new business model. The implementation of value chains in the forest industry should make it possible to take full advantage of forest resources and expertise, way beyond what any single business could do on its own.

<u>How to implement value chain optimization in the forest sector?</u>

The goal of value chain optimization is to provide integrated solutions to enable the right tree to be grown, harvested, transported and manufactured into the right products to be sold in the right market. For FPInnovations, optimization of the value chain means that we will approach the genome to market concept in a holistic and integrated way. We will look at strategic linkages of different parts of the value chain and use innovation and technology to explore new linkages and new solutions to enhance value and margin. This involves shifting from a market "push mode" to a "pull mode" (meaning thinking market before product) and developing new solutions to enhance value and maximize profit.

To achieve this we must:

- Improve net value
- Improve decision processes
- Automate operations
- Optimize logistics

- Develop market-driven processes (pull)
- Implement new business models (e.g., share profits/costs)
- Create full partnerships with suppliers (e.g., contractors)

Concepts such as precision forestry, logistics, flexible manufacturing and so on will be used to give industry the ability to merchandize cost effectively at each step of the entire value chain.

Where does the logger fit in all this?

Harvesting and transportation are key links in a value chain optimization network. The ultimate objective is to maximize returns from existing forests by first identifying the attributes of different forest/tree types that can be exploited to manufacture products of higher quality and value. Once these attributes are identified within a forest type, within species, within different portions of a tree and ultimately within a log, this raw material needs to be segregated and delivered to the processing facility that can best take advantage of its specific attributes. Logging is the first place where this sorting can start. In a value chain optimization system, turning a heterogeneous resource into a uniform raw material through optimizing processing, sorting, segregation and multiple transportation delivery sites takes an ever-increasing importance. Whereas sorting by species or separation by log sizes are already common logging practices, value chain optimization will mean more sorts and more sophisticated merchandizing strategies. In such a scenario, logging, which for most companies was traditionally perceived as a cost, becomes an integral part of a production process which aims at adding value to the product at every step of the way through the chain.

In value chain optimization, harvesting and transportation are no longer activities that are disconnected from the mill manufacturing process and markets. The name of the game is no longer to supply the mill with fibre at the lowest cost. The objective becomes to supply the (right) mill with a raw material that will allow it to manufacture a product that will fetch the maximum profit margin in the market. A raw material of higher quality (e.g., fresher wood) may actually cost more at the mill gate, but may result in savings at the manufacturing phase which compensates many times for the extra cost.

Such an approach necessitates a clear understanding of the interrelationships between raw material characteristics, milling processes, product quality and cost. Modeling of the value chain from forest to market becomes an important decision making tool.

The loggers and forest engineer will still need to control costs, but their opportunity to contribute to the value of the end product will increase.

Let's remember the basics: profit = value-cost, and profit can be increased by decreasing costs but also by increasing value. The cost of fibre isn't as important as its worth.

Financial feasibility of a log sort yard handling small-diameter logs

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The value of the trees removed in fuel reduction thinning and restoration treatments could be enhanced if the wood were effectively evaluated and sorted for quality and highest value before delivery to the next manufacturing destination. However, past studies indicated that costs for running a log sort yard for small-diameter logs could outweigh the revenue generated by sorting and pre-processing those logs. This study was to evaluate the financial feasibility of running a log sort yard that serves as a log market to buy and sell small-diameter logs in western Montana. We modeled a log sort yard to process and sort small-diameter logs to seven products (sawlogs, house logs, stud logs, peeler logs, post & pole, pulpwood, and hog fuel). The financial feasibility of a log sort yard would largely depend on prices that the yard pays and product revenues that the yard receives from selling sorted and processed logs. The delivered log input costs represent 78.1% of the total sales revenue while the yard's operating costs account for 17.7% of the revenue. The log sort yard operating cost was $3.85/piece or $71.46/MBF. Species and product types were important factors determining gross revenues. Douglas-fir would make the biggest contribution to the yard's gross margin since this species both represents the largest volume (45% of the log) into the log sort yard and produces high value products (house logs and veneer logs).

Introduction

The value of the trees removed in fuel reduction thinning and restoration treatments can be enhanced if the wood can be effectively evaluated and sorted for quality and highest value before delivery to the next manufacturing destination. However, past studies indicate that costs of operating a small-diameter log sort yard often outweigh the revenue generated by sorting and pre-processing those logs (Sessions et al. 2005; Dramm et al. 2003; Sedney 1992). Small-diameter logs often yield lower product value and cost substantially more to process on a per unit (volume) basis than large-diameter logs. For example, it takes about four times as many 6-inch small-end diameter logs to equal the same volume found in 12-inch small-end diameter log of the same length (Barbour 1999). Small softwood logs also have relatively uniform log quality, leaving less opportunity to improve value recovery that may cover expenses incurred in pre-processing and sorting these logs into different grades (Dramm et al. 2002).

Log procurement costs and value recovery of log products are highly variable depending on local economic conditions in the forest products industry and resource availability, while log sort yard costs can be somewhat controlled by effective business and operations planning. The operational objectives of a log sort yard should be clearly identified, and then a proper business plan needs to be developed (Howe and Bratkovich 1995, Safranski and Kwon 1991). In our study, a sort yard is proposed to 1) improve utilization of small logs from fuel reduction thinning and restoration treatments; 2) process a mix of logs with various quality and wood properties to desired specifications for diverse wood processing firms; 3) improve and expand local wood processing business by providing a consumer-specified supply of raw material to optimum end-uses; and 4) provide inventory and sorting services.

Under these objectives, a team of USDA Forest Service and university researchers was assembled to conduct a market analysis for small wood and forest biomass-based products and evaluate the costs and benefits of a centralized processing and sorting system (i.e. log sort yard) in conjunction with a series of fuel reduction treatment scenarios on a landscape level. The specific objectives of this study were to evaluate:

- the financial feasibility of running a log sort yard
- factors critically affecting financial feasibility
- sensitivity analyses on key cost and revenue factors, and
- cost components in log sort yard operations

Log Supply

In order for a log sort yard to be successful, it must have a steady supply of diverse logs with varying characteristics that are recognized in the marketplace (e.g. size, species, grade, etc.). The projected log supply also helps to dictate the size of the sort yard and the type of capital equipment it should employ to handle logs efficiently. The log supply information has been developed by a group of researchers in the USDA Forest Service Rocky Mountain Research Station in Missoula and the University of Montana, based on the projected fuel reduction thinning treatment scenarios in western Montana. The following summary of log supply information was used for this study:

- 31,000 thousand board feet (MBF) per year or 27 truck loads/day (4.5 MBF/truck load)
- Operating 250 days/year; 664,063 tree-length logs per year or 2,656 pieces/day.
- Small-diameter logs: 65% of logs produced from the trees with diameter at breast height (DBH) less than 9 inches.
- A mix of conifer species: value in ( ) indicates percentage of the total input volume of logs.

- subalpine fir (*Abies lasiocarpa*, 11.4%)
- Douglas-fir (*Pseudotsuga menziesii*, 45.3%)
- Englemann spruce (*Picea engelmannii*, 8.1%)
- grand fir (*Abies grandissime*, 1.3%)
- lodgepole pine (*Pinus contorta*, 20.0%)
- ponderosa pine (*Pinus ponderosa*, 12.6%)
- red cedar (*Thuja plicata*, 0.3%)
- western larch (*Larix occidentalis*, 0.9%)

Sort yard Operations and Financial Analysis

Log sort yard design considerations and operations highly depend on the volume and number of logs to be handled, sorting and processing requirements, and inventory options. Based on the log supply information, a medium size sort yard as defined by Sinclair and Wellburn (1984) would efficiently handle up to 250MBF/day of log volume. The basic functions of a log sort yard include receiving/scaling, unloading, transport, grading, merchandising, sorting, reloading, and log storage/inventory. Log sort yard equipment for each function was selected based on the equipment selection guide from Dramm et al. (2002) and personal communications with log sort yard operators and forest products professionals The financial analysis was performed using the Log Sort Yard Cash Flow Analysis (LSY) model (Bilek, 2008). LSY is an integrated financial model which provides ten-year cash flows and before- and after-tax net present values (NPV), internal rates of return (IRR) and other financial information. It can also be effectively used for break-even and sensitivity analysis to estimate maximum log procurement costs that maintain a desired return on investment. The assumptions shown in Tables 1 and 2 were made to perform the financial analysis of a log sort yard handling small-diameter logs.

Table 1. Delivered product output values (2007) by species and product types which include costs of hauling products from the log sort yard to markets in western Montana.

	Product Output Name						
	Saw log	Stud log	Veneer log	House log	Post & pole	Pulp log	Hog fuel
Log Species	($/MBF)						
Ponderosa pine	443	-	-	-	-	224	159
Douglas-fir	-	354	444	1,471	-	224	159
Lodgepole pine	443	354	-	1,471	450	224	159
Engleman spruce	443	354	-	1,471	-	224	159
Western larch	-	354	444	1,471	-	224	159
Red cedar	443	-	-	-	-	-	159
Subalphine fir	-	309	-	-	-	224	159
Grand fir	-	309	-	-	-	224	159

Table 2. Cost assumptions by equipment type used in the log sort yard

Capital equipment name	Initial cost ($)	GDS life (years)	ADS life (years)	Economic life (hours)	Economic life (years)	Salvage value ($)	Horse power	Operating hours (hrs/shift)
Front end loader (CAT 980)	559,000	5	6	10000	5	55,900	318	9
Front end loader (CAT 966)	377,000	5	6	10000	7	37,700	262	5
Cut-to-length processor (used)	200,000	5	6	10000	5	20,000	215	5
Tracked loader (CAT 325d FM)	438,000	5	6	10000	5	43,800	204	9
Log merchandising/sorting system	550,000	5	6	15000	7	55,000	150	9
Grinder (Peterson 2710C - used)	150,000	5	6	5000	7	15,000	475	2

Notes:
- GDS life: equipment's depreciable life under the Internal Revenue Service (IRS)
- ADS life : equipment's depreciable life under the IRS
- Diesel fuel cost: $4.25/gallon; Oil cost: $8.00/gallon

Results and Discussion

<u>Financial feasibility of running a log sort yard</u>

Based on the log input and commercial equipment data supplied, the preliminary financial feasibility of a log sort yard processing a mix of mostly small-diameter logs in western Montana looks promising. The financial indicators are shown (Table 3).

Table 3. Summary of financial indicators over the 10-year project planning period

	Net present value ($)	Nominal[1] IRR (%)	Real IRR[2] (%)
Before finance & tax[3]	2,891,150	28.9%	25.1%
Before tax[3]	3,103,599	41.1%	37.0%
After tax[4]	2,380,993	28.0%	24.3%

[1] Internal rate of return including an inflation rate (3%)
[2] Internal rate of return over and above an inflation rate (3%)
[3] Net present values before finance & tax and before tax are discounted at 11.6%
[4] Net present value after tax is discounted at 7.0%

An investor would earn a 24.3% internal rate of return after accounting for inflation and income taxes from the log sort yard business under the assumptions that were made in the economic analysis including an average delivered log input value of $300/MBF. The present value of additional after-tax profits is about $2.38 million. This present value is in addition to the calculated weighted average nominal after-tax return on capital of 7.0%. The importance of the various cost factors could be seen by looking at their relative importance with respect to sales revenues since all costs must first be deducted from revenues before profits can be determined. At $300/MBF, the delivered log input cost represents 78.1% of the total sales revenues earned by the proposed sort yard over a 10-year period (Table 4). The percentage of delivered log input costs to the total cost is quite sensitive to the price change for the logs being delivered to the log sort yard. This explains why the real after-tax IRR sharply decreases with increases of the average delivered log input costs, and reinforces the importance of procuring logs at the lowest possible per unit cost.

The second largest cost factor was the sort yard operating cost, which represents 17.7% of the total sales revenue (Table 4). Within the operating cost, the direct production cost including wages for hourly employees and machine operating cost share the largest component (10.2% of the total sales revenues), followed by the capital investment ($2,274,000 at Year 0) in major equipment (3.8% of the total). It should be noted, however, that equipment should be selected to reflect the work load for each piece of equipment and put together in a system that will perform its function at high efficiency and minimum cost. While the operating cost could be controlled and minimized through well-designed project planning and efficient operations, delivered log input prices and product output prices normally depend on market conditions (i.e. beyond an investor's control). Fixed and overhead costs in Table 7 include land & building, labor for salaried employees, and other administrative expenses.

Table. 4. Summary of cost and revenue.

	After-tax present value ($)	Values based on input volume ($/piece)	($/MBF)	Percent of sales (%)
Gross revenue				
Sales revenue	104,665,594	21.18	384.30	100.0
Log input costs	-81,706,863	-16.53	-300.00	-78.1
Subtotal (gross margin):	22,958,731	4.65	84.30	21.9
Operating costs				
Capital cash flows	-3,954,798	-0.80	-14.52	-3.8
Direct production costs	-10,671,941	-2.16	-39.18	-10.2
Fixed costs and overheads	-3,451,125	-0.70	-12.67	-3.3
Working capital	-410,751	-0.08	-1.51	-0.4
Subtotal:	-18,488,615	-3.74	-67.88	-17.7
Financing, capital gains,and taxes				
Financing cash flows	-93,051	-0.02	-0.34	-0.1
Capital gains and income taxes	-1,996,072	-0.40	-7.33	-1.9
Subtotal:	-2,089,123	-0.42	-7.67	-2.0
Net profit (loss)	2,380,993	0.48	8.74	2.3

Product value recovery at the log sort yard

The yard would make its largest margins by handling Douglas-fir. This species accounts for 45 percent of the total volume but 46.8 percent of the total gross margin. In contrast, subalpine fir and grand fir had negative gross margins at an input cost of $300/MBF. This means that the yard would be losing money by processing these species. Veneer logs and sawlogs should be the first choice to produce since these products allow recovering highest values and makes the largest contribution, representing 40% and 42% of the gross margin, respectively. Post & pole also generate a positive contribution (14%) to the gross margin. Pulp log and hog fuel would cause large losses if these were the primary products for logs delivered to the yard. These low-valued products will be inevitably produced as a result of the yard's merchandising process, but their production should be minimized as much as possible.

Log sort yard operating costs

The proposed log sort yard operating cost based on pieces handled is projected to be $3.74/piece or $71.46/MBF including volume loss due to log breakage and processing loss. The proposed western Montana log sort yard should generate net revenues greater than $71.46/MBF to be financially feasible. At current log input price ($300/MBF) and market product prices, all the species (except subalpine fir and grand fir) coming into the log sort yard would generate net profit greater than $71.46/MBF. This result further emphasizes that log input price and product market value would greatly influence on the economic feasibility of a log sort yard.

In the proposed yard, direct production costs account for $41.25/MBF, or nearly 60% of the operating costs, and these direct production costs are split closely between equipment operating costs (not including labor) of $17.83/MBF and total hourly wages and employee accessories costs of $23.42/MBF. Capital cost ($15.28/MBF), fixed costs and overhead (13.34/MBF) and working capital ($1.59/MBF) make up the remaining to $71.46/MBF. It should be noted that log input prices and log output market values may not be controlled, but operations efficiency in the proposed log yard should be maximized to lower total operating costs.

Conclusion

The financial feasibility of a log sort yard that processes primarily small logs largely depend on prices that the yard needs to pay and product revenues that the yard would receive from selling product outputs. Under most scenarios delivered log input prices represent two-thirds to three quarters or more of the total log sort yard cost, and it is critical for a log sort yard to procure logs at a minimum cost to be successful. It was further noted from the breakeven analysis that under the initial cost analysis and assumptions for the log market at the time of this analysis in western Montana, a medium-sized log sort yard should annually process at least 22,709 MBF of logs to earn the minimum after-tax required rate of return (7.0%) on investments.

The direct benefits of log merchandising at a centralized sort yard could be accomplished maximizing revenue to cover all the log sort yard costs and generate profits as a result of the sort yard operation. Species and product types are important factors determining gross revenues. Douglas-fir, accounting for 45 percent of the total volume, generates the largest margins (46.8% of the total gross margin) by sorting and merchandising those logs in a log sort yard. Subalpine fir and grand fir have negative gross margin at an input cost of $300/MBF. Sawlogs made the highest contribution to the total gross margin (42%), followed by veneer logs (40%) and post & pole (14%). House logs generated the highest individual product profit margin, but the total volume of house logs represented only 0.2% (or 3% of the gross margin).

Preliminary financial feasibility analysis for a log sort yard in western Montana processing largely smaller-diameter logs indicates that such a yard might be successful. Given the assumptions used in our analysis, the financial indicators of net present value and internal rate of return are favorable. The projected log sort yard operating costs of $3.74/piece input or $71.46/MBF indicate the magnitude of value that must be added by the sort yard operation in order for it to be financially viable. These cost figures suggest that the financial viability of a log sort yard handling mainly small-diameter logs (less than 10 inches in large-end diameter) in western Montana would be a challenge to achieve, although it looks possible under the assumed market conditions. It should be further noted that the success of any log sort yard would be highly depend on the ability of the yard to fill a function of improving value recovery and utilization that is not being realized for various reasons such as log supply and market conditions.

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Application of Hook-lift Trucks in Centralized Slash Grinding Operations

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Abstract

Chip vans are the most typical, commonly used mode of transporting processed woody biomass, provided the roads are suitable for the truck. Previous studies indicate using trucks that effectively negotiate adverse road conditions such as sharp curves and steep grades improves access to forest residues (i.e. logging slash) located in remote areas. This study evaluated the operational performance and costs of a biomass harvesting system utilizing a hook-lift truck in centralized grinding operations in northern California. A standard time study method was used to find the productivity and costs of the biomass recovery. Slash on site was loaded into 40 cubic yard bins by an excavator and then transported to a centralized grinding site nearby (less than 3 miles). To evaluate the effect of slash conditions on productivity, slash types were characterized into four pile types in slash arrangement and three categories by in material size. Productivity for different machines varied from 10 to 37 BDT/PMH, with a total production of 267.5 BDT over 70 hours. Production cost ranged from $6.30 to $16.22/BDT, with a total system production cost of $48.08/BDT at 36% moisture content. The overall system productivity was significantly affected by adverse road hauling distances, slash pile type, and diesel fuel price. Slash pile arrangement and material size were found to have a significant effect on productivity of loading. Typical size material arranged or piled by processors (pile class 2) was found to be the most effective pile type when considering loading productivity, yielding the smallest predicted cycle time (36 seconds). Discounted cash-flow analysis indicates that a full scale production operation would be financially feasible with a net present value of $277,822 at the end of a ten year period.

Introduction

Rising energy costs, concerns about emissions from fossil fuels, and the threat of wildfires have sparked interest in the recovery and removal of woody biomass for multiple benefits (Evans 2008). Woody biomass, including sub-merchantable trees, small diameter trees, tops, limbs, logging slash, produced from mechanical thinning and conventional saw-timber harvesting creates an opportunity for generating power (Han et al. 2004).

The demand for bioenergy and the feedstock used in the process is growing. In recent years more than 20 states across the U.S. have adopted renewable energy portfolios or standards (Nicholls et al. 2008). These standards typically include goals of up to 30% increase in renewable energy production (megawatts) within a 10-15 year time period. Twenty percent of all biomass used for bioenergy comes from the forestry sector, but improvements in the supply of feedstock is necessary to meet the demands of today's renewable energy development and to better utilize biomass that is currently being wasted.

There are many opportunities to harvest woody biomass from forested land across the United States. Fire hazard reduction has become increasingly important due to the potential risk of catastrophic forest fires in the western United States, where 397 million acres are in need of fuels reduction (USDA Forest Service 2000). Sub-merchantable materials produced from fuel reductions could be communited for energy production. Logging slash after traditional sawlog harvesting are often piled and burned. Approximately 41 million dry tons per year of forest residue produced by traditional logging and land clearing operations goes uncollected (Perlack et al. 2005). These materials have long been a useful but underutilized byproduct of forest management activities due to limited access and high costs associated with collection and transportation (Evans 2008; Han et al. 2004).

Although extensive biomass resources are physically available, barriers to utilizing biomass all point to issues surrounding: harvesting, collecting and transporting to markets (Nicholls et al. 2008). Forest residues are often not utilized because collection and transportation costs are greater than the market value of the materials (Withycombe 1982). Chip vans are the most cost-efficient mode of transporting woody biomass, provided the roads are suitable (Rawlings 2004). Unfortunately, large amounts of woody biomass cannot be collected even when it is located in close proximity to the market, because of adverse road conditions (Tiangco et al. 2005). Using smaller more negotiable trucks such as hook-lift trucks (Fig. 1) that can access remote locations ensures removal of materials (Han et al. 2008).

Figure 1: Hook-lift truck

The overall objective of this project was to determine the operational cost and performance of a logging residue recovery system. In this study our emphasis was given to an integration of hook-lift trucks which were used for hauling slash on a short distance (< 3 miles) with a centralized grinding operation. Important variables, such as hauling distance and moisture contents, were itemized to understand their effects on productivity of collection and transportation. In particular, slash piles were characterized to evaluate the effect of slash type on productivity, based on arrangement and size of slash materials.

Methods

Study Sites

Three clearcut harvest sites were located on Green Diamond Resource Company forestland in northern California. These sites are part one timber harvest plan and range from 7 to 32 acres in size. The vegetation at each site varied but was generally dominated by small Douglas-fir (*Pseudotsuga menziesii)* and small redwood (*Sequoia sempervirens)*. A forester from Green Diamond Resource Co. suggested these sites were expected to yield anywhere from 50-75 tons/ac from clearcut operations (Alcorn 2008). Data was collected across a wide variety of slope conditions (0-30%). There were many slash pile types in terms of size and arrangement present across these sites (Fig. 2). The round trip distance from each harvesting site to the centralized grinding site ranged between 0.90 to 5.22 miles (Table 1).

Table 1: Road type, one-way distance, and average travel speed.

Harvest site	**Spur road**	**Dirt road**	[2] **Gravel road**	[1] **Gravel road**	**Total**
	-------------------------------(miles)------------------------------				
Unit A	0.53	0.29	0.68	1.64	2.61
Unit B	0.25	0.92	0	1.58	2.5
Unit C	0.25	0.04	0	0.41	0.45
Avg. Speed (miles/hr)[0]	5.3	8.0	18.0	22.7	

[0] Average speed = distance/observed time traveled

[1] Gravel road = double lane rocked road

[2] Gravel road = single lane rocked road

Dirt road = single lane seasonal dirt road constructed with native soils

Spur road = unimproved temporary dirt spur within harvest unit

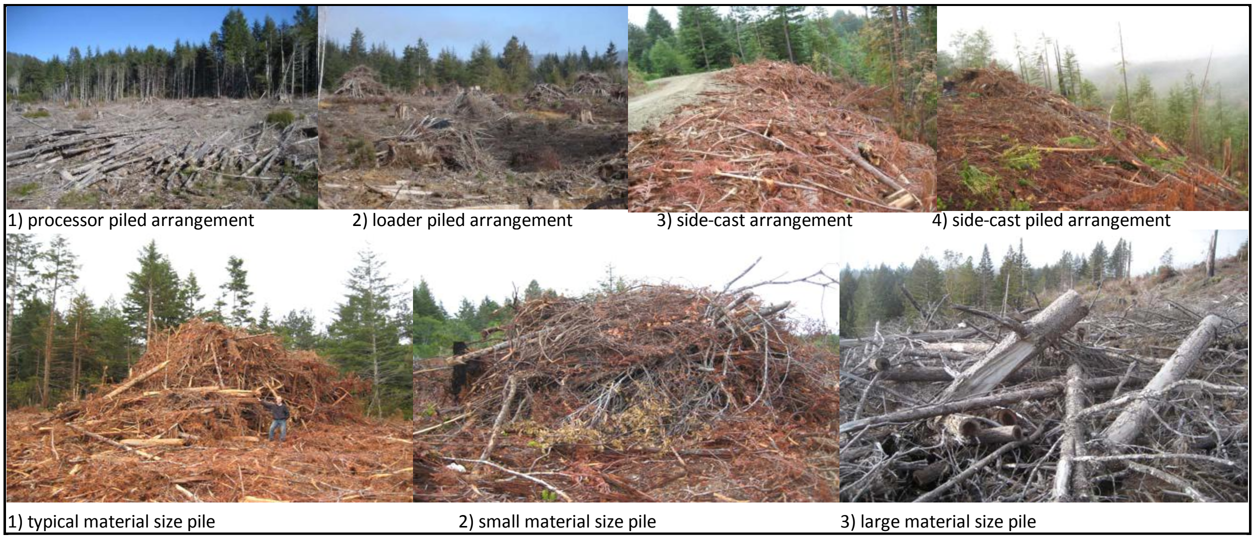

Figure 2: Slash pile classification by arrangement and material size.

A two week trial was conducted starting in mid-July of 2008 to collect and process woody residues after the commencement of commercial timber harvesting operations. The system collected material pre-piled at landings and along roadsides with an excavator (PC 220LC) and loaded slash into 40 cubic yard containers along the roadside. The containers were trucked to the central grinding location by “hook-lift” trucks. When collection and transportation of materials was complete a grinder (Peterson Pacific 7400) was set up at the centralized grinding site and ground all materials into hog fuel. Hog fuel was then belt fed into 120 cubic yard chip vans and transported to a local power plant. The experiment was designed so that several harvest sites could pool material to a centralized grinding location nearby (< 3 miles; Fig. 3).

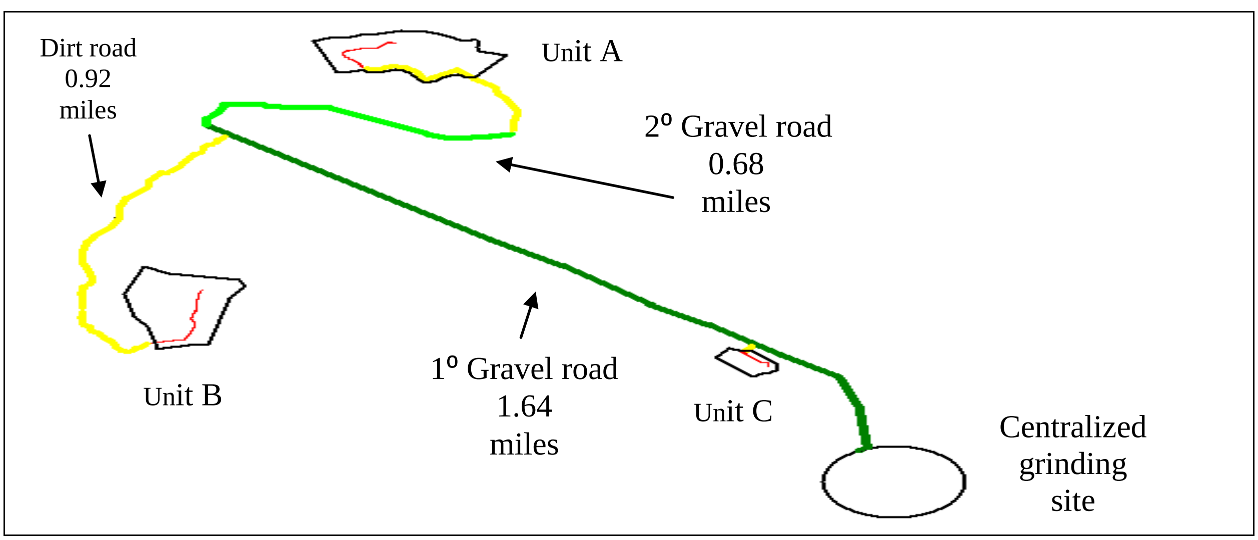

Figure 3: Operation layout map with corresponding road segments.

Data Collection and Analysis

Hourly machine costs (Table 2) measured in dollars per scheduled machine hour (SMH) were calculated using standard machine rate calculation method (Miyata 1980). For each machine in the system purchase price, insurance and tax rates, repair costs, fuel consumption, and labor costs were all obtained from the consulting contractor. Diesel fuel price receipts were averaged throughout length of the operation ($4.60/gal) and applied to machinery. All machinery was assumed to work 1800 scheduled machine hours annually and have an economic life of ten years except for the grinder which was 5 year economic life. Time study data was collected to calculate hourly production (BDT/hr) using standard time study techniques (Olsen et al. 1998) for each element in a machines operation cycle by stop watch. A hook-lift trucking cycle includes traveling empty the harvest unit, dropping an empty container at the roadside, positioning the truck, loading a container filled with slash, traveling loaded to the centralized grinding site, and unloading/dumping the slash. An excavator's loading cycle starts from traveling to a slash pile followed by swinging empty to the slash pile, grappling the slash, swinging loaded back to the container, and compacting slash into the container. Three types of delay time, including operational delays, mechanical delays and personal delays, were recorded.

Table: 2 Machine assumptions and hourly cost ($/SMH) used in the study.

Machine	Initial Price	Utilization Rate	Fuel Consumption	Total houly cost
	($)	(%)	(gal/hr)	($/SMH)
Peterson Pacific 7400 grinder	650,000	85	30	305.41
Komatsu PC-220LC excavator	350,000	90	6	113.94
Komatsu 400 front-end loader	375,000	90	7	107.88
Kenworth T800 hook-lift truck	150,000	90	7	93.45
Kenworth 600A service truck	120,000	90	7	83.12
Kenworth 900A fuel truck	80,000	90	6	79.23
Kenworth 900A water truck	80,000	90	5	73.74

SMH = Scheduled machine hour

Biomass weight for each cycle was measured using portable scales (Intercom PT300). The trucks were tare-weighed before and after they were loaded, the difference was equal to the weight of the slash hauled. Weight measurements were recorded along each axle and the sum of axle weights was equal to the total weight hauled in tons. Wood Residues were randomly sampled to estimate variation and mean in moisture content with a Delmhorst BD-2100 hand held moisture meter. The data was collected from all sizes of material based on diameter size classes of slash as well as from ground material. Slash moisture content samples were randomly collected from piles. A single measurement was used for the small diameter class samples (< 3 in). For the larger size classes the material was cross sectioned and three measurements were taken and averaged, in order to account for the moisture variability (Han 2008). Moisture content of hog fuel was measured by oven drying the samples collected from loaded trucks since the material was too small to obtain an accurate reading with the Delmhorst BD-2100. Delivered hog fuel prices in the region during the time of study was surveyed at $50 a bone dry ton (BDT).

Results & Discussion

Average delay-free cycle time for the excavator to arrange, pick up material, and place it in a bin took 40 seconds. It took an average of 21 cycles or 14 minutes to fill an entire bin with slash which had an average weight of 4.7 BDT. The elements of a typical cycle, their observed times and variables that affected them were summarized in Table 3. The compacting element of a loading cycle was the most time consuming part of the loading process because the operator took extra effort to maximize the weight of each bin. Traveling took the least amount of time (0.01 min) on average because the operator rarely moved the excavator, placing himself between the pile of slash and the bin within reach of his boom.

Table: 3 Summary statistics of observed loading cycle independent variables (n = 600).

Loading Cycle Element	Variable	Mean	Range	Standard Deviation	Minutes*	% Cycle
Travel	Distance (ft)	1.07	0-40	5.03	0.01	1.7%
Empty Swing	Degrees Rotated (90o increments)	139.95	0-270	2.22	0.07	9.6%
Grappling	# of grapples	2.01	1-11	25.74	0.27	34.8%
Loaded Swing	Degrees Rotated (90 increments)	145.95	0-270	3.84	0.09	12.3%
Compacting	# of compactions	3.19	1-16	30.34	0.32	41.7%

*Observed averaged time spent for corresponding element of total cycle.

The delay-free trucking cycle from the centralized grinding location to the harvest unit and back took on average 28 minutes. The hauling cycle was relatively short considering round trip distance, and adverse road conditions which resulted in traveling speeds of less than 10 mph (Table 1). Travel empty and travel loaded consumed the largest amount of a delay free cycle (8-9 minutes), and were similar because the same routes were used on the way to and from harvest sites. Unloading and loading share similar percentages among the total time (Table 4). Loading the bin was faster on average than unloading the bin because an entire bin was picked up onto the truck. Whereas the unloading of a bin requires the driver to get out of the truck open the back doors of the bin, tilt the bin back and then pull forward to empty the contents much like a dump truck.

Table 4: Summary of observed trucking cycle time (min) and its independent variables (n=58).

	Cycle Elements	Distance (ft)	Minutes	Time (%)	
Travel empty	Central processing site	311	0.81	2.84	
	1° Gravel	7183	3.36	11.83	
	2 Gravel	1483	0.93	3.27	
	Dirt	2340	2.80	9.87	
	Spur	431	0.78	2.74	30.6
Loading	Position	185	2.82	9.95	
	Drop	N/A	0.94	3.32	
	Travel to Bin	97	0.08	0.29	
	Load	N/A	0.91	3.21	16.8
Travel loaded	Central processing site	457	1.34	4.73	
	1° Gravel	7183	3.08	10.84	
	2 Gravel	1483	0.88	3.09	
	Dirt	2332	3.03	10.67	
	Spur	523	1.05	3.69	33
Unloading	position	88	0.39	1.38	
	unload	N/A	5.19	18.27	19.6
	Total	**24096**	**28.38**	**100**	

Note: 0.90 to 5.22 miles round trip

Regression models for delay-free cycle time (Table 5) were developed using the pre-identified independent variables associated with each cycle. The collected time study data were screened for normality and outliers using histograms and residual plots, and were used to develop predictive equations by running multiple regressions using ordinary least squares estimators, performed in R 2.4.1 statistical software program (R 2006). The final predictive models developed in the study include only variables that were found to be statistically significant (p-value <0.05, α = 0.05; Table 5). Dummy variables were used to examine the effect of material type and slash pile classification on cycle time as well as their interaction with continuous variables. Both models for the excavator and the hook-lift truck had high r square values, which indicate that they might be effective in estimating the productivity for loading and hauling (Table 5).

Table 5: Delay-free average cycle time equations for loading and hauling activities.

Machine	Average cycle time estimator (centiminutes)	r^2	Standard error	P-value	Standard error *	F-stat	n
Excavator	= 3.70	0.80			0.24		600
	+ 0.49 (number of compactions)		0.02	< 0.0001		805.90	
	+ 0.04 (travel distance in feet)		0.00	< 0.0001		108.78	
	+ 0.39 (number of grapples)		0.02	< 0.0001		417.78	
	+ 0.21 (loaded swing degrees)		0.027	< 0.0001		60.38	
	+ a (pile classification)			0.002		4.17	
	+ b (material type)			< 0.0001		24.05	
	+ c (material type * number of grapples)			< 0.0001		11.70	
	+ d (material type * number of compactions)			0.024		2.82	
Hook-lift truck	= 1129.24	0.93			181.64		58
	+ 0.18 (loaded primary gravel road distance in feet)		0.01	< 0.0001		279.19	
	+ 0.11 (loaded dirt road distance in feet)		0.02	< 0.0001		47.86	
	+ 0.23 (loaded spur road distance in feet)		0.06	< 0.0001		17.23	

a-d = Coefficients for pile classification, material type, and interactions, see Table 6.

e.g. if a predicted cycle included pile class 1 use -0.00447 (Table 6) for the "a" coefficient value.

Standard error * = standard error of the regression equation

Table 6: Loading factor level coefficients and coefficients of interactions.

Machine	Average cycle time estimator (centiminutes)	Standard error	P-value
Excavator	- 0.00447 (pile class 1)	0.03	0.889
	+ 0.00634 (pile class 2)	0.03	0.838
	+ 0.04147 (pile class 3)	0.04	0.269
	+ 0.08724 (pile class 4)	0.03	0.002
	- 0.13058 (pile class 5)	N/A*	N/A*
	+ 0.05644 (limbs)	0.02	0.015
	+ 0.05731 (tops)	0.03	0.075
	- 0.23894 (logs)	0.03	0.000
	+ 0.12519 (mixed materials)	N/A*	N/A*
	- 0.13288 (number of grapples * limbs)	0.03	0.000
	+ 0.05822 (number of grapples * tops)	0.03	0.066
	+ 0.15788 (number of grapples * logs)	0.03	0.000
	- 0.08322 (number of grapples * mixed materials)	N/A*	N/A*
	- 0.02991 (number of compactions * pile class 1)	0.03	0.279
	- 0.06178 (number of compactions * pile class 2)	0.03	0.033
	- 0.04048 (number of compactions * pile class 3)	0.04	0.334
	+ 0.01598 (number of compactions * pile class 4)	0.02	0.519
	+ 0.11619 (number of compactions * pile class 5)	N/A*	N/A*

pile class 1 = typical size material, loader piled

pile class 2 = large size material, processor piled

pile class 3 = typical size material, side-cast piled

pile class 4 = typical size material, processor piled

pile class 5 = small size material, loader piled

N/A*= values not avilable from R statistical program output.

When considering the effect of pile classification on estimated cycle time for loading, pile class 4 (typical size material, processor piled) was the only pile class found to be statistically significant (p-value <0.05, $\alpha = 0.05$; Table 6). Using the predicted model for the excavator and holding all other variables constant pile class 4 resulted in the longest predicted cycle time of 42 seconds. Pile class 2 (large size material, processor piled) yielded the smallest predicted cycle time of 36 seconds. This difference in predicted cycle time is linked with compacting, which consumes the largest portion of a total loading cycle and has a significant interaction with pile class. Processor piled materials are generally aligned parallel which is preferable for loading into bins because of the reduced need for compacting, especially when materials are of large size. When loaders pile material they tend to rake the slash into heaping piles with lots of air space. The poor arrangement coupled with smaller size material amounts to a greater number of compactions, and a longer loading cycle.

The average observed time for the grinder to belt feed a chip van was 21 minutes, which carried on average 14.1 BDT/truck. Grinding activities produced a total of 267.5 BDT over a total of 7 hours, which were delivered to the local energy plant.

Table 7: Estimated system production and cost.

	Loading	**Hauling**	**Grinding**	**Support**	**Total [1]**
Hourly Cost ($/PMH) [2]	$126.60	$103.84	$595.71	$57.72	$883.86
Hourly Production (GT/PMH)	27.60	13.83	57.60	N/A	
Cost ($/GT) [3]	$4.59	$7.51	$10.34	$9.72	$32.16
Cost ($/BDT)	$6.30	$10.32	$16.22	$15.25	$48.08

Moisture content during loading and hauling stages of operation was 27.20%, and 36.23% during grinding.

[1] Total system cost does not include move in costs, transportation to market, or profit allowance.

[2] PMH: productive machine hour

[3] GT: green ton

BDT: bone dry ton

The hourly production of each machine was determined by dividing the average weight of bins (tons) by the predicted cycle time (minutes/PMH). Cost per ton of material was calculated by dividing the machine hourly cost by the production rate (Table 7). The sum of the production costs ($/ton) are equal to the total system cost of $48.08 per dry ton.

Moisture content of the slash during loading and hauling stages was 27.20% and then increased to 36.23% during grinding, due to the two days of rain that occurred during grinding activities. The average cost of grinding $16.22/BDT was the most costly process of the system representing one third of the total production cost. The high cost of grinding stresses the importance of maximizing the grinders productivity by supplying enough material to the centralized grinding site, and maintaining a constant flow of residues. One would have to increase the number of machines in the loading and hauling stage to supply more than 37 BDT/PMH to the grinder or, in the case of this study wait to grind until all collection and transportation of slash is complete.

Support costs are often an overlooked component of forest operations. Fuel trucks are needed to deliver and fuel existing machinery, water trucks are required for dust abatement purposes, and service trucks have the tools and parts necessary for daily maintenance and repairs. The support cost ($15.25/BDT) in this system is the second largest component of total system cost, this includes the cost of owning all of the support vehicles and their assumed use of 30 minutes daily divided by the total tons produced during the operation.

Hauling costs represented approximately one quarter of the total production cost, but proved to be highly variable depending on road conditions. Sensitivity analysis indicates minimizing road types such as single lane dirt and spur roads which have traveling speeds of less than 10 mph greatly improves trucking productivity and reduces Production costs (Fig. 4). Holding all other variables of system cost constant, every mile increase of dirt road hauling distance equates to a $2.12/BDT increase in total system cost. Due to the variability in transportation costs and the high costs associated with hauling on forest roads, it suggested that a harvest site should be located no more than 5 miles away from the centralized grinding site.

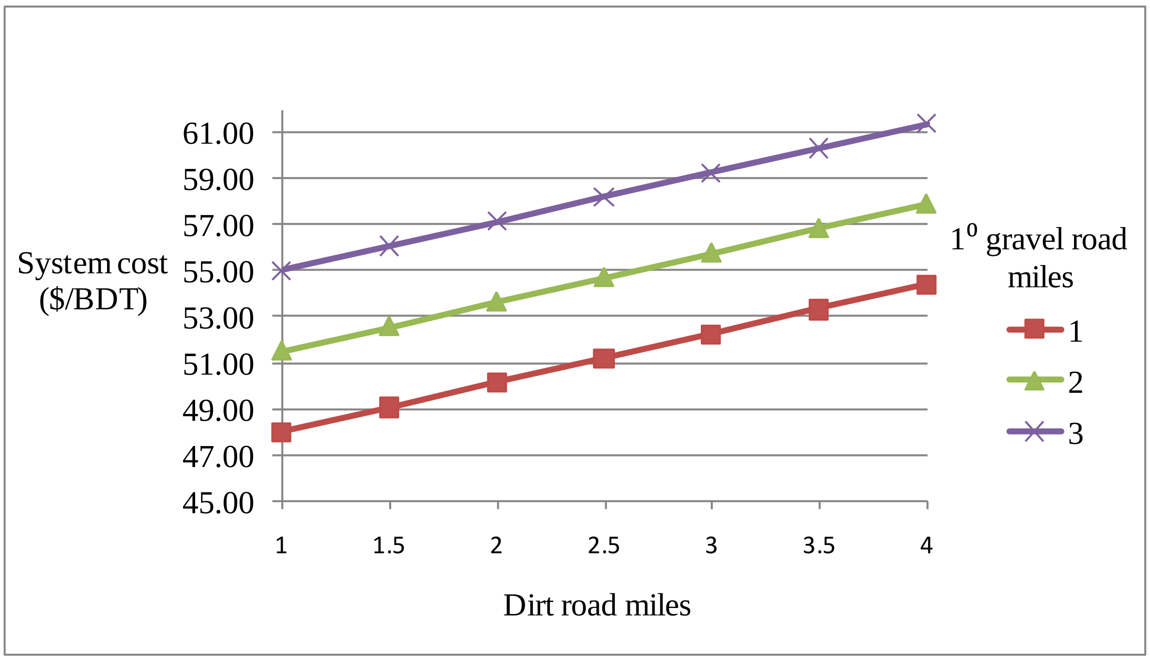

Figure 4: Sensitivity analysis of system production cost on various transportation distances.

One interesting factor that had an effect on the overall system cost was diesel fuel prices which were at a national peak during the study in the summer of 2008. Diesel fuel price assumed for the operation was $4.60/gal. Six months after commencement of operations fuel prices in the region dropped to $2.50/gal. Holding all other variables of system cost constant, every dollar reduction of fuel price represents around a $3.22/BDT reduction in overall system cost (Fig. 5).

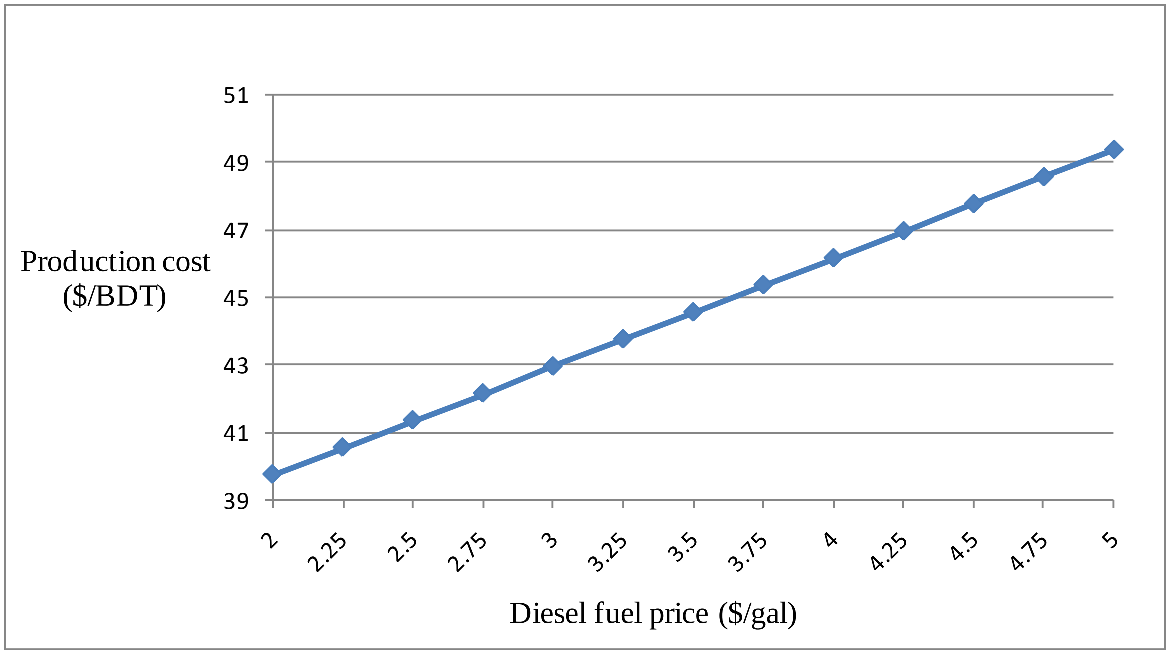

Figure 5: Sensitivity analysis on system production cost with various fuel market prices.

A cash-flow analysis was performed to evaluate the economic feasibility of running a biomass harvesting system. The discounted cash-flow includes the purchase of a second hook-lift truck to balance loading and hauling productivity which would be more practical under a full scale production operation (Table 8). Assuming twice the production of the unbalanced system (13,910 BDT annually) at a delivered fuel price of $50/BDT, this operation would be financially feasible. Over the ten year operation a contractor would earn a 6.5% rate of return on their investment after taxes with an additional net present value (NPV) of $277,822.

Table 8: Cash-flow analysis of a biomass recovery system

Year	Investment[1]	Salvage	Revenue[2]	Expenses[3]	Before-tax Cash flow	Depreciation ($)	Taxable income	Taxes	After-tax Cash flow	Discount factor	After-tax Discounted cash flow
0	$ (1,955,000)				$ (1,955,000)				$ (1,955,000)	1.000	$ (1,955,000)
1			$ 695,496	$ (448,553)	$ 246,942	$ (391,000)	$ (144,058)	$ (36,014)	$ 282,957	0.939	$ 231,871
2			$ 751,135	$ (486,050)	$ 265,085	$ (625,600)	$ (360,515)	$ (90,129)	$ 355,214	0.882	$ 233,715
3			$ 811,226	$ (528,513)	$ 282,713	$ (375,360)	$ (92,647)	$ (23,162)	$ 305,875	0.828	$ 234,044
4			$ 876,124	$ (576,806)	$ 299,318	$ (225,216)	$ 74,102	$ 18,526	$ 280,793	0.777	$ 232,667
5	$ (650,000)	$ 247,000	$ 946,214	$ (1,034,961)	$ (88,746)	$ (225,216)	$ (313,962)	$ (78,491)	$ (10,256)	0.730	$ (64,774)
6			$ 1,021,911	$ (695,208)	$ 326,704	$ (112,608)	$ 214,096	$ 53,524	$ 273,180	0.685	$ 223,901
7			$ 1,103,664	$ (768,016)	$ 335,648		$ 335,648	$ 83,912	$ 251,736	0.644	$ 215,992
8			$ 1,191,958	$ (852,141)	$ 339,816		$ 339,816	$ 84,954	$ 254,862	0.604	$ 205,328
9			$ 1,287,314	$ (949,680)	$ 337,634		$ 337,634	$ 84,409	$ 253,226	0.567	$ 191,558
10		$ 604,950	$ 1,390,299	$ (398,191)	$ 992,108		$ 992,108	$ 248,027	$ 744,081	0.533	$ 528,522
										NPV =	$ 277,822

[1] Capital investment includes purchase of grinder, excavator, front-end loader, water truck, fuel truck, service truck, and two hook-lift trucks with 40 cubic yard bins.

[2] Revenue assumes 13,910 BDT annual production over 1800 SMH/yr, at $50/BDT market price.

[3] Expenses include annual maintenance and reapairs, insurance, labor, and fuel costs.

[6] Decpriciation based on IRS modified accelerated cost recovery system (MACRS) with a 5 year-property class.

Tax rate was assumed to be 25%

A discount factor of 6.5% was assumed.

Conclusion

This study evaluated harvesting productivity and cost of a wood residue recovery system collecting forest biomass for electrical energy production. Productivity for different machines varied from 10 to 37 BDT/PMH, with a total production of 267.5 BDT over 70 hours. Production cost ranged from $6.30 to $16.22/BDT, with a total system production cost of $48.08/BDT at 36% moisture content.

Loading slash into bins was efficient and had a low cost of $6.30/BDT. Loading costs could be inflated if the material is not located within one swing of the road edge, because of increased travel per cycle. The hook-lift truck effectively negotiated adverse forest roads and allowed the removal of slash from traditionally difficult to access sites, without burning slash. Harvest sites ideally should be located within close proximity to a centralized grinding site (< 5 miles).

Due to the complexity of variables and their effects on overall system cost and productivity, it is apparent that operations like the one observed in this study take careful planning and strategic logistical arrangements. Slash pile arrangement and material size were found to have a significant effect on productivity of loading. Typical size material arranged or piled by processors (pile class 2) were found to be the most effective pile type when considering loading productivity, yielding the smallest predicted cycle time (36 seconds). System cost can drastically change with increased hauling mileage on single lane dirt roads, due to slow traveling speeds (<10 mph). For example, the total system cost increases $2.12/BDT for every one mile increase in dirt road hauling distance. The cost of the Fuel price among other variables was found to have a significant effect on total system cost, resulting in a $3.22/BDT for every $1/gal increase in fuel.

Forest biomass can be removed successfully and cost effectively from previously harvested timber sites with the surveyed regional market value of $50/BDT. Appropriate pairings of machines may reduce system bottlenecks and greatly improve total system productivity. A full scale production operation would be financially feasible, earning a 6.5% rate of return with a NPV of $277,822 at the end of ten years of operation. Success of an operation will depend on consistent production of the highest quality hog fuel at the lowest cost.

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Combining slash bundling with in-woods grinding operations

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Abstract

Although extensive woody biomass resources are physically present, forest residues (i.e. logging slash) are under-utilized because collection and transportation costs are often greater than the market value of the materials and of the limited access to the site. This study quantified the operational cost and performance of a biomass harvesting system utilizing a John Deere 1490D energy wood harvester, combined with in-woods grinding operations. The experiment took place at four recently harvested sites in northern California where logging slash was piled or scattered along the roadsides or across the clearcut units in various amounts and arrangements. Produced bundles were transported to a centralized processing site where they were ground into hog fuel and delivered to a local energy plant. Productivity for each phase of the operation ranged from 8 to 42 bone dry tons (BDT)/productive machine hour (PMH), with a total production of 280.7 BDT over 70.2 hours. The total system production cost was $60.98/BDT at 28.95% moisture content. Regression analysis indicated that pile classification in terms of material size and arrangement had a significant impact on productivity of bundling ($p<0.0001$). Pile class 3 (mixed size materials piled & side-casted) yielded the shortest predicted cycle time of 1.60 minutes/bundle. Single-lane dirt roads were found to have the greatest effect on increasing total production costs by $3.07/BDT for every mile hauled on. Every $/gal increase in diesel fuel price reflects a $3.52/BDT increase in total production cost for the system. Forest biomass that was not accessible using traditional highway chip vans was successfully removed with hook-lift trucks. Optimal pairings of machines may greatly improve total system productivity.

Introduction

Bioenergy is the second largest source of renewable energy in the United States, with over 11 gigawatts of installed capacity (Beckert 2008). Woody biomass, including sub-merchantable trees, small-diameter trees, tops, limbs, logging slash, produced from mechanical thinning and conventional saw-timber harvesting creates an opportunity for generating power (Han et al.

2004). Forest operations have the potential to supply 368 million dry tons of woody biomass annually (Perlack et al. 2005). The annual available biomass in California was estimated at 26.8 million dry tons (Tiangco et al. 2005). Prescribed burning has long been the preferred method of disposing of forest biomass, but mechanical removal of biomass is becoming more popular due to increased restrictions on open field burning, or in areas like the wildland urban interface (WUI) where burning is not an option.

Forest residues are often not utilized because collection and transportation costs are greater than the market value of the materials (Withycombe 1982). Lack of research in this field has made harvesting and transportation costs are notoriously difficult to estimate because there are critical gaps in the data and methods for predicting costs (Rummer et al. 2008).

New, more efficient harvesting equipment like energy wood harvesters could reduce the associated processing costs with their increased productivity. These machines compact and bundle woody biomass into log-shaped bundles, and could produce up to 40 half-ton bundles per hour with a production cost of $16 per dry ton (Rummer et al. 2004). Quantifying costs and productivities of these new systems for biomass recovery from northern California will aid land managers in the planning and execution of cost-effective biomass supply for energy.

The overall objective of this project was to determine the operational cost and performance of a biomass collection and densification system, called slash bundler, in combination with a centralized grinding operation. Important variables, such as hauling distance and moisture contents, were itemized to understand their effects on productivity of collection and transportation. In particular, slash piles were characterized to evaluate the effect of slash type on productivity, based on arrangement and size of slash materials.

Methodology

Study site and system description

The study was conducted in three clearcut harvesting sites in northern California, ranging from 17 to 32 acres. The vegetation at each site varied but was generally dominated by second growth redwood (*Sequoia sempervirens)* and Douglas-fir (*Pseudotsuga menziesii)* with an average tree age of 60 years. The three sites had an average tree diameter at breast height (DBH) ranging from 20-22 inches, and ground slopes ranged from 0 to 30 percent. The stands were harvested using a ground-based shovel logging system. There were many slash pile types in terms of size and arrangement present across these sites (Fig. 1). A forester working for the land owner suggested these sites were expected to yield anywhere from 50-75 tons/ac of slash from clearcut operations (Alcorn 2008).

		
Pile Class 1 = Mixed size material, loader piled	Pile Class 2 = Large size material, processor piled	Pile Class 3 = Mixed size material, side-cast piled
		
Pile Class 4 = Mixed size material, processor piled	Pile Class 5 = Small size material, loader piled	Pile Class 6 = Mixed size material, side-cast

Figure 1: Slash pile classification by arrangement and material size.

A two week trial was conducted to collect and process woody residues after commercial timber harvesting operations. The system collected material pre-piled at landings and along roadsides with a slash bundler (John Deere 1490D). The bundler compacted and wrapped slash into 10ft long bundles with an average diameter of 27 inches. Bundles were then loaded into 40 cubic yard containers along the roadside with a loader (Hitachi EX 200-3). The bundles were delivered to a nearby central grinding location (< 3 miles; Fig. 3) by hook-lift trucks. A grinder (Peterson Pacific 7400) was set up at the centralized grinding site and ground all the bundles into hog fuel. Hog fuel was then belt fed into 120 cubic yard chip vans and transported to a local power plant.

Figure 2: John Deere 1490D energy wood harvester which produces the bundles, and hook-lift truck used to haul bundles.

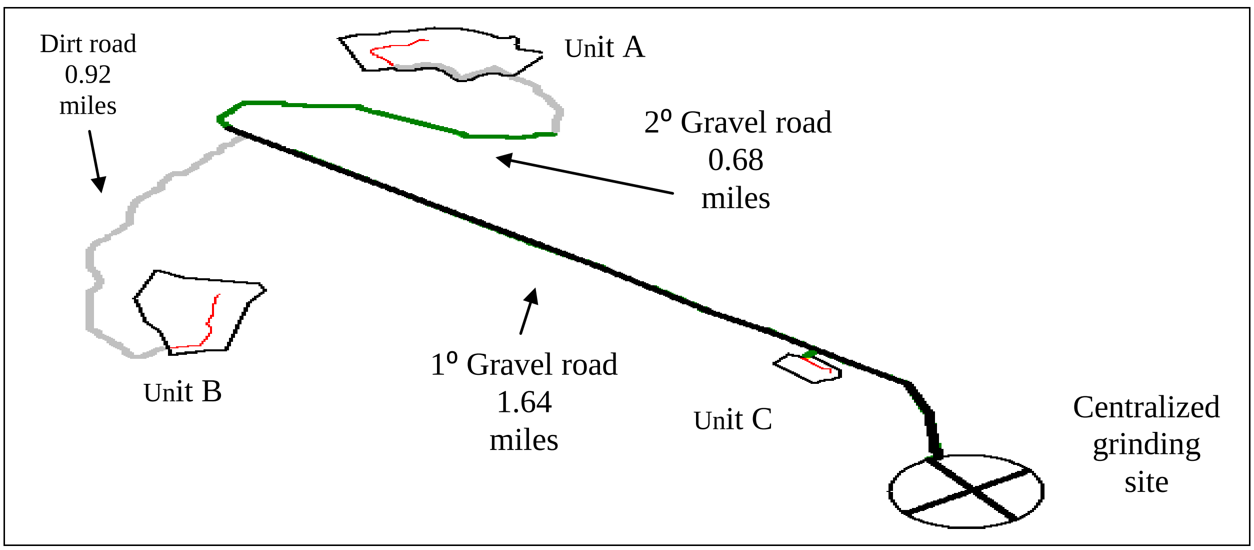

Figure 3: Operation layout map with corresponding road segments.

Data collection and analysis

Hourly machine costs (Table 2) measured in dollars per scheduled machine hour (SMH) were calculated using standard machine rate calculation method (Miyata 1980). For each machine in the system purchase price, insurance and tax rates, repair costs, fuel consumption, and labor costs were obtained from the contractor, diesel fuel price receipts were averaged throughout length of the operation ($4.60/gal). All machinery were assumed to work 1800 SMH annually and have an economic life of ten years except for the grinder which was 5 year economic life due to associated wear, and the bundler which was assumed to work 2100 SMH as suggested by John Deere Company.

Time study data was collected to calculate hourly production (bone dry ton (BDT)/productive machine hour (PMH)) using standard time study techniques for each element in a machines operation cycle by stop watch (Olsen et al. 1998). A bundling cycle includes traveling to the slash pile, followed by multiple grapples and swings of slash to the in-feed table, and ended when the bundle produced was cut free from the machine. A loading cycle started from traveling to a bundle, followed by swinging empty to the bundle, grappling the bundle, swinging loaded back to the container, and ended by compacting bundle into the container. A hook-lift trucking cycle includes traveling empty to the harvest unit, positioning the truck for loading, loading a container filled with bundles, traveling loaded to the centralized grinding site, and unloading/dumping the bundles. Three types of delay time, including operational delays, mechanical delays and personal delays, were recorded.

Regression models for delay-free cycle time were developed using the pre-identified independent variables associated with each cycle. The collected time study data were screened for normality and outliers using histograms and residual plots, and were used to develop predictive equations by running multiple regressions using ordinary least squares estimators, performed in R 2.4.1 statistical software program (R 2006). The final predictive models only include variables that were statistically significant (p-value <0.05; $\alpha = 0.05$). Dummy variables were used to examine the effect of slash pile classification on delay-free cycle times.

Table: 2 Assumptions and hourly machine cost ($/SMH) used in the study.

Machine	Initial Price	Utilization Rate	Fuel Consumption	Total houly cost
	($)	(%)	(gal/hr)	($/SMH)
Peterson Pacific 7400 grinder	650,000	85	30	305.41
John Deere 1490D energy wood harvester	500,000	90	3	119.87
Hitachi EX 200-3 loader	350,000	90	6	113.94
Komatsu 400 front-end loader	375,000	90	7	107.88
Kenworth T800 hook-lift truck	150,000	90	7	93.45
Kenworth 600A service truck	120,000	90	7	83.12
Kenworth 900A fuel truck	80,000	90	6	79.23
Kenworth 900A water truck	80,000	90	5	73.74

SMH = Scheduled machine hour

Biomass weight for each cycle was measured using a portable scale (Intercom PT300). The hook-lift trucks were tare-weighed before and after they were loaded to measure the weight of the bundles hauled. The total bundle weight was divided by the number of bundles to determine the average weight/bundle in tons.

Wood residues were randomly sampled to estimate variation and mean in moisture content with a Delmhorst BD-2100 hand held moisture meter. The data was collected from all sizes of material based on diameter size classes of slash as well as from ground material. Slash moisture content samples were randomly collected from bundles. A single measurement was used for the small diameter class samples (< 3 in). For the larger size classes the material was cross sectioned and three measurements were taken and averaged, in order to account for the moisture variability (Han 2008). Moisture content of hog fuel was measured by oven drying the samples collected from loaded trucks. Wet-based moisture content averaged 22.55, 24.27, and 28.95 percent for bundling, loading and hauling, and grinding stages of operation respectively. Regional delivered hog fuel prices during the time of study was surveyed at $50 a bone dry ton (BDT).

Results & Discussion

Cycle time regression equations

Regression equations developed from the time study data with significant variables ($p < 0.05$, $\alpha = 0.05$) were summarized in Table 3. Both models for the bundler and the hook-lift truck had high r-squared values, indicating that they might be effective in estimating the productivity for loading and hauling.

Bundling cycle time was affected mainly by different handling and arranging activities such as, the number of grapples to pick up slash, or the number of in-feeds to place the slash on the in-feed table for bundling. The grappling element consumed the greatest amount of time during an average bundling cycle (0.85 minutes, 44.5%), while the traveling element was responsible for the smallest portion of cycle time (0.09 minutes, 4.8%; Figure 4). This was most likely due to the fact that the machine could remain stationary because of the amount of slash available within reach, and spent the greatest of time grappling in order to properly align slash for efficient in-feeding. The regression equation also indicated that the number of swing cycles for which the bundler picks up slash and places it on the in-feed table had a significant effect on cycle time. When considering the effect of pile classification on estimated bundling cycle time, pile class 1, pile class 2, and pile class 6 were the only pile classes found to be statistically significant (p-value <0.05; $\alpha = 0.05$).

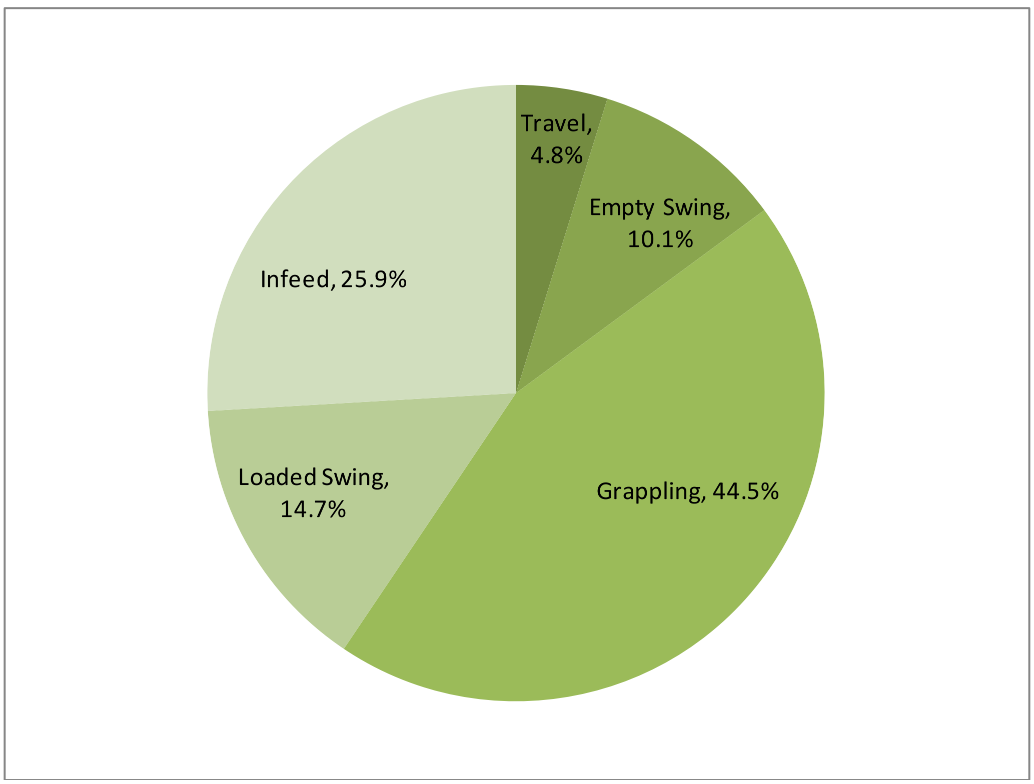

Figure 4: Observed components of a typical bundling cycle, and their percentage of total cycle time.

Grappling the bundles and compacting them into the bin proves to significantly affect the loading cycle time. Loaded swing degrees in which the machine had to rotate to place a bundle in the bin was also found to be significant, along with the travel distance necessary to reach a bundle. The regression analysis suggests that decreasing the travel distance and minimizing swing degrees would greatly reduce the predicted cycle time.

The transportation distance along various road types positively affected the hauling cycle time. Only loaded hauling distances were used to develop the trucking regression equation because the same routes were used to and from harvest units. The positioning distance for a hook-lift truck to position himself to be loaded was also found to have a significant effect on cycle time because this was done while driving in reverse, and had to be done carefully to properly align himself for loading by the Hitachi loader.

Table 3: Delay-free average cycle time equations for bundling, loading, and hauling activities.

Machine	Average cycle time estimator (centiminutes)	Variable range	Mean	r^2	n	P-value	F-stat	Standard error [1]
Bundler	= 3.87			0.81	300			0.17
	+ 0.03 (travel distance in feet)	0-280	5.56			< 0.0001	72.27	
	+ 0.54 (number of grapples)	1-22	7.61			< 0.0001	303.35	
	+ 0.41 (number of infeeds)	1-11	4.40			< 0.0001	111.45	
	- 0.20 (number of swing cycles)	1-8	4.52			< 0.0001	14.82	
	- 0.08 (pile class 1)					0.002		
	+ 0.13 (pile class 2)					< 0.0001		
	- 0.11 (pile class 3)					0.092		
	- 0.03 (pile class 4)					0.305		
	- 0.03 (pile class 5)					0.210		
	+ 0.13 (pile class 6)					0.038		
Loader	= 3.88			0.54	465			0.20
	+ 0.45 (number of compactions)	1-5	1.23			< 0.0001	216.42	
	+ 0.06 (travel distance in feet)	0-220	1.51			< 0.0001	164.41	
	+ 0.42 (number of grapples)	1-3	1.08			< 0.0001	66.76	
	+ 0.22 (loaded swing degrees)	90-270	126.81			< 0.0001	72.08	
	+ 0.09 (% slope)	5-10	6.58			0.003	8.99	
Hook-lift truck	= 987.40			0.84	30			344.97
	+ 0.22 (loaded primary gravel road distance in feet)	2189-8635	7436.27			< 0.0001	30.16	
	+ 0.22 (loaded dirt road distance in feet)	200-4846	2423.97			< 0.0001	38.56	
	+ 1.44 (position for loading distance in feet)	10-600	261.33			0.011	7.47	

pile class 1 = mixed size material, loader piled
pile class 2 = large size material, processor piled
pile class 3 = mixed size material, side-cast piled
pile class 4 = mixed size material, processor piled
pile class 5 = small size material, loader piled
pile class 6 = mixed size material, side-cast

Production rates

The hourly production of each machine was determined by dividing the average weight of bundles or bins (tons) by the predicted cycle time (minutes). Average predicted delay-free cycle time for the bundler to make one ten foot long bundle was 1.74 minutes, meaning the machine produced about 34 bundles per productive machine hour. With the bundles having an average moisture content of 22.55%, and an average length and diameter of 10.1ft and 27.6 inches respectively, the bundler productivity was determined at 8.03 BDT/PMH (Table 4).

Using the predicted model for the bundler and holding all other variables constant pile class 2 and pile class 6 resulted in the longest predicted cycle time of 2.04 minutes (Table 4; Table 5). Pile class 3 yielded the smallest predicted cycle time of 1.60 minutes. The difference in predicted cycle time between piles is linked with grappling, which consumes the largest portion of a total bundling cycle. Processor piled materials are generally aligned parallel which is preferable for the bundler because of the reduced need for grappling, but larger size materials are harder to grapple and don't bundle as well resulting in poor bundle integrity. When loaders pile material they tend to rake the slash into heaping piles with lots of air space and poor material alignment, which is negligible considering the machine's compacting force, especially when smaller size materials are bundled.

Table 4: Predicted delay-free average cycle time and production rate.

	Bundler		Loader		Hook-lift truck	
	Cycle time (min)	Prod. Rate (BDT[1]/PMH[2])	Cycle time (min)	Prod. Rate (BDT/PMH)	Cycle time (min)	Prod. Rate (BDT/PMH)
Unit A	1.72	8.23	0.46	41.22	34.28	11.49
Unit B	1.93	7.30	0.44	42.77	42.83	9.20
Unit C	1.61	8.77	0.43	43.33	22.37	17.61
Overall	1.76	8.04	0.44	42.32	35.43	11.12

[1]BDT: bone dry ton

[2]PMH: productive machine hour

Table 5: Bundling productivity predicted using regression equations based on slash Pile Classifications.

Pile Class[1]	# Bundles	Avg. time (min/bundle)	Tons/PMH	# Bundles/PMH
1	70	1.66	8.7	36
2	31	2.04	7.1	29
3	5	1.60	9.0	37
4	148	1.75	8.2	34
5	40	1.73	8.4	35
6	6	2.04	7.1	29

[1] Refer to Figure 1 or Table 3

Average predicted delay-free cycle time for the loader to pick up a bundle, and place it in a bin took 0.44 minutes or 26 seconds (Table 4). It took an average of 21 cycles or 9 minutes to fill an entire bin with bundles which had an average weight of 6.6 BDT, meaning the loader could produce and astounding 42.32 BDT/PMH. The compacting element in a loading cycle was the most time consuming part of the loading process due to the time used to carefully stack and maximize the number of bundles inside the bin. Traveling took the least amount of time (0.01 minutes, 3.1%) because the bundles were properly roadside decked minimizing the operators need of travel.

The delay-free trucking cycle took on average 35 minutes, with a production rate of 11.1 BDT/PMH (Table 4). Loading the bin consumed the greatest percentage of the cycle time (37.2%, 11 minutes) and was longer on average than unloading the bin because a truck had to wait to be loaded at the harvest site by the Hitachi loader. Whereas the unloading of a bin took less time (2 minutes), the driver would tilt the bin back and then pull forward to empty the contents like a dump truck. If possible bins should be pre-loaded on site and then picked up by the hook-lift truck. Pre-loading of bins could reduce total cycle time by up to 8 minutes, increasing the hauling production to nearly 14 BDT/PMH.

The average observed time for the grinder to belt feed a chip van was 21 minutes, which carried on average 20.8 BDT/load. Grinding activities produced a total of 280.7 BDT over a total of 8 hours or 33.14 BDT/PMH.

Table 6: Road type, one-way distance, and average travel speed.

Harvest site	Spur road	Dirt road	Gravel road [2]	Gravel road [1]	Total
	---------------------------------(miles)---------------------------------				
Unit A	0.53	0.29	0.68	1.64	2.61
Unit B	0.25	0.92	0	1.58	2.5
Unit C	0.25	0.04	0	0.41	0.45
Avg. Speed (miles/hr)	5.3	8.0	18.0	22.7	

Average speed = distance/observed time traveled

1 Gravel road = double lane rocked road

2 Gravel road = single lane rocked road

Dirt road = single lane seasonal dirt road constructed with native soils

Spur road = unimproved temporary dirt spur within harvest unit

Production costs

The production costs ($/ton) including bundling, loading, hauling, grinding and supporting activities was $44.94/GT or $60.98/BDT (Table 7). Wet-based moisture content of the slash during bundling was 22.55% which increased to 24.27% during loading and hauling stages, and finally increased to 28.95% during grinding. The increase in percent moisture content was most likely a result of heavy fog, and the two days of rain that occurred during grinding.

The average cost of grinding $17.97/BDT was the most costly process of the system, representing nearly one third of the total production cost. The high cost of grinding ($595.71/PMH) reflects the cost of running the grinder, front-end loader, and Hitachi loader simultaneously, which is necessary in order to achieve the high level of production (33.14 BDT/PMH).

Bundling production costs (16.20/BDT) was the second highest component of system cost, due to the high hourly cost $133/PMH and the low production rate of 8.04BDT/PMH. Loading bundles into bins proved to be the most cost effective stage of the harvesting system with a production cost of $2.99/BDT, primarily due to the machines high rate of production (42.32 BDT/PMH), the highest in the system. The densification of slash into bundles makes the material easier to handle, and increases the average weight per cycle, thus improving productivity of loading and hauling stages while reducing their production costs. However, the bottleneck in this system appears to be the bundling stage, with a low production rate production compared to the next stage of loading. Decoupling the bundling stage may reduce the potential system bottleneck by creating a buffer of bundles to be loaded and hauled, thus maximizing a loaders utilization rate.

Support costs are often an overlooked component of forest operations. Fuel trucks are needed to deliver and fuel to existing machinery, water trucks are required for dust abatement purposes, and service trucks have the tools and parts necessary for daily maintenance and repairs. The support cost ($14.48/BDT) in this system is the third largest component of total system cost, this includes the cost of owning all of the support vehicles and their assumed use of 30 minutes daily divided by the total tons produced during the operation 280.7 BDT. System supports costs may be greatly reduced if the operation were to be full scale, by increasing the total tons produced.

Table 7: Estimated system production and cost.

	Bundling	**Loading**	**Hauling**	**Grinding**	**Support**	**Total** [1]
Hourly Cost ($/PMH) [2]	$ 133.19	$126.60	$103.84	$595.71	$57.88	$1,017.22
Hourly Production (GT[4]/PMH)	$ 10.62	55.88	14.68	46.65	N/A	
Cost ($/GT) [3]	$ 12.55	$2.27	$7.07	$12.77	$10.29	$44.94
Cost ($/BDT)	$ 16.20	$2.99	$9.34	$17.97	$14.48	$60.98

Moisture content for bundling was 22.55%, 24.27% in loading and hauling, and 28.95% during grinding.

[1] Total system cost does not include move in costs, transportation to market, or profit allowance.

[2] PMH: productive machine hour

[3] GT: green ton

BDT: bone dry ton

Hauling the bundles to the centralized grinding site cost $9.34/BDT the second lowest component of system cost. Hauling costs represented approximately 15% of the total production cost, but proved to be highly variable depending on road conditions. Sensitivity analysis indicates minimizing road types such as single lane dirt roads which have traveling speeds of less than 10 mph greatly improves trucking productivity and reduces production costs (Fig. 5). Holding all other variables of system cost constant, every mile increase of dirt road hauling distance will cause a $3.07/BDT increase in total system cost. Due to the variability in transportation costs and the high costs associated with hauling on forest roads, it suggested that a harvest site should be located no more than 5 miles away from the centralized grinding site.

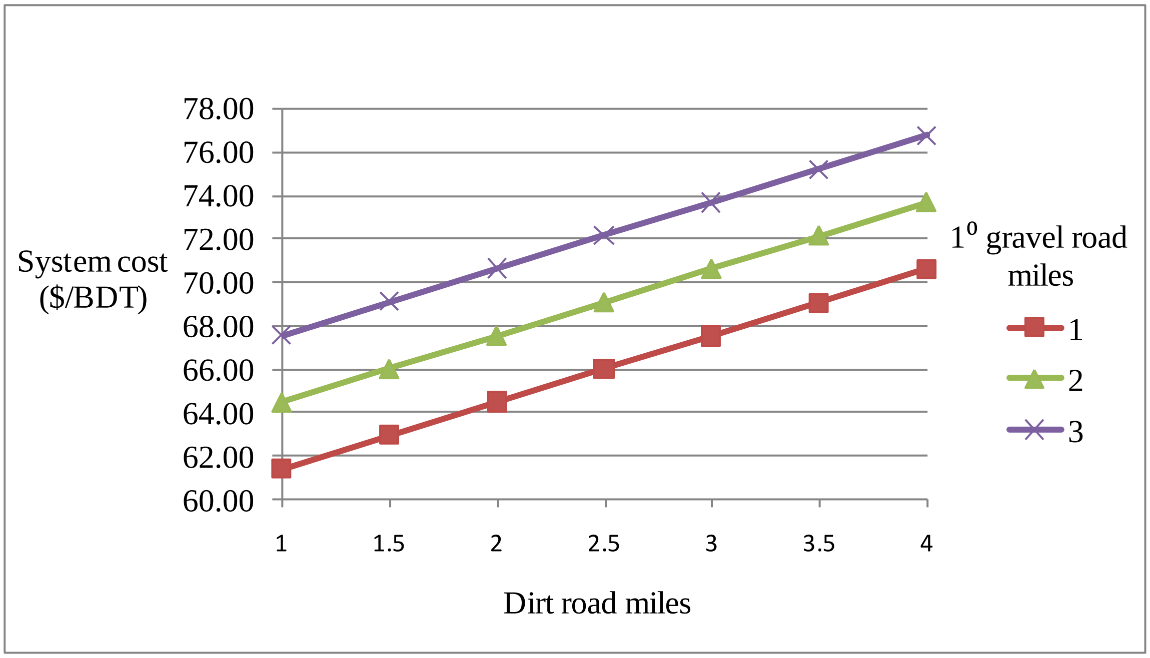

Figure 5: Sensitivity analysis of system production cost on various transportation distances.

One factor that had an effect on the overall system cost was diesel fuel prices which were at a national peak during the study in the summer of 2008. Diesel fuel price assumed for the operation was $4.60/gal. Six months later fuel prices in the region dropped to $2.50/gal. Holding all other variables of system cost constant, every dollar reduction of fuel price represents around a $3.52/BDT reduction in overall system cost (Fig. 6).

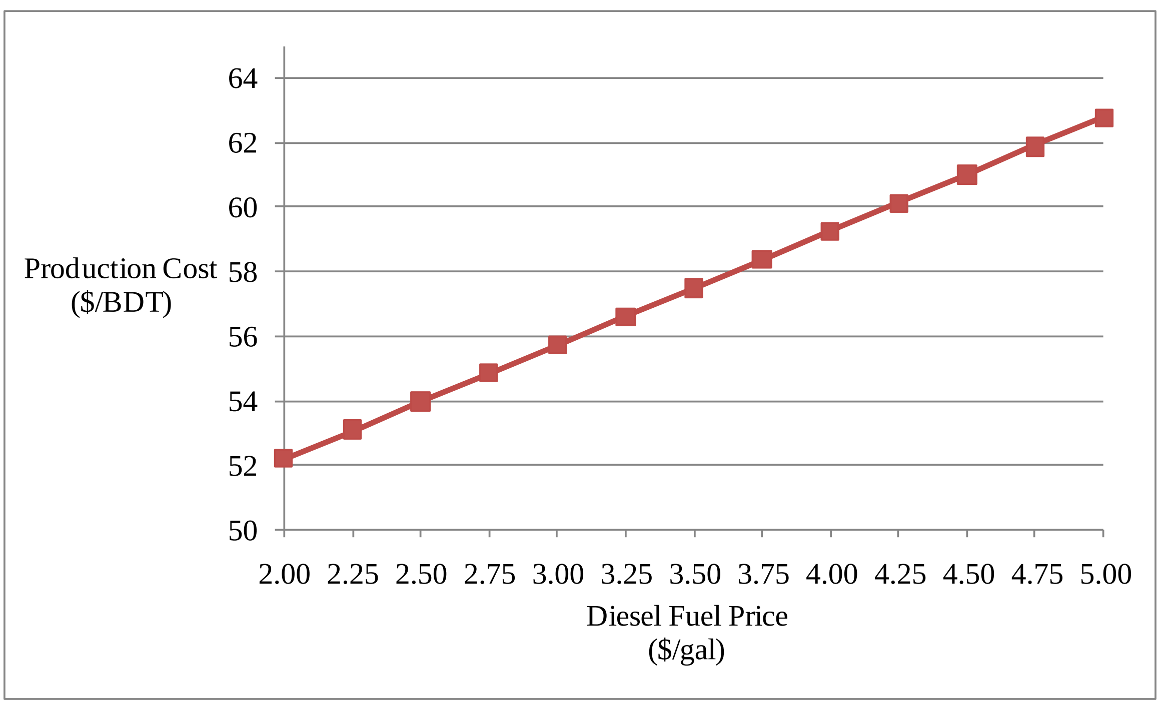

Figure 6: Sensitivity analysis on system production cost with various fuel market

Conclusion

This study evaluated harvesting productivity and cost of a woody biomass recovery system using a slash bundler. Productivity for different machines varied from 8 to 42 BDT/PMH, with a total production of 280.7 BDT over 70.2 hours. Production cost ranged from $2.99 to $17.97/BDT for different system components, with a total system production cost of $60.98/BDT at 28.95% moisture content.

The bundler tested on ground based clearcut sites performed well producing 29-37 10ft bundles per productive machine hour. Slash pile arrangement and material size were found to have a significant effect on productivity of bundling. Pile class 3 (typical size material, side-cast piled) was found to be the most effective pile type when considering bundling productivity, yielding the smallest predicted cycle time (1.60 minutes).

Loading slash into bins was efficient and had a low cost of $2.99/BDT. Loading costs could be inflated if the bundles were not located within one swing of the road edge because of increased travel distance. The hook-lift truck effectively negotiated adverse forest roads and allowed the removal of slash from traditionally difficult- to-access sites, without burning slash. Harvest sites ideally should be located within close proximity to a centralized grinding site (< 5 miles).

Due to the complexity of variables and their effects on overall system cost and productivity, it is apparent that operations like the one observed in this study require careful planning and strategic logistical arrangements. System cost can drastically change with increased hauling mileage on single lane dirt roads, due to slow traveling speeds (8 mph). The total system cost will increase $3.07/BDT for every one mile increase in dirt road hauling distance. The cost of the fuel price was found to have a tremendous effect on total system cost, every $1/gal fuel price increase would result in a system cost increase of $3.52/BDT.

Forest biomass was removed successfully from previously harvested timber sites with poor access issues, but the overall system production cost was still high. The high system cost is primarily due to the poor system balance and the low level of production associated with being an experimental rather than full scale operation. Appropriate pairings of machines may further reduce system bottlenecks and greatly improve the system productivity which may further reduce system cost.

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DEVELOPMENTS IN LOG-MAKING IN NEW ZEALAND

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ABSTRACT

Over the last 3 decades, log making in the New Zealand plantation forest industry has progressed from the production of 10-12 m preferred lengths, to lengths that are usually only 3-6 m today. This is in an industry that has otherwise essentially adapted western North American logging systems for over a century. In earlier times there was limited linkage between markets and woods merchandising; today the response to markets is much stronger. Management emphasizes audits based on comparisons between as-cut and expert, generally non-automated, solutions. Bucking decisions have been automated, but in many cases later de-automated. The location of the segmentation operation, once usually at the woods landing, was for a period moved to central processing yards at many operations. In recent years, most operators have opted to return merchandising to the woods landing, while others have retained or upgraded their processing yards. These changes have been driven by:

- changes in raw material characteristics,
- highly specific demands in log markets,
- changes in ownership of the resource,
- developments in processing technology,
- the development of optimizing technology for bucking decisions,
- environmental considerations,
- operational experience with new technologies,
- transportation options,
- the results of value audits, and
- not least by some cost surprises.

INTRODUCTION

Three decades ago, New Zealand radiata pine loggers primarily produced preferred lengths of 10-12 m, with some mills accepting random unmeasured lengths. Today, preferred lengths are typically in the 3-6 m range. Merchandising has shifted from the woods landing to central processing yards at many operations, then shifted back to the woods landing in recent years. Given that historically the New Zealand industry has adapted Pacific Northwest logging systems, it is instructive to examine why these changes have occurred, and whether there are any lessons for North American loggers.

To give context to this discussion, a brief description of New Zealand forest operations is in order. Radiata pine is extensively grown in plantations, and is the primary species cut in that country. These plantations have supported a substantial increase in production over recent decades, from 9.5 million cu.m in 1980 to 20 million cu.m in 2008. Typically radiata pine is clearcut at age 25 to 30, with a mean DBH between 500 and 700 mm. Usually it is skidded in tree-length, and bucked at the woods landing into sawlog, peeler, pulp, and export sorts. Radiata pine generally has coarse, persistent limbing, which the forester attempts to control through genetic selection, pruning, and manipulation of stand density.

CHANGES IN THE LOGGING ENVIRONMENT

Changes in log-making practices—including bucking shorter lengths—have developed in response to changes in industrial structure as well as physical changes in the nature of the resource. These various changes are inter-related and a brief discussion follows.

Ownership

Just as in the US, there has been a radical change in ownership of the resource. At one time the forest industry in New Zealand was vertically integrated, with common ownership of land, timber, and conversion facilities. Today, ownership of land, timber and conversion facilities is usually separated, with TIMOs (Timber Investment and Management Organizations) owning and operating a large portion of the resource.

Market Responsiveness

There has also developed a far greater responsiveness between log merchandising and markets. Paradoxically, the vertically-integrated operations of yesteryear had limited linkage between the woods and the conversion facilities. There was little accountability for efficiency in raw material allocation or usage, at any part of the supply chain. Today, it is common to see 12-20 different log sorts on a single landing, just for the single species. Each sort responds to a specific market niche.

This heightened responsiveness is coupled to a greatly increased specialization in log markets. Today's mills are highly specialized in the products they produce for their specific markets, and in turn they demand a tightly-specified log.

The new ownership paradigm, where the timber owner typically does not own conversion facilities, furthermore means that the logger is supplying multiple, highly specialized, markets, instead of a single conversion complex as before.

Resource Characteristics

The resource itself has changed greatly. Until about 1980, most companies operated in forest that had received little or no silviculture after planting. These stands were typically well-stocked, limiting limb development. In the 1980s a transition occurred to a large percentage of stands that had been intensively silvicultured. These tended stands were pruned to a height of 3 to 8 m, and thinned at an early age to maximize growth of the pruned trees. Such stands developed heavy limbing in the unpruned part of the tree, in response to the wider spacing and also in response to pruning. Furthermore, such a tree has much more taper than an unpruned tree. Therefore, there is a much greater value differential within a pruned tree than an unpruned tree. The first, pruned, log has high value, typically about $NZ130/cu.m delivered, since it produces a large proportion of clears. The second log may have a value only half this, as a low-grade export log for the Korean or Indian markets, because of the large knots.

To capture the value differential within a pruned tree, the logger must generally buck quite short lengths. Firstly, it is obligatory that he segment the pruned butt from the rest of the tree, resulting in a first cut of typically only 3-6 m. Then, the second cut is often heavily limbed and tapered, in response to thinning and pruning, so it, too, is likely to be a short length before a grade diameter break is reached. Very soon, while the limb size may fall off higher in the tree, taper mandates steadily falling diameters and therefore grades. Hence, log lengths are short, usually 6 m or less. This is exacerbated by the poor form exhibited by radiata pine that has not seen the most advanced genetic selection: crooks, sweep, forks and other defects abound, compared to many other coniferous species. The complexity of the decision-making is such that “log makers” are employed on every landing, to make merchandising decisions, marking cuts for the landing buckers.

CENTRAL PROCESSING YARDS

To merchandise over a dozen sorts, a tree-length landing must be large—if possible, at least 40 x 60 m. Even so, it is not unusual to skid to one landing while merchandising is in progress on another, alternating landings every few hours. To provide a safer, quieter, less obstructed merchandising environment, central processing yards became common in the 1990s. Stems were delimbed at the landing, then hauled to a processing yard that was located either remotely in the forest, or at an intermodal transportation transfer (e.g. road-rail), or at a conversion complex. At the yard, stems were merchandised and the resulting logs sorted, inventoried, and shipped to buyers.

Today, most of the remote yards have ceased to operate. They were more costly to operate than anticipated, especially when all of the associated incremental costs were included, such as for debris disposal, increased fire control (for spontaneous combustion in debris), and increased road pavement depth on some soils to carry off-highway axle loads. At the same time, value recovery did not improve as much as anticipated. Also, in some cases leachates contaminated adjacent streams.

More of the larger, more central processing yards, located at conversion facilities and/or transportation interfaces, have survived, being more economic.

Also contributing to the decline of the processing yard was the realization that log makers at the woods landing were actually doing a better job of mechandising than had been thought, as audit procedures improved. Additionally, the industry has improved its management protocols to enhance value recovery from merchandising at the woods landing.

WOODS PROCESSING TECHNOLOGY

Another cause of the reversion to merchandising at the woods landing has been improvement in processing technology, to the point where many managers feel increasingly comfortable with length measurements in particular, this being a critical issue in such a heavily-limbed species. With an excavator-mounted processing head, merchandising can be done more safely at the woods landing than by personnel on the ground. Mechanized processing has become standard in more densely-stocked stands where tree form is better, limbs are smaller, and piece size is smaller. However, not all managers yet feel comfortable with this method, especially where the wood is rougher and a larger piece size limits the economic advantage of mechanized processing; on these operations, motor-manual processing at the woods landing is the norm.

COMPUTER OPTIMIZATION

For several years, hand-held computers were widely used with software to optimize bucking decisions. This approach, too, has largely been abandoned. It was found that a trained log-maker could make a better decision, faster, than the computer. The software could not adequately take into account defects such as sweep and crook, for which the geometry is difficult to describe without actually scanning the log. Where stems were of sufficiently good form that the computer did make an accurate optimization, it was found that its solution was actually too good: technically correct, but resulting in an excessive volume at the very low end of each grade spec, which was not acceptable to buyers.

Many mechanized processors are equipped with optimizers, but these are often not used, as operators feel they can make a better decision, faster, than the computer.

Computerized optimization is successful at some of the large processing yards, where true 3-D scanning is employed and a truly optimal bucking solution is generated.

MANAGEMENT AND AUDITING

Managers typically generate a weekly cut plan for each side, based largely on contract logger projections, specifying the volume of each sort planned to be cut. Loggers usually cut very close to this plan. Also at typically weekly intervals, a cut card is generated for the use of log makers, showing the various log sorts in order of priority. Some managers assign a numerical weight to each priority. At one time this weight was the calculated stumpage yielded by that sort, but presently the weight is generated more arbitrarily, to reflect both the stumpage for that sort and also other criteria such as a shipping deadline or volume quota for the sort.

CONCLUSIONS

In summary, then, the New Zealanders have adapted their log-making practices to changes in the resource and in organizational structure. In the process, they discovered that central processing yards were successful in some situations, but not others, and the trend away from their use continues. After initially high expectations, they abandoned the attempt to automate the bucking decision process, except in advanced, high-volume central processing yards, where it is successful.

What lessons can we infer for western North American operations?

Firstly, I do not intend to suggest that we should cut short logs as the Kiwis do. That decision is a function of their own resource characteristics and the other factors described above. However, we should always be open to revising bucking instructions in response to changing resources and markets; the decision algorithm must be dynamic. In particular, we need to be less tied to spurious solutions based on the idiosyncracies of the Scribner scale.

Secondly, we can never let down our guard against the "garbage in/garbage out" syndrome. Technological advancement is critical to our success, but it must be implemented critically.

Thirdly, analysis must not be too simplistic or naïve. Many decisions to build central processing yards appear to have been made on the basis of simplistic, optimistic economic assumptions. We have long had the same problem in North America.

Lastly, it is essential to have a comprehensive knowledge of incremental costs and values. This is especially true in recovering biomass, which has an intrinsically low value, and where every opportunity to capture additional value and to control costs must be taken.

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Optimizing the Use of a John Deere Bundling Unit in a Southern Logging System

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Key words: Forest residue, Biomass, Feedstock, Cellulosic ethanol, Pulpwood, Chip-n-saw, Saw timber, Bole, Wind rows

Abstract

Enormous amounts of untapped energy sources exist within the forestry realm. With the current energy crisis and with petroleum prices skyrocketing, all sources of alternative fuels need to be explored. John Deere's Biomass Bundler unit is an effective machine for harvesting forest residues, which can be used as a source of fuel wood and/or a feedstock for biofuel and biobased product production. This project aims to explore an avenue that could supply a very promising source of readily available energy in Southeastern forested lands.

In order to fully utilize forest resources, all available material must be captured. Typical, southern harvesting operations consist of whole tree harvesting in which trees are felled, then skidded to a landing. Limbs and tops from the deck are usually either deposited over the landscape or piled in wind rows. The biomass bundler will serve to capture the otherwise non merchantable material and maximize the marketability of the entire tree. In order to reduce costs, maximize efficiency, and implement the bundler in a tree length harvesting operation, this project will test a prototype harvesting system. The objectives of this venture are to: a) adapt the John Deere 530B bundler unit to a motorized trailer; b) design the optimum deck configuration; c) conduct a productivity study of the bundler unit.

Introduction

There is 368 million dry tons of biomass available annually on a sustainable basis from forest-derived resources in the US (Perlack et al 2005). This represents a huge potential resource for energy production (Rummer et al 2004). With the current energy crisis and with petroleum prices skyrocketing, all sources of alternative fuels need to be explored. John Deere's biomass bundler unit is an effective machine for harvesting forest residues, which can be used as a source of fuel wood and/or a feedstock for ethanol based fuel production. Although technologies and markets for such innovative practices have not yet matured, this project aims to explore a system that could supply a very promising source of readily available energy in Southeastern forested lands.

According to the United States Department of Energy's Comprehensive Energy Plan, one of the key goals for the nation is to diversify America's energy supply. The government aims to promote alternative and renewable sources of energy (Bodman 2005). The Energy Policy Act, part of the energy plan, sets goals of producing 250 million gallons of cellulosic ethanol by 2013, and one billion gallons by 2015 (Morris 2006). One of the most prevalent sources of cellulose for ethanol production are forest residues (Perez-Verdin 2008). Such ambitious national energy goals require a vast supply of renewable feedstocks.

In order to fully utilize forest resources, all available material must be captured. Typically, southern harvesting operations consist of whole tree harvesting in which trees are felled, and then skidded to a landing. Limbs and tops are removed from the tree and either deposited over the landscape or piled in wind rows. The biomass bundler will serve to capture this otherwise non- merchantable material and maximize the marketability of the entire tree. The bundler unit is utilized by feeding slash into a set of four compression feed rollers. Two compression arms then further compress the slash while sliding the bundle forward. A rotating twine magazine then fastens the bundles with bailing twine. At a predetermined length, the automated cutting saw severs the compressed slash resulting in a slash bundle sometimes referred to as a compressed residue log (CRL) (Martin 2008).

The John Deere biomass bundler is commonly used in applications with cut-to-length harvesting systems that require it to travel within a stand. John Deere currently manufactures the 1490D which consists of a B380 biomass bundling unit mounted on a forwarder chassis. In order to reduce costs, maximize efficiency, and implement the bundler in a tree length harvesting operation, this project will test a prototype harvesting system. The objectives of this venture are to: a) adapt the John Deere B380 bundler unit to a motorized trailer; b) design the optimum deck configuration; c) conduct a productivity study of the bundler unit.

Figure 1

Figure 2

Courtesy of John Deere; Figure 1: John Deere 1490D Slash Bundler, Figure 2: John Deere B380 Bundler unit

Auburn University's School of Forestry and Wildlife Science will lead the research. Personnel from Auburn University's Biosystems Engineering, John Deere, and the USDA Forest Service will aid in the cooperative effort. John Deere is providing a 437C knuckle-boom loader, a motorized trailer, a B380 bundling unit, and technical support to the project. The School of Forestry and Wildlife Science will provide testing sites for the study. Biosystems Engineering and the Forest Service will provide tools and equipment for the mounting of the bundling unit and any fabrication of parts.

Project Justification

Current forest harvesting practices in the southern United States are very proficient in harvesting timber; however, the harvest of forest residues are economically inefficient or nonexistent in most of the conventional harvesting configurations in the region. Most logging crews in the South that capture the forest residues do so using a drum chipper. Chipping forest biomass is effective; however, it requires a large amount of capital investment to an already economically stressed industry. In woods chipping operations require the purchase of a chipper as well as chip vans for transport.

Figure 3: Pile of wood chips

Figure 4: Slash bundle

Outputs of the two operations differ as well. Wood chip piles, shown in Figure 3, pose a moisture content issue. Although the top and outer portions of chip piles can be dried to much lower moisture contents, the insides of chip piles remain much more saturated. With many of the biomass consuming plants desiring low moisture contents, any low energy process to dry biomass could prove to be a huge asset to the industry. Figure 4 shows a bundle which have much more air space and air dry much better than chip piles. Within one month, bundles lost between 10 and 25% moisture content (Patterson 2008). According to an energy content equation, the loss of moisture content through evaporation in the bundles causes a 12-28% increase in energy content per unit volume (Karha 2006).

The configuration of the forwarder mounted slash bundler is an unreasonable application for use in the whole tree harvesting operations. With all of the stems being transported to the deck, the bundler is just as functional in a stationary configuration as it would be mounted on a prime mover. The John Deere B380 will be mounted on a trailer for transport and will be fed by the loader at the deck. The exclusion of the forwarder will result in far less overhead. Currently, 1490D slash bundling units list for around $600,000, and the proposed unit will be marketed for significantly less.

Figure 5: Trailer mounted B380

The proposed configuration, consisting of the bundler mounted on the motorized trailer, require less capital investment. The biomass bundling unit will require a very similar amount of initial investment as the chipper, but the bundles can be transported by customary log trailers. The use of ordinary log trailers will cut costs as well as create less deck crowding.

Although the absence of the chip vans will cause less deck crowding, optimal deck configuration with the bundling unit present is essential for logging crews to operate in the most efficient manner. The slash bundling must not interfere with the more lucrative product harvesting and processing, but it must be effective. The travel of the skidders must be unhindered because they are typically the limiting factor in harvesting operations. Merchandizing of the products also must not be impeded in order for the loader operator to maximize productivity.

Currently, loggers are purchasing the entire tree in a timber sale and only getting a return on the bole of the tree. Bundling enables the timber buyers to get the maximum return on their investment. At present, timber buyers can expect to see about $8-10 per ton for slash bundles.

As the market for such material begins to mature, prices and incentives for such innovative practices will be rewarded. The markets in the South are growing with bioenergy plants being built and will potentially come on line in the next 5 years (Example, Perdue 2007). These positive developments in the marketability of the bundles foreshadow the growing demand for forest residues.

Approach

Mounting the Bundler

In mounting the bundler on the motorized trailer, safety and functionality are of upmost concern. The bundler must be able to perform all of the designed swivel and tilt movements without risk of obstruction or instability. The slash must be able to enter and exit the bundling unit without impediment. Mounting connections are designed to withstand the large amount of torque and forces associated with the cantilever setup of the bundler and the position of the slash bundles.

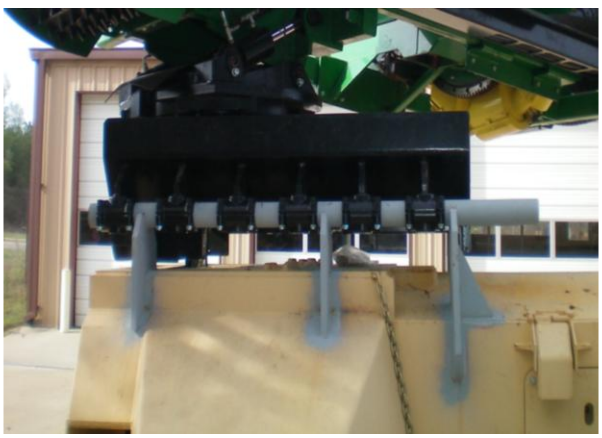

Figure 6

Figure 7

Mounting configuration consists of the mounting block fastened to two 4″ steel tubes.

The motor for the motorized trailer will be based on the flow demands of the John Deere bundling unit. The maximum flow demand for the unit's functionality is 24 megapascals (Mpa)/3480psi (John 2008). Sizing of the engine is based on the horsepower demands of the hydraulic pump that powers the bundler. A 153 HP engine and a 75 gallon per minute variable displacement pump will provide the power and flow rate needed for the bundler to perform. A thirty gallon reservoir to house the hydraulic oil will also be mounted on the trailer. The tank for the hydraulic oil will be equipped with a cooling unit in order to regulate the temperature of the oil in the Alabama summer heat.

Design Optimum Deck Configuration

Deck configuration is very important element in a logger's productivity. "Good landings are important for a safe, efficient operation" (Stenzel 1985). If a deck is cramped and congested, the mobility of the workers and machines could be limited. The bundling operation cannot interfere with the travel of the skidder or the merchandizing or delimbing of stems by the loader; however, the trailer mounted B380 must be close enough to the knuckle-boom loader that it can feed the bundler the forest residue. Our objective is to find the ideal deck configuration for the implementation of the bundling unit through testing different arrangements.

Production Study

Productivity will vary depending on the amount of material available on a site. John Deere reports 20-40 bundles per hour for the 1490D Slash Bundler dependent upon the availability and condition of slash (Martin 2008). In the forwarder mounted configuration, the unit would travel to retrieve slash. This study will test the trailer mounted B380 bundling unit's productivity on a logging deck in which material will be available in very close proximity.

The study will include data collection on six study sites comprised mostly of southern pine species with a small hardwood element in central Alabama. Two of the sites will undergo first thinning timber stand improvement harvests. These sites will potentially contain varied amounts of pulpwood and a large amount of residue. Two sites will be second thinning sites in which most of the stand will be composed of pulpwood with some chip-n-saw. The last two sites will be clear-cut or final harvests. Saw timber, poles, and chip-n-saw will make up the majority of marketable wood classes present on the site. The latter four sites will have a significant amount of residue from limbs, tops, and other non-merchantable stems that will be bundled at the deck. The survey of timber classes on each of the six sites will give researchers an idea of bundler production rates in the three harvesting operations. Bundler production will be assessed by recording the number of bundles and a tonnage production rate.

Methods

Preliminary stand data will be gathered before each harvest. The type of harvest, approximate stand age, and the species composition of each stand will be collected. Each harvesting operation will be monitored for two complete eight hour shifts. The Yellow Box® activity recorders will be mounted on the B380 to monitor use. The activity recorder is activated by vibrations of the engine and will simply return work and stop codes, as well as their respected time. The Yellow Box® will assist in productive and scheduled machine hour calculations for productivity analysis.

Student workers will be tasked with the collection of elemental time study data for the bundler operation. Video cameras will be used to gather all of the information and post processing will output most of the data. Production rates for the bundler will be calculated based on the time and output of the B380.

According to a May 2004 release from the Forest Service, ten foot bundles work well in transportation (Rummer 2004). For this study, the bundler software will be configured to output ten foot bundles. Elements for the bundler time study are feeding slash, cutting, and a delay element. The feeding of slash begins element begins as the slash from the knuckle-boom loader enters the feed rollers. The element ends when the chainsaw bar starts a downward motion. The cutting element begins when the saw begins its downward cutting motion and ends when the saw is in the upright position. Delay elements represent any delays the bundling process might encounter. Production rates will be reported in time/bundle, bundles/productive machine hour (PMH), bundles/scheduled machine hour (SMH), and tons/PMH. In order to increase efficiency and cut down on fuel costs, the bundling unit will only be operational when slash levels on the deck are high.

Literature Review

Published work on the bundling of forest residue is not very abundant. Because the configuration in this study is a prototype system, there is no prior literature on this particular machine. However, studies have been performed demonstrating the John Deere 1490D Slash Bundler's operational abilities. The USDA Forest Service performed an operational performance analysis of the slash bundler in Idaho, Oregon, Montana, and California. The Forest Service's main goal was to reduce fuel levels on the lands to thwart the threat of wildfires. Material bundled ranged from logging slash to small diameter trees. In Idaho City, Idaho, with large amounts of readily available slash, the bundler averaged twenty-four bundles per hour. Production levels ranged from five to twenty-four bundles per hour depending on the sites slash density and slash arrangement (Rummer 2004).

One study was performed in Arkansas by members of the Forest Products Society. The study consisted of four case studies performed on four different sites. Each of the sites underwent a different harvest regime. The first site consisted of a mature stand of loblolly pine clear cut harvested by conventional logging equipment. Logging residue was piled along the roadside to increase accessibility. The slash bundler produced 22.3 bundles per hour with an average cycle time of 2.69 minutes. Site 2 was a twenty-six year old stand of pine plantation undergoing a second thinning by the same harvesting system. Limbs and tops were piled at the deck and the slash bundler was able to produce more than 31 bundles per hour. Site 3, a stand of eleven year old loblolly pine plantation, produced 36.1 bundles per hour (Patterson 2008).

The fourth site in the study was a thinning operation in seventeen year old loblolly pine plantation. Cut-to-length harvesting equipment was utilized on the site which meant that the 1490D had to travel in-woods to gather material. The resulting 13.8 bundles per hour reflect the operational differences. The average weight of the bundles for sites one through four are 883, 916, 950, and 957 lbs (Patterson 2008).

John Deere published numbers in a presentation of a study done in France showing 2006 production numbers. Study conditions are unknown, but the France study reported eighteen to twenty-five bundles per hour was feasible with the 1490D. An aside was made that these production rates could be achieved with an experienced operator and appropriate site planning (Martin 2008).

Hypothesis and Future Research

Production of the John Deere B380 is largely dependent on the flow of slash. In southern logging operations, where slash is readily available at the deck, the stationary application of the unit is ideal. Thirty-five to forty bundles per productive machine hour for the proposed trailer mounted bundler is realistic in ideal stand conditions. The reduced cost and ease of transportation, for both the bundles and the machine, will make the bundler configuration a marketable commodity in the near future for whole tree harvesting systems.

After successfully completing this venture, research will continue on improving the bundler configuration. Instead of powering the B380 using a motorized trailer, the feasibility of a knuckle-boom loader powering the hydraulic flow demands of the bundler can be investigated. If the loader can fully satisfy the hydraulic flow demands of the bundler unit, research into mounting the bundler onto a knuckle-boom trailer will be explored.

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Stump Harvesting

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Abstract

Increased use of forest fuel requires larger and larger procurement areas. Inclusion of stump material within the shorter distances could make this unusual source of biomass more economical to harvest. Land clearing activities are also helping to raise interest in stump harvesting. Processing stump material for biomass is an alternative to other, more costly, woody waste disposal alternatives. This paper reviews some of the existing research regarding harvesting equipment and systems, feedstock quality, and identifies environmental considerations related to the practice of stump harvesting.

Introduction

Stumps are a source of woody biomass, but stump harvesting is not a common practice in the United States. Stumps are often lifted, or pushed over, in land clearing operations prior to new residential or commercial construction. The cost associated with pushing up stumps, piling stumps and debris, and burning is often regarded as normal pre-construction activity. However, due to burning restrictions, some construction contractors are forced to find alternative means for removing stumps from work sites. Some are sub-contracting to logging contractors for stump removal services. In addition to receiving service contract payments for removals, the logging contractors may also comminute and sell the biomass that is produced.

Stump and root mass harvesting may seem like a very strange and costly way to obtain biomass. Transportation costs would be high because the odd-shaped pieces, with main root masses attached, would not compact well. Some type of communition in the woods is needed to reduce the size of the pieces, thus increasing payloads for transport. Splitting may help in breaking the material up to facilitate larger payloads for in-woods transport.

Different comminution equipment may be needed based on the physical characteristics of the root masses. Oversized root masses may be too large to fit into the throat of a horizontal grinder without pre-processing. Disc chippers would be difficult to use because most do not have a horizontal conveyor in-feed. Tub grinders have historically been used to process stumps. Some stump harvesting systems may require stump splitting as a pre-processing step prior to comminution with a traditional grinder or horizontal-feed chipper.

The delivered value of the biomass material from stumps must be high enough to pay for the cost of processing and transport. In addition, the comminuted material may have high levels of contaminants such as soil and rocks. The feedstock quality can impact the delivered price and it can also limit the biomass delivery locations to those purchasers who can accept some impurities in their handing systems and conversion processes. This review of stump harvesting examines the harvesting systems and equipment, feedstock quality, and identifies environmental considerations related to the practice of stump harvesting.

Harvesting Systems and Equipment

Stump harvesting in Scandinavia is becoming more common. Their studies into stump harvesting occurred in the 1970s and 1980s as a way to increase the amount of raw material for the pulp industry. Their research has been renewed with the recent interest in bioenergy. Because increased use of forest fuel requires larger and larger procurement areas, the inclusion of stump material within shorter distances could make this resource more economical to harvest.

Stump harvesting is usually restricted to final harvests in Scandinavian countries. Hakkila and Aarniala (2003) report that fuel yield from stumps can be as high as the yield from above-ground residues. It is not typically implemented in thinnings because of the risk of damaging the remaining trees in the stands.

Excavators are the typical equipment used for extracting stumps and root masses (Hakkila and Aarniala, 2003; Vickery, 2008; and Henningsson, 2008). A boom-mounted attachment is used to lift, then shear (or split) stumps into smaller pieces. Some operations use the attachment to pull soil back into the hole in preparation for planting. Some boom attachments are manufactured with a separate metal piece welded to the outside to aid in filling and smoothing the soil back into the stump hole.

Figure 1. Stump lifting and splitting attachment

Many of the stump harvesting production references are for spruce, pine and birch in Scandinavian countries. For stump lifting after a regeneration harvest, lifting time increases as stump diameter increases (Henningsson, 2008). Also, stump volume has a positive relationship with stump diameter (Palander, 2009). On the other hand, stump diameter has an inverse relationship with stump processing time (Laitila, 2008). These relationships are not as well documented in the United States. The relationships between stump processing times and the impacts of soil types on processing times are not known for many tree species and soil type combinations in the United States. However, a late 1970s era publication (Sirois, 1977) tested a machine that was commercially available at the time, a Rome THX Tree Extractor. With this machine, researchers were able to shear the lateral roots of trees, and then extract the stumps with an upward pulling action. In testing common hardwood species of the southern United States (sweet gum (*Liquidambar styraciflua L.*), hickory (*Carya* spp.) southern red oak (*Quercus falcata* Michx), and white oak (*Quercus alba* L.)), researchers determined that the amount of biomass available in the stump and in the main root mass was about 18% of the total above-ground biomass available in each stem. Stems of up to 9 inches in dbh could be extracted fairly easily, and red oaks were easier to extract than the other species. Trees were pulled from two different soil types, but the significant variable for predicting the shearing and extraction forces of the forest operation was dbh. Lateral root depth, coupled with the limited 10-inch shear depth, impacted the ability to extract some stems by this machine. In general, the lateral root depths of pine aren't as deep as the hardwoods tested in this study.

Smaller stump sizes in younger material may not be economical to harvest. In the United States, non-industrial forest lands that are being converted to other uses are another opportunity to harvest biomass from stump material. This biomass can be in the form of large stumps, but can also be found in standing younger trees. When stumps are harvested from these younger stands, loggers have used a whole-tree pulling method rather than stump lifting. This requires a different type of excavator attachment. A logger in Georgia is using a demolition grapple for this purpose. The excavator grips single trees or multiple trees and pulls them out with the main root mass attached.

Figure 2. Demolition grapple attachment

Operator protection for worker safety is a concern when using excavators in forest operations. Previous research by Rummer et al (2003) analyzed the rollover performance and thrown object performance of hydraulic excavators and recommended improved standards to the International Organization for Standardization (ISO). The current standard for self-propelled machinery for forestry roll-over protective structures (ISO 8082: 2003) does not apply to machines having a rotating platform with a cab and boom on the platform.

Figure 3. Whole tree harvesting with stumps attached

A fledgling stump harvesting system in Finland is comprised of an excavator for extraction, off-road transport by forwarders, and special large-volume trucks for transport to mobile or stationary comminution equipment (Hakkila and Aarniala, 2003).

Forwarders are not as common in the United States as they are in Europe. In ground-based harvesting systems, in-woods transport is typically accomplished by skidding. Skidding stumps and split stumps is probably not the most effective way to move the stump material to the logging ramp. Off-road transport would need additional research to determine the best methods to be implemented in various regions of the United States.

Two different stump harvesting systems have been observed in two locations in the southeastern United States. In a land clearing operation in Alabama, stumps were lifted and split using an excavator with a stump lifting and shearing attachment. No attempt was made to fill in the holes. The split material was loaded onto off-road dump trucks to transport the material to a horizontal grinder located in a log processing area of the land clearing. A trailer-mounted loader was used to feed the material into a horizontal grinder. There wasn't a planned time lag to allow for transpirational drying of the biomass material.

In another land clearing operation in Georgia, pushed-over stump material and logging debris from a recent clearcut was pushed into large piles with a brush blade mounted on a dozer. A large horizontal grinder was moved to each debris pile where a trailer-mounted loader was used to feed the grinder. Because of the large pile size, a wheeled log loader was also used to move portions of the pile closer to the trailer-mounted loader, as needed.

Feedstock Quality

The typical Finnish consumers of stump biomass material are power plants that utilize fluidized bed boiler technology (Laitila, 2008). Although fluidized bed systems can accept a broad range of biomass specifications, there could be benefits from improving feedstock quality through harvesting methods. Several of the previously described harvesting systems recommend shaking the pieces of stumps before piling them in the harvesting area (Palander et al, 2009; AEBIOM, 2007) to release soil and stones from the biomass. This action should help decrease the ash content of the biomass.

In Scandinavian countries, piles of split stumps are left in the harvesting area to dry before being transported to roadside, and to allow rain to wash soil off of the roots. Once at roadside, they are again piled for further drying and storage until needed (AEBIOM, 2007). Sometimes, these piles are covered. This multi-stage process is believed to increase the feedstock quality by reducing both the amount of impurities and the moisture content in the biomass material.

In Finland, stumps are left to mature in the ground before being lifted (Laitila et al, 2008). During this maturation time, the cohesion between the roots and soil decreases. As larger roots start to dry, shrink and decay, the forces required to lift the stumps decrease. The result of this maturation time could be a reduction of soil in the biomass.

Blending at a delivery location is another way to improve the feedstock quality when using stumps for biomass. By blending the stump biomass with other biomass deliveries, a more homogenous and standardized product can be created.

Environmental Considerations

In Sweden, 30 years of study indicate that stump harvesting does not negatively impact the growth of the next stand. Egnell et al (2007) suggest that stump forwarding should follow the same path as used in the round timber extraction to limit soil impacts. Soil disturbance associated with stump lifting can be exacerbated with clay soils. In clay soils, larger amounts of soil loss can occur because it remains more firmly attached to roots. In the United Kingdom, the stumps are stored over winter to help the site retain soil through the action of rainfall and freeze-thaw (Forest Research, 2009). Apart from the obvious initial concerns regarding soil disturbance, there are other environmental considerations related to stump harvesting.

A benefit of stump harvesting is that it can reduce the spread of some root fungi. For example, some western United States species of conifers are susceptible to annosus root disease (Dekker-Robertson et al, no date). The disease causes crown yellowing and thinning, and decayed wood. When the roots of a healthy tree come in contact with diseased roots, the infection spreads. Annosus can live for decades in large stumps. One recommended way to control the spread of the disease is through stump extraction. Healthy stumps are also recommended for removal to provide a buffer around the infected area.

Carbon sequestration is another concern that arises with stump harvesting. Soil contains more carbon than the above-ground parts of the forest (Forest Research, 2009). Stump extraction can involve extensive, localized, soil disturbance that can increase decomposition rates and related carbon release from the soil. The impact of stump removal on carbon loss may be directly related to the proportion of soil organic matter found in different soil types. Egnell et al (2007) state that although a substantial amount of carbon is removed with logging residues and stump harvesting, it is minor over a 60-90 year rotation period. Revegetation may promote carbon sequestration that can help mitigate the negative effects on soil carbon loss. But, on land clearing sites where the land use is changing, the carbon impact may not be mitigated by revegetation. Research is needed to determine the relationship between carbon loss and soil types found in the United States to better understand the environmental impacts of stump removal.

Nutrient cycling is often cited as a concern from the removal of logging debris. This concern may also extend to stump harvesting in the Untied States. The mitigation of stump removal impacts on soil nutrients is addressed in a Finnish publication (Paananen and Kalliola, 2003). In stump extraction, the area of soil disturbance is limited as much as possible around each stump. After each extraction, the organic layer is covered with mineral soil to limit the release of nutrients and heavy metals. In addition, about ¼ of stumps and the greater part of all roots are left in the soil to benefit soil organisms.

The removal of stumps may have an impact on biodiversity. Stumps can provide a structural shelter or an environment for insects, mosses and lichens. Research is needed to determine the impact of stump removal on a variety of forest resources, and to develop guidelines on how to mitigate negative environmental impacts of stump removal.

Summary

There are a variety of studies available regarding stump harvesting. Most of the recently documented studies are in Scandinavia and Europe. Equipment is currently available in the United States to accomplish many of the harvest system functions. Additional research is needed to determine the impact of tree species, tree ages, soil types and other variables on feedstock quality, production rates, and costs of stump harvesting in the United States. Information on the environmental impacts of stump harvesting on a variety of forest resources is also needed.

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Identifying Loggers' Reactions and Priorities in an Increasingly Fragmented Landscape

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ABSTRACT – Through the process of parcelization, tracts of undeveloped land are subdivided, sold, and often converted to urban or exurban land-uses. Some consequences of sprawl-type growth include habitat fragmentation, reduced water quality, and forest management difficulty. The changing values of neighboring landowners, the management restrictions they impose, and the productivity losses from reduced tract size alone make it difficult for loggers to maintain viability. To investigate the effects of parcelization on the logging workforce, a repeatable survey was distributed to the members of two professional timber producer organizations in South Carolina. Questions inquired about trends in changing parcel size, moving and hauling costs, and crew characteristics. Seventy-three percent of respondents have noticed a reduction in tract size. In 1998, the majority of respondents were harvesting tracts 80 acres or larger, whereas now most loggers operate on 20-40 acre tracts. Thirty-two percent have adapted by reducing their number of employees; 26 percent by downsizing their system; 15 percent by refusing to harvest small tracts; and 13 percent by increasing their productivity. Thirteen percent of respondents have made no adjustments whatsoever. In addition to observing a reduction in parcel size, loggers have identified that fuel prices (36.5 percent) and fixed costs (31.1 percent) are also to blame for a diminishing workforce.

INTRODUCTION

The subdivision of contiguous tracts at the Wildland-Urban Interface (WUI) contributes to urban sprawl, habitat fragmentation, and a reduced economic yield of managed resources, including forest products (Macie and Hermansen 2003). This problem is pronounced in the southeastern United States where smaller parcels diminish the economies of scale in highly mechanized harvesting operations. As the previously undeveloped wildland is subdivided and resold in smaller parcels, some forest owners resist the pressure to build, leading to a fragmentation of forest resources. Fragmentation reduces the likelihood that remaining forested properties will later be managed or harvested (Barlow et al. 1998). Timber producers here must also adapt to changing business pressures resulting from increasing residential populations and changing resident values, as population density has been shown to have an inverse effect on probability of harvest (Wear et al. 1999, Sampson and DeCoster 2000).

Reference:
Moldenhauer, M.C., and M.C. Bolding. 2009. Identifying loggers' reactions and priorities in an increasingly fragmented landscape. In: Proc. 32nd Annual Council on Forest Engineering Meeting; Kings Beach, CA. 5 pgs.

Background

The majority of privately owned forests in the U.S. occur in the form of NIPFs; occupying 363 million acres, under 10.3 million owners (Blinn et al. 2007). The average NIPF size is 24 acres (LaPierre and Germain 2005). Ten million acres of NIPFs were lost to development between 1982 and 1997, with 70 percent more lost between 1992 and 1997 than from 1982 to 1991 (Best 2002). Where population density is 19 people per square mile the probability of management is 75 percent (Sampson and DeCoster 2000), and where population exceeds 150 individuals per square mile, it is unlikely that management will occur (Wear et al. 1999).

Approximately 58 percent of the southern forest land base is under the NIPF category of 'family forest owners' (Butler 2008). Twenty-six percent of forestland is in counties with more than 250,000 people, occupying about 28 million acres; 43 percent of which is unmanageable for timber resources (Barlow et al. 1998). In Georgia, Atlanta sprawl consumed about 355,500 acres between 1982 and 1997 (Best 2002), and from 1982 to 1989, parcels less than 10 acres in size increased almost 7 percent, while parcels greater than 200 acres decreased about 18 percent (Greene et al. 1997). Though overall productivity in Georgia has increased over the last 20 years, loggers have noticed a decreased return on investment from factors related to parcel subdivision and changing landowner values (Baker and Greene 2008).

South Carolina's NIPFs accounted for 74 percent of the state's 12.3 million acres of timberland as of 1993 (Thompson 1997). Sixteen percent (1.5 million acres) were in tracts greater than 500 acres; 31 percent (2.8 million acres) were in tracts between 101 and 500 acres, and 10 percent (0.9 million acres) were in tracts 10 acres or less. The dominant size category was between 11 and 100 acres, accounting for 43 percent (3.9 million acres).

Concern for Profitability

Row (1978) found that economies of scale for minimized harvest cost were effective between 20 and 40 acres, and that they are negatively impacted by reduced parcel size. Similarly, Greene et al. (1997) found that in Georgia harvesting costs increase rapidly on tracts less than 50 acres, and there is little motivation for harvesting tracts less than 20 acres. Parcelization and changing land use leads to a reduced number of timber sales, while logger expenses (fuel, machinery, hauling, and labor) can increase on smaller tracts. Small parcels may be suitable for harvesting, but this is unlikely in the southeast where most harvesting systems are highly mechanized.

Moving costs should include the cost of transporting equipment between sites, wages paid to unproductive employees, fixed costs for idle equipment, and the value of timber not being actively harvested (Cubbage 1982). Small partially-mechanized systems may cost between \$400 and \$1,100 per move, while highly mechanized systems may cost between \$2,200 and \$5,400 per move (Cubbage 1982, adjusted to 2008 dollars). Small systems cost less to move, and require less time to move than highly mechanized systems.

METHODS

A repeatable survey instrument was designed to assess the threats of parcelization on SC timber producers and the forest products industry. Mailing lists of logging contractors were obtained from the South Carolina Timber Producers Association (SCTPA) and the South Carolina Forestry Association's Timber Operations Professionals (TOP) program. The initial survey population consisted of 437 firms contacted during the summer of 2008.

Modeled after Dillman's Tailored Design Method (2000), the survey materials were distributed in four separate mailings. The first mailing included a prenotice letter; the second mailing included the 28-question survey with accompanying cover letter, a letter of support from the President of the SCTPA, and a Clemson Forestry decal as a token of appreciation. The third mailing included a reminder/thank you postcard, and a fourth mailing containing one additional survey was distributed to nonrespondents. The survey questions addressed topics like firm demographics, parcelization and tolerances, moving and hauling, reactions to rising costs, and firm priorities.

Completed questionnaires from responding firms were recorded in a spreadsheet upon their receipt. Responses were coded using numerical representations of the answer, permitting the calculation of descriptive statistics. Most analyses included simple averages and percentage calculations.

RESULTS AND DISCUSSION

Of the 437 questionnaires that were successfully mailed, 179 were completed and returned, yielding a total response rate of 41 percent. The questionnaire was divided into five sections including firm demographics, parcelization and tolerances of reduced tract size, moving and hauling, reactions to rising costs, and logging firm priorities. The first four sections inquired about their average time and dollars spent carrying out various tasks associated with timber production. The loss of competition among logging firms and its influence was the subject of the fifth section.

Firm Demographics

Sixty-two percent of respondents obtain at least 80 percent of their production from family forests, while 15 percent of respondents produce 60 to 80 percent of their timber from family forests. This indicates a dependence on family-forests for a continuous timber supply. Twenty-four percent of the responding firms are located in the lowcountry of SC, 23 percent in the midlands, and 53 percent in the upstate. Average family forest dependence in the lowcountry is 40 to 60 percent, and 60 to 80 percent in the midlands and upstate. Twenty-two percent of responding firms were established in the 1970s; 27 percent during the 1980s, and 34 percent have been established since 1990.

With usage at 90 percent, a large majority of respondents operate a conventional feller-buncher/skidder system, three percent operate a track-feller/skidder system, one percent operate a harvester/forwarder system, and six percent operate a manual system. For their main product, most firms (48 percent) harvest softwood pulpwood, 23 percent harvest softwood sawtimber, 18 percent harvest hardwood pulpwood, and 10 percent harvest hardwood sawtimber. Only one percent of firms included fuelwood as a major product. Highly mechanized systems like the feller-buncher/skidder system are popular throughout the southeast where firms are focused on high system productivity and pulpwood extraction. As tracts continue to subdivide, loggers should find a balance between the productivity of the traditional feller-buncher/skidder system, and the moving efficiency of a smaller system with fewer pieces of equipment.

Parcelization and Tolerances

Seventy-three percent of responding firms noticed a reduction in parcel size in recent years. In reaction, 32 percent have reduced their number of employees, and 26 percent have downsized their system. Other adaptations included refusing to harvest smaller tracts (15 percent), increasing system productivity (13 percent), or making no adjustments to their operation whatsoever (15 percent). Forty-nine percent of respondents modified their system in two or more ways to cope with reduced tract size; the most common combination being a reduction in employee number and pieces of equipment.

As identified in Table 1, 33 percent of logging firms were harvesting tracts 80 acres or greater in 1998, while only 8 percent were harvesting tracts less than 10 acres. Currently, 33 percent of respondents are harvesting tracts between 20 and 40 acres, and 14 percent harvest on tracts less than 10 acres. During the next 10 years, respondents expect the distribution of tract size to be such that 26 percent of operations are on tracts less than 10 acres; 25 percent on 10 to 20 acre tracts, and 27 percent on 20 to 40 acre tracts. They estimate that 17 percent of operations will be on 40 to 80 acre tracts and only 5 percent on tracts greater than 80 acres.

Twenty percent of respondents said they would consider harvesting tracts 10 acres or less; 27 percent would harvest 10 to 20 acre tracts, and 24 percent would harvest 20 to 40 acre tracts. Twenty-nine percent would only consider harvesting tracts at or greater-than 40 acres. Fifteen percent of respondents would tolerate production levels of 1 load or less per acre; 41 percent would tolerate production levels of 2 loads per acre, and about 44 percent would require a minimum of 3 loads per acre (Table 2). Respondents are concerned about other site factors such as tree volume, timber quality, terrain, and the amount of site-preparation and other special practices required (e.g. Best Management Practices). Forty-five percent of firms are spending 2 to 4 weeks on each tract, though most (43 percent) would consider moving their operation for 4 to 6 working days.

Table 1: Average tract size harvested in South Carolina.

	< 10 acres	10-20 acres	20-40 acres	40-80 acres	> 80 acres
10 years ago	8	12	18	289	**33**
5 years ago	9	16	25	**35**	15
Currently	14	17	**33**	26	9
5 years predicted	19	**26**	28	22	5
10 years predicted	**26**	25	27	18	5

Table 2: Minimum tract requirements for firms to willingly harvest timber.

Tract size	% response	Working days	% response	Loads per acre	% response
<10 ac.	20	≤3 days	16	<1 load	3
10-20 ac.	27	4-6 days	44	1 load	12
20-40 ac.	24	7-10 days	22	2 loads	41
40-80 ac.	21	11-15 days	9	3 loads	16
>80 ac.	8	>15 days	10	>3 loads	28

Reference:
Moldenhauer, M.C., and M.C. Bolding. 2009. Identifying loggers' reactions and priorities in an increasingly fragmented landscape. In: Proc. 32nd Annual Council on Forest Engineering Meeting; Kings Beach, CA. 5 pgs.

Moving and Hauling

Fifty-six percent of respondents haul their products between 40 and 60 miles for processing, and 26 percent haul between 20 and 40 miles. Only two responding firms (1 percent) haul to a processing facility within 20 miles of their operation – both are located in the SC upstate. Forty-eight percent of firms own and operate their own trucks; 13 percent completely contract their secondary transport, and 38 percent use a combination of company-managed and contract trucking.

Fifty-seven percent of harvesting sites are 20 to 40 miles apart and 26 percent are 40 to 60 miles apart. Most respondents (35 percent) spend 4 to 6 hours moving between sites; 23 percent require 2 to 4 hours to move, and 22 percent require 6 to 8 hours per move (Table 3). To minimize the disruption of moving, most logging operations move their system either after hours (27 percent), during the weekend (29 percent), or in phases (30 percent).

Table 3: Parameters for moving between tracts.

Distance	% response	Time	% response	Cost	% response
<20 miles	13	<2 hours	5	<$0.25/ton	2
20-40 miles	56	2-4 hours	23	$0.25-0.75/ton	16
40-60 miles	26	4-6 hours	35	$0.75-1.25/ton	19
60-80 miles	5	6-8 hours	22	>$1.25/ton	25
>80 miles	1	>8 hours	15	Don't know	39

Reactions to Rising Costs

The survey was distributed from June to August 2008, when fuel prices were at their recent all-time high. During these months the national price for low-sulfur diesel fuel averaged $4.48 per gallon (EIA 2008). In reaction to high fuel prices 31 percent of respondents reduced their number of employees; 27 percent downsized their system; 14 percent purchased more fuel-efficient equipment; 11 percent have not adjusted their system at all, and 17 percent have modified their system in various other ways. These include minimizing moving or hauling distance, reducing their number of days worked per week, reducing skid distance, cutting only high quality timber, hauling loads over legal weight limits, and cutting their family forest to pay for fuel. Many loggers have considered terminating their operation altogether. Respondents adjusted their systems similarly in reaction to high fixed costs.

Firms employing less than 3 people per crew increased from 22 percent in 1998 to 42 percent in 2008 (Table 4). Twenty-three percent of firms had 6 to 8 employees ten years ago, whereas now only 7 percent of firms employ 6 to 8 people. A diminishing workforce has negative consequences for unemployed operators and the future of the forest products industry.

Table 4. Changes in crew size in South Carolina.

	≤3 employees	4-6 employees	6-8 employees	8-10 employees	≥11 employees
10 years ago	22	31	23	13	11
5 years ago	23	39	23	8	7
Currently	42	44	7	5	3

Logging Firm Priorities

Eighty-seven percent of respondents have noticed a reduction in competing logging contractors – only 11 percent of respondents consider parcel size to be a contributing factor. Thirty-seven percent of firms credit fuel-related expenses as contributing to a loss in competition; 31 percent of responding contractors blame high fixed costs, and only 15 percent of respondents feel that the logging-workforce availability is contributing to a loss in competing contractors. Firms are attempting to streamline their crews by reducing employee numbers, implying that an adequate workforce is readily available, but budgetary constraints (related primarily to fuel expenses) have forced companies to downsize. Six percent of respondents list other reasons for reduced competition, including low log value, mill quota, equipment repair expenses, and poor silvicultural practices. All of the above factors, including fuel-related expenses, will increasingly constrict loggers if parcelization continues at its current rate.

CONCLUSION

Population growth and development are leading to a reduction in NIPF size, and changing resident values are influencing the way timber is harvested. It can be assumed that logging companies are harvesting a greater number of tracts through increasingly selective measures to maintain production levels and business viability. Regionally comparable studies have identified that firms are increasing the mechanization level of their operation, and their moving frequency.

According to this research, South Carolina timber producers have observed a decrease in parcel size in the NIPF family forests category. Respondents admit that during the next ten years they may face challenges for rising fuel costs and fixed costs, and a more limited availability of timber. This survey identifies that many loggers have taken measures to reduce the size of their system, usually by cutting their number of employees, or their number of pieces of equipment. As parcel subdivision continues, firms will continue to make decisions about the scale of their harvesting system. In a smaller system a logging contractor may realize:

- Reduced capital investment – fewer pieces of equipment
- Reduced fixed costs – fewer employees
- Less site-damage – easier BMP compliance
- Reduced moving time – fewer trips
- Reduced moving expenses – fewer working hours and less volume sacrificed

As a limiting factor, parcelization is not yet so great that firms cannot adapt, so they need not divest themselves of highly mechanized equipment. However, many companies are struggling and making extreme sacrifices just to stay in business, particularly from high fuel expenses and fixed costs. The scale of the system should properly address the scale of the site, and loggers should be aware of this as parcelization becomes a greater hindrance to their productivity. Timber quality, yield, and accessibility may be the most important factors for maintaining firm viability as parcels continue to subdivide. Fostering good relationships among neighboring forest owners and among the forestry professions may improve the effectiveness of cooperative management. Landowners and professionals should be active in local land-use planning efforts, to encourage the perpetuity of contiguous and continuous supplies of forest resources.

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The estimation of carbon emissions from harvested wood products in Japan -Application of a new approach for appropriate forestry-

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Abstract: The forest resource has a fundamental role in sustainable development if it is used within its growth potential. Out of the forest resource, Harvested Wood Products (HWP) hold the largest share and are consumed widely for building materials, paper, and other uses. Especially, after the adoption of United Nations Framework Convention on Climate Change (UNFCCC) in 1992, HWP is focused on biomass substituted for fossil fuel in some countries where the forest resources are rich and the related industries are active. On the contrary, in Japan, the forestry activities have been developing in some areas under severe conditions such as sharp fluctuations in exchange rates. Systematic forestry is needed, based on zoning and planning for HWP supply while maintaining good conditions. In this study, a new approach is proposed for promoting the use of HWP as woody biomass, and the amount of carbon emission is estimated and compared with that from the previous approaches. Statistical data used for calculation was collected from government and other sources. HWP consists of three sectors; sawn wood, paper, and others. The percentage share of total green house gas emissions in Japan was 3.8% in 2000 and 3.6% in 2005, almost the same as carbon uptake specified by the Marrakesh Accords.

Key words: forest resource, alternative, fossil fuel, new approach, Kyoto Protocol

1. Introduction

Since "Our Common Future (Brundtland Report)" by Commission on Sustainable Development (CSD) published in 1987, people in many countries have been conscious of this concept linked with environmental issues. The phrase "sound material-cycle society" was revealed in 1990 by the Environment Agency in Japan to achieve ecologically sound, sustainable development. According to the report, human activities should match with the carrying capacity of natural resources and global ecology. Subsequently, the UN Conference on Environment and Development (UNCED, Earth Summit) in 1992 ushered in a promising epoch for forest research because the Statement of Principles for the Sustainable Management of Forests adopted at the

Conference contributed to the management, conservation and sustainable development of forests. The main concept of forestry science is the maintenance of forest resources for future generations. The study of forest management plays an important role in using the resource properly, especially through inventory and satellite monitoring. At the COP3 (The 3rd Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change), the Kyoto Protocol was adopted for use in 1997. Under this Protocol, "Annex I" (industrialized) countries agreed to reduce their collective GHG emissions by 5.2% compared to the year 1990 over the five-year period 2008-2012 (First Commitment Period). According to Article 3.3, net changes in carbon emissions resulting from human-induced land-use change and forestry activities, limited to afforestation, reforestation and deforestation (ARD activities) since 1990, can be measured as verifiable changes in carbon stocks to meet the commitments included in Annex I countries. Unfortunately ARD activities in Japan will be net carbon sources during the First Commitment Period because deforestation will surpass afforestation and reforestation (Forest and Forest Products Research Institute, 2000). Under Article 3.4, several countries can gain additional credit for CO_2 absorption through forest management activities that have occurred since 1990. The Bonn Agreement allows countries to meet part of their targets through four types of land use, land use change and forestry activities: forest management, cropland management, grazing land management, and re-vegetation (UNFCCC, 2001a). The Marrakesh Accords capped carbon uptake credit at 13.0 million tons-C/year for implementing silvicultural practices in Japanese forests (UNFCCC, 2001b). Total greenhouse gas emissions in the base year were 344.0 million tons-C/year, and forest management activities contributed 3.8% of this (Greenhouse Gas Inventory Office of Japan, 2008). Forest Management is defined as “a system of practices for stewardship and use of forest land aimed at fulfilling relevant ecological (including biological diversity), economic and social functions of the forest in a sustainable manner” (The Government of Japan, 2008). Japan interprets the definition of “Forest Management” as the following.

a) Activities for “Forest Management” are appropriate forest practices including regeneration (land preparation, soil scarification, planting, etc.), tending (weeding, pre-commercial cutting, etc.), and thinning and harvesting which have been carried out since 1990.

b) Activities for “Forest Management” are practices for the protection or conservation of forests including controlled logging activities and land-use changes which have been carried out under the laws.

2. Research purpose

On the global level, it was estimated that forest vegetation and soils contain about 1,146 petagrams of carbon, with approximately 37% of this carbon in low-latitude forests, 14% in mid-latitudes, and 49% at high latitudes (Dixon, et al., 1994). In 1990, deforestation surpassed forest area expansion and growth per year, producing a net flux of carbon to the atmosphere. On the other hand, it was calculated that the areas regarded as suitable for large-scale plantations and agroforestry for the sole purpose of sequestering carbon was less than the amount of carbon required to offset current carbon emissions (Nilsson, et al., 1995). Focusing on specific tree species, biomass accumulation rates were maximal in the shortest rotations for aspen, but in mid-length rotations for pine and spruce (Seely, et al., 2002). These ecological studies indicate forest vegetation may be a carbon source for the world as a whole over a specific time period, whereas plantations of specific tree species have an ability to accumulate carbon temporally in each forest stand.

Based on a revised definition of forest and an improved growth curve, Matsumoto (2001) calculated the carbon stock and absorption of forests in 1995. Carbon stock and net absorption were 1.24 billion tons-C and 2.25 million tons-C respectively. Proceeding from the age structure of Japanese managed forests, NBP (Net biome production) potential was estimated at 16 million tons-C/year (Alexandrov, et al., 2002). This value serves as a target for sink enhancement efforts, with the potential to uptake up to 4% of fossil fuel emissions. Identifying Forest Management (FM) of plantation forests per The Marrakesh Accords, FM plantation sequestered 8.0-10.5 million tons-C carbon in inverse proportion to the harvesting volume of 21.0-14.0 million m^3 (log volume) (Hiroshima, 2004). These studies indicate the potential of carbon sequestration in Japan, whereas the current Article of the Kyoto Protocol allows the same amount of fossil fuel to be used.

In addition to carbon uptake of forest, Harvested Wood Products (HWP) have an important role as an alternative resource if they substitute for fossil fuel. An IPCC expert meeting held in 1998 examined a range of three approaches for estimating the emissions of CO_2 from HWP, and compared these approaches with the one in the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Brown, et al., 1998). Carbon emissions of HWP were calculated with an FAO database to determine what differences occur in carbon emissions by country (Winjum, et al., 1998). The proposed three approaches, however, focused on carbon source-sink balance in forests and HWP, and they don’t consider the efficiency of substituting for fossil fuel.

The purpose of this study is to demonstrate a new approach of HWD carbon accounting as previously proposed by Nose (2005). Following this approach, carbon emission was calculated for the Japanese forestry sector in 2000 and 2005 and compared with previous approaches. The prospects of forestry and its technical aspects are discussed to implement environmentally sound forest operations.

3. Previous approaches and new approach of carbon accounting

The system boundary defined for the previous three approaches encompasses only the forest and HWP. The following simplified figures shows the carbon source-sink of both modules (Fig. 1) and calculated elements of HWP (Fig. 2). Calculation of carbon basically used the annual data of FAOSTAT disclosed on the website. The equation of each approach is as follows;

IPCC default = a – b – c

Atmospheric Flow = a – b – d

Stock Change = a – b –d + (e – f)

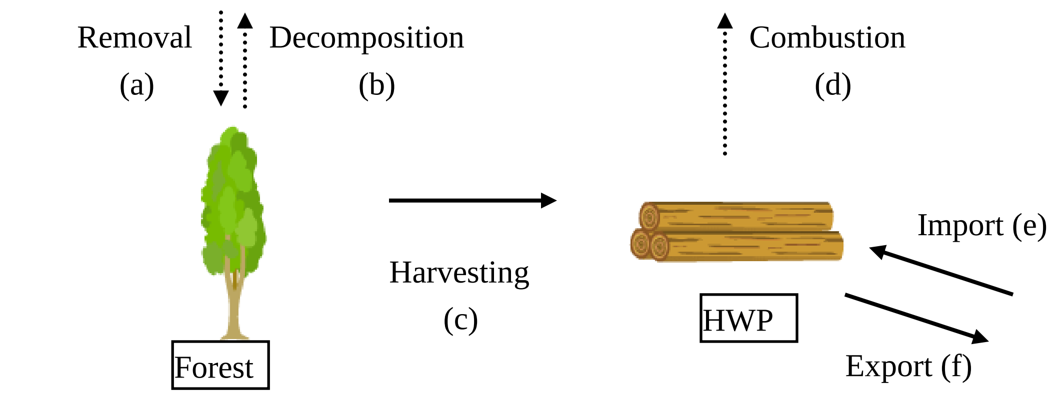


Figure 1 Carbon source-sink of forest sector

Source: Obara (2000)

Note: log and wood products: ⟶ atmospheric CO_2 ⋯⋯▸

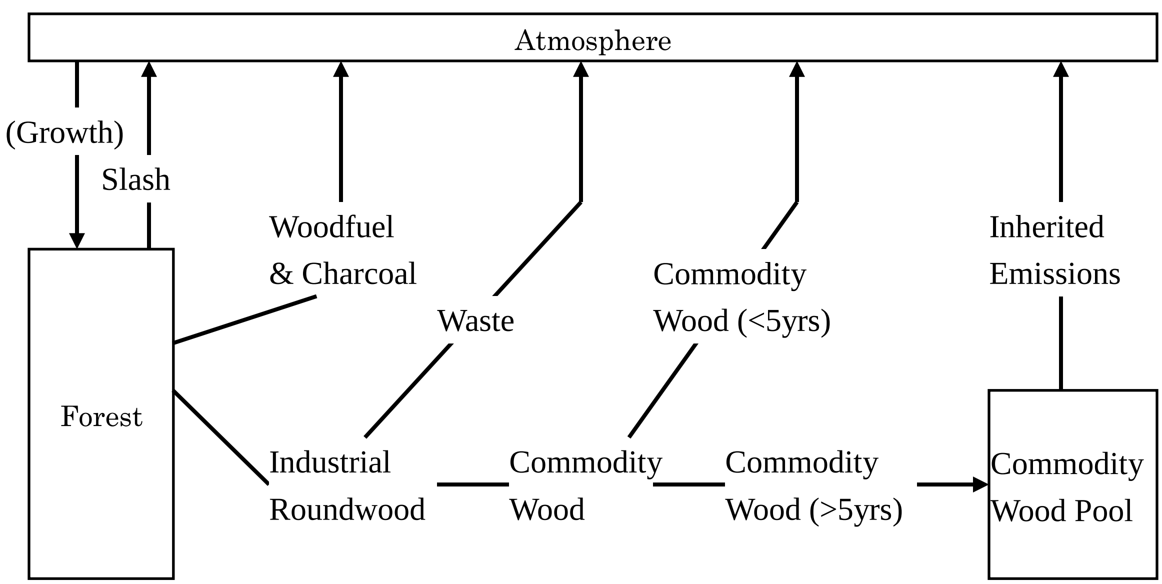
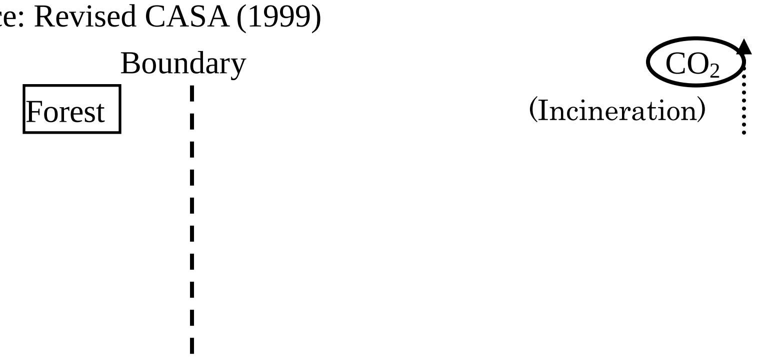


Fig. 2 Calculated elements of HWP

Source: Revised CASA (1999)



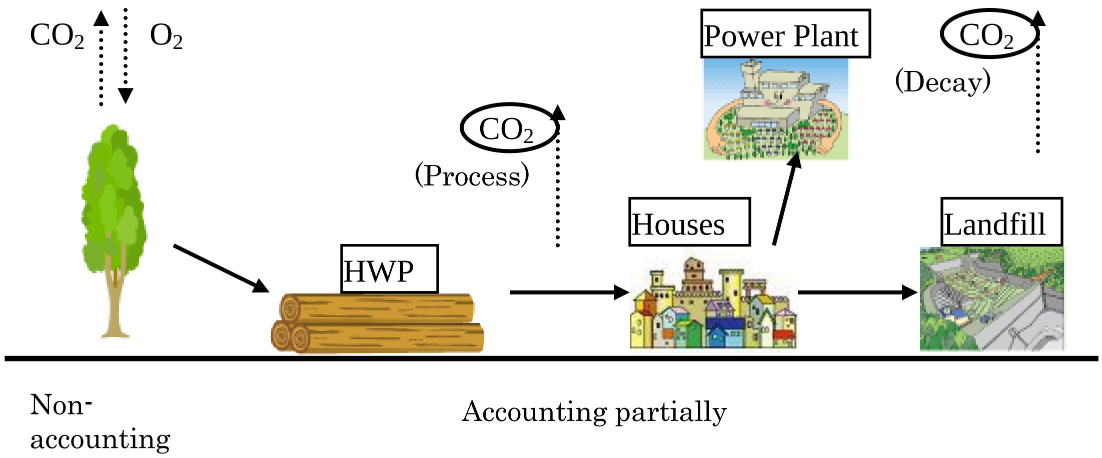


Figure 3 Carbon accounting of new approach (Sawnwood)
Note: Same as Figure 1

The outline of a new approach was introduced in a paper presented at an international meeting held in Malaysia (Nose, 2005). The newly proposed approach is a simple method to estimate CO_2 emissions (Fig. 3). The sectors of calculation consist of sawnwood, paper, and others. It is necessary to apply this approach across the whole world in order to promote domestic HWP production and consumption. Carbon emission was accounted for when the actual CO_2 from HWP was released to the atmosphere and considered any substitution for fossil fuel such as through generation of electricity in a power plant.

4. Results

4.1. Previous approach

Before showing the results of the new approach, total net carbon flux and emissions of two previous approaches, applied to Japan in 2000 and 2005, are indicated in Tables 1 and 2. Comparing of the two years under the Stock Change approach, carbon flux would become negative from positive, indicating that forest and HWP became a net carbon source over the five years because the stored commodity had decreased in proportion to economic decline. On the other hand, carbon emissions under the Atmospheric Flow approach accounted for 7.75 and 8.83 million tons-C in 2000 and 2005 respectively. The waste was calculated as the difference between net consumption of industrial roundwood and consumption of woody commodity, because the latter included imported products and was larger than the former. Carbon emissions calculated by the Atmospheric Flow approach amounted to 2.1% in 2000 and 2.4% in 2005 respectively. Stored commodity and waste decreased gradually in proportion to the economic situation in Japan whereas inherited emissions increased due to the past accumulation.

Table 1 Carbon flux of Stock Change approach

Unit: million tons-C

Category	Roundwood Production	Slash	Commodity stored > 5 yr	Inherited emissions	Total
2000	4.24	2.15	12.31	5.83	0.10
2005	3.77	1.78	9.52	6.47	-2.50

Table 2 Carbon emissions of Atmospheric Flow approach

Unit: million tons-C

Category	Slash	Inherited emissions	Commodity stored < 5 yr	Waste	Woodfuel & Charcoal	Total
2000	2.15	5.83	4.74	-5.13	0.16	7.75
2005	1.78	6.47	3.38	-2.96	0.16	8.83

4.2. New approach

As described before, actual carbon emission of HWP was shown at Table 3. Forest fire, shifting cultivation and inherited emissions of logs from thinning were excluded from this calculation because of a lack of statistical information. Calculated carbon emissions were larger than those by both previous approaches because most used paper was disposed by incinerator rather than being recycled, and tended to decrease with the trend of declining timber consumption. Percentage share of total greenhouse gas emissions in Japan was 3.8% in 2000 and 3.6% in 2005, almost the same as the carbon uptake specified by the Marrakesh Accords. However, deduction of emissions increased a little owing to the rising use of waste wood for energy at paper manufacturing facilities. It is important to highlight the carbon deduction in the paper sector through the effective use of black liquor and old paper nowadays.

Table 3 Carbon emissions of new approach

Category	Emissions (million tons-C)	Percentage share (%)	Deduction (million tons-C)	Percentage share (%)
2000	13.78	3.8	1.43	0.4
2005	13.18	3.6	1.72	0.5

5. Conclusions and future problems

Carbon stock in forest is so large that we will have the duty to use this resource continuously for future generations and set up the system of effective use in Japan. In this study, it was indicated that previous approaches for carbon emissions of HWP could be calculated by common methods based on FAO statistical data. But these approaches don’t reflect the specific situation of each country and were shown to underestimate emissions in Japan. This paper focused on fossil fuel substitution as well as land use change and forestry activities. It aimed for mitigating the numerical target of carbon emission from fossil fuel. It showed that the Kyoto Protocol doesn’t sufficiently consider utilized forest resources.

On the contrary, the new approach estimated the actual carbon emission and deduction of HWP, whereas it amounted to carbon sequestration by “Forest Management” determined through Marrakesh Accords. If this proposal could be applied to all countries in the world, we will have to study the fundamental elements of using HWP based on appropriate forestry. The future problems to resolve are as follows;

1) Enrichment of resource information

The new approach requires actual information on the production, consumption and disposal of forest and HWP. Unfortunately, not even accurate estimates of forest area and stock are available, although inventories of forest owners have been completed in Japan. The growing stock of forests, less that in areas reserved for preservation, is needed for stable log production considering the social economic situation of each local area. Forestry activities will be established based on ecology and the conservation of biodiversity.

2) Trial of Life Cycle Inventory (LCI)

Even if HWP are substituted for fossil fuel, there is an environmental loss because the input/output ratio became less than 1.0 through the process. LCI can provide an indicator of the adequacy of HWP use, and sensitivity analysis can indicate the critical point of decrease in carbon emissions. LCI methodology for HWP is now in the developmental stage, and we have to identify the boundary and proper units for calculation.

3) Preparation for infrastructure

Forest engineering plays an important role of this element. Forest roads and multi-functional forestry machinery are developed to reduce the cost and energy of harvest operations. Roads may have large environmental impacts, and machinery affects the employment and working conditions of forest workers. Especially, a large amount of imported wood chips discourages the use of domestic supply in Japan. We should also focus on the development of forestry machinery for wood chips to be used at biomass energy generators.

At last, I would like to introduce the impressive and informative phrase President Barack Obama stated during his Inaugural Address. Accepting the following statement, we will have to think about the direction of technical development and intensively invest in research to solve future problems.

“We say we can no longer afford indifference to suffering outside our borders, nor can we consume the world's resources without regard to effect. For the world has changed, and we must change with it.”

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*, in Japanese.

Production for a Biomass Harvesting System in Pine

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Key words: Forest residue, Biomass, Feedstock, Cellulosic ethanol, small scale harvesting

Abstract

A substantial amount of woody biomass feedstock is available on a sustainable basis from forests in the eastern United States. Current harvesting methods are limited in their ability to sustain the growing demand for biomass feedstock and cannot cost-effectively harvest small diameter material. Auburn University and cooperators have developed and are currently testing a harvesting system designed primarily for the purpose of producing biomass feedstock. The components of the system include equipment for felling (John Deere 75C with a Fecon shear head), extraction (Awassos MD-50 skidder), and processing (Morbark Typhoon self-loading chipper). This system was used under a variety of silvicultural prescriptions in both pine and hardwood ecosystems. A trial harvest was performed to familiarize the operators with the equipment and to provide information about the machinery, followed by production studies completed in pine stands. Benefits of the harvesting system include cost-effectively utilizing small diameter material, maintaining low residual stand damage in dense or sensitive stands, and the ability to work on small tracts and urban areas.

Introduction

A project was initiated in 2007 in an effort to develop a small scale harvesting system that will economically and efficiently deliver a biomass product to an alternative energy plant. Several criteria were considered important in the development of this system:

a) The system has to operate in an environmentally friendly manner. Landowners are becoming more selective and aware of good harvesting practices that meet important state best management practices and increasing aesthetic expectations.
b) Capital requirements for the system should be kept to a minimum. Most small businesses cannot afford large up-front investments.
c) The system should be fuel efficient – fuel is not only expensive, but it is important to keep the strong positive energy balance derived from using forest products.
d) Daily operating costs need to be minimal to economically deliver a product to a market that does not have much price allowance for their raw material costs.

Various equipment for the harvesting system were procured in late 2007 and early 2008. The system consists of the following three pieces of equipment:

1) ***Felling:*** Felling was completed by a small excavator (John Deere 75C) with a Fecon shear head (Figure 1). This was a new type of harvester that has not been evaluated. The ability of this machine to reach for trees rather than driving from tree-to-tree enhanced productivity with the small stems. It also minimized residual stand damage and ground disturbance. Initial testing of this machine demonstrated some inefficiency in the boom design and speed of the shear; we hope to address both of these problems with continued studies.
2) ***Extraction:*** The primary extraction machine was a small 50 h.p., hydro-static drive Turbo Forest skidder (Figure 2) mounted with a Fecon swing arm grapple. There is currently only one manufacturer of a small skidder in North America, so demonstrating the viability of a small machine might open this market for additional manufacturers. Operation of this skidder determined the current machine is slightly underpowered and the swing grapple did not grab enough trees; thus limiting production.
3) ***Processing:*** Once the material was brought to the landing, it was fed to a Morbark Typhoon 325 horsepower chipper (Figure 3). The chipper was equipped with a small loader for easy handling of the material and eliminated the need for a separate loader. This configuration was chosen because it allowed one operator to complete all the work on the landing.

Figure 1. John Deere 75C with a Fecon shear head.

Figure 2. Turbo Forest skidder with a grapple attachment.

Figure 3. Morbark Typhoon chipper with a loader attachment.

If the entire system was purchased new, the complete cost could be less than $300,000 (<50% of the cost of a conventional mechanized system). Fuel consumption was also determined to be low, with the feller-buncher and skidder both using less than 2 gallons per hour and the chipper around 10 gallons per hour. Under production, this system was able to put the chipped material into a van for about 1 gallon of fuel per green ton of chipped material. Considering many of the biomass to ethanol conversion processes estimates 80 gallons of ethanol per dry ton of biomass, this should keep a very positive energy balance for this system.

Stand description and treatment applications

Two stands were harvested on Auburn University's Mary Olive Thomas Educational Forest just outside of Auburn, AL. The first stand was a twelve year-old loblolly pine plantation with a small to moderate amount of natural regeneration. At the time of harvest the stand had no previous silvicultural or operational treatments applied to control the natural regeneration or to thin the stand. The second stand was an eighteen year-old naturally regenerated loblolly pine stand with a small hardwood component. This stand was subject to annual burns for the purpose of thinning the stand and controlling the small hardwood component.

Both stands were approximately five acres in size. Each stand had rows approximately 30 feet apart marked for the operator. All rows in the stand were cut on the first pass and then the feller-buncher thinned between rows on a second pass. The silvicultural objective of the biomass harvest was to thin both stands to a residual basal area of 70. Trees per acre and removal per acre can be seen in Table 1. The residual stands reached their target basal area with the Plantation having a 67.83ba and the Natural stand having a 72.51ba

Table 1. Stand data and removals volumes of harvested areas.

Stand	Beginning (TPA)	Residual (TPA)	Removal (tons/acre)
Plantation	676	292	45
Natural	1022	252	48

Results

Equipment production

The operators had previous experience harvesting both pine and hardwood tracts. Data was collected by several methods, including the use of data recorders, videotaping the machines during operation, and in some cases manually recording data. The following tables include data to estimate the production of the three machines. More time is needed to develop curves indicating the impact of tree size on felling performance and how distance affects skidding production.

The productivity data for the feller-buncher is summarized in Table 2. Both stands showed very similar results. Data was further divided into cutting rows and thinning between rows; this data showed some discrepancies in cycle times with thinning between rows being slightly more time consuming.
Bunch size was limited by the size of the grapple on the skidder and the operator did a good job of sizing the bunch to optimize the pull. Heavier TPA counts in the Natural stand did lead to slightly more residual down woody debris.

Table 2. Trees per minute and Trees per Bunch for the John Deere feller-buncher

Site	N	Trees/Minute	Trees/Bunch
Plantation	249	2.10	4.06
Natural	242	2.17	4.34
Total	491	2.13	4.20

Turn times and turn distances were collected for the skidder using a MultiDAT recorder. Four-hundred and thirty-five cycles for the skidder were recorded (Table 3). Distance was measured for the full roundtrip cycle as was turn time. With an average turn time of 4:53 minutes, the operator was able to make approximately 13 turns per productive hour. Turn volume was estimated by recording tree size, and was also calculated by determining the volume in a truck divided by the total number of turns.

Average volume per turn for the study was 0.55 green tons/turn. For this study on these sites, total skidder productivity was determined to be 7.15 tons per productive hour.

Table 3. Skid distances and cycle times for the skidder from GPS data.

		Distance (feet)			Time (minutes)		
Site	N	Mean	Min	Max	Mean	Min	Max
Plantation	172	856.08	167.54	1742.08	3.83	1.17	7.42
Natural	263	1339.49	546.88	2396.07	5.00	2.32	12.20
Total	435	1148.34	167.54	2396.07	4.53	1.17	12.20

Collecting production data for the chipper was less comprehensive because it could far out-produce the other two machines. Several vans were filled in just over 1 hour each; others took longer because of tree size or crooked material. Average load size was 24.71tons/load. Production for the chipper was determined to be ~20tons/productive hour.

System costs

An excel spreadsheet program developed by Robert Tufts called CashFlow was used to estimate the total cost per ton to load the material into a van. This program uses the current depreciation schedule as required by the IRS, and includes costs for maintenance, fuel and interest costs for loans on equipment to do an after-tax analysis. It summarizes the total cost of owning and operating a machine over the economic life of the machine.

Several assumptions were made for the analysis including:

1) Fuel cost of $2.50/gallon for off-road diesel
2) Economic life of 5 years for all three pieces of equipment
3) Loan life of four years with no down payment
4) 6 percent interest rate on loans
5) Total production rate of 14,523 tons per year
6) 33% indirect cost was added onto total equipment estimates

Capital costs for the three machines were estimated at $95,000 for the feller-buncher, $90,000 for the skidder, and $110,000 for the chipper. Total cost to run the system and load vans was calculated to be between $16.00 and $16.50/ton, depending on the type of stand, over a five-year ownership period. Slightly over two truckloads per day are being produced depending on the skid distances and stand types. When you add in trucking and something for stumpage and profit, this cost estimate is higher than most biomass markets can currently pay. Higher production is needed to make the system economically feasible. Most likely, three to four loads a day should provide the volume needed to make the system cost effective.

System production was based on observation of the machines running on each site for a specific amount of productive time. For the cost analysis, utilization was set at 75%, which is higher than was attained by the students. This higher utilization is justified because the students had downtime due to data collection, trucking delays, and the swing grapple on the skidder causing problems. The swing grapple configuration will likely not be used by the manufacturer of a small skidder; a more conventional grapple will be installed on machines coming to market.

To attain the goal of three to four loads per day, several improvements could be implemented. The first has already been mentioned; changing the grapple configuration to a more conventional arrangement. This modification will have two benefits: it will reduce downtime, but should also allow for greater sized bunches to be pulled to the landing, thus making the skidding function more productive. The feller-buncher could also become more productive with some slight modifications (which we cannot do on a leased piece of equipment). Purchasing the machine without a boom and retro-fitting the machine with a boom better configured for a woods application will make the machine more productive. Also, getting more flow to the shear head through use of an auxiliary hydraulic pump will improve the felling cycle times. The chipper is currently being underutilized, so attaining additional production requires no changes.

Total system costs were re-analyzed with these changes. The capital cost of the feller-buncher was increased by $5,000 for the modifications. Machine production was raised from 9.7 tons/PMH to 12.5 tons/PMH, reflecting the improvements in performance from the modifications. Total system production was raised to 25,000 tons/year, or 75 tons/day(3 truck loads). Indirect costs were kept at 33%. Total system cost decreased to $12.23/ton. If haul distance is kept under 40 miles or so, the market should allow enough to pay the trucker, give the landowner something and still have a profit for the logger.

Residual damage

Damage was divided into stem and crown damage, and further categorized into minor and major damage for each category (Table 4). Minor damage is damage that a tree can typically recover from, whereas major damage could result in adverse effects for the tree. It should be noted that the percent damage is based on the residual stand, and some comparable damage studies base the percentages against the pre-harvest stand (the original TPA).

The natural stand was higher in both residual stem and crown damage. This is most likely due to the heavy initial stand stocking (1022 TPA) in comparison to the plantation site (676 TPA), and that there were no well defined rows established before harvest. Overall, 15% of the natural stand incurred some type of stem damage opposed to 7.6% of in the plantation, while 7.1% of the crown in the natural stand incurred damage opposed to 3.8% in the plantation.

Table 4. Percentage of residual stand damaged.

Stand	Damage of Residual Stand			
	Stem Minor (<10cm^2)	*Stem Major (>10cm^2)*	*Crown Minor (<1/3)*	*Crown Major (>1/3)*
Plantation	7.6%	0	3.8%	0
Natural	4.3%	10.7%	0	7.1%

Table 5 is a list of the disturbance classes and their percentage of the sampled plots. Shallow disturbance (litter removed or litter and topsoil mixed), deep disturbance (topsoil disturbed to a greater extent), and slash cover were measured at more precise disturbance levels, but are combined under a general disturbance class for the purpose of this summary.

Soil disturbance results are very similar for both stands. The plantation retained 60% of the stand in an undisturbed state, had a moderate amount of shallow disturbance, and had a very minimal deep disturbance. When we combine this with the fact that there was no recorded major stem or crown damage in the stand, we can be very pleased with the environmental sensitivity of the harvesting system. The natural stand also did well with 50% of the site remaining undisturbed. Shallow and deep disturbance were also very minimal for the site.

Overall, the slash content for the natural stand was higher than that of the plantation. This is most likely due to the heavier stocking of smaller trees in the plantation which resulted in the breaking and knocking down of smaller dead trees during harvest.

Table 5. Soil Disturbance Analysis

Stand	Sample	Disturbance Class				
		Undisturbed %	Shallow Disturbance %	Deep Disturbance %	Slash Cover %	Non-soil %
Plantation	*pre*	89.18	1.43	0	3.88	5.51
	post	59.96	31.02	1.02	7.96	2.04
		-29.22	***29.59***	***1.02***	***4.08***	***-3.47***
Natural	*pre*	80.82	6.53	0.61	9.18	2.86
	post	48.78	34.08	2.24	12.04	2.86
		-32.04	***27.55***	***1.63***	***2.86***	***0***

Summary

The objective of the project was to investigate the feasibility of a small scale harvesting system that would produce a biomass feedstock for an alternative energy plant. The system had to be cost competitive and environmentally friendly. A boom-type, feller-buncher, a small skidder and a chipper were tested as a system. Based on residual damage assessment, the system can do an acceptable job for a landowner, but residual damage seems to increase with a greater pre-harvest TPA counts. This seems logical, as since there are more initial trees in the stand, it will be harder to avoid making contact with residual trees as we work in the stand.

Production from the system did not reach the desired levels, but some modification should make at least the 3 load/day goal attainable. The system was able to produce slightly over two truckloads per day; some changes to the feller-buncher and skidder will be necessary to complete the third load. The system currently can fill a van for ~$16.50/ton, but if the increased production can be attained costs will drop to $12.23. When trucking, stumpage and profit are added, the market will need to be in the low $20 range to make the higher producing system economical.

There are several areas where future research could help. Implementing some of the improvements we listed and documenting the increased production will show the economic feasibility of the system. Also, related to biomass, developing a system to efficiently handle residues from a conventional operation could be a viable application across the South.

Do Synthetic Ropes change the design principles of standing skylines ?

Abstract:

Cable logging is often the only sound logging technology for sensitive mountainous regions. European cable systems are mainly operating as standing skylines. All design routines estimate or calculate the forces in the cables (especially the skyline) under the presumption of fixed anchor points. The usage of synthetic ropes as guy lines may change this. The flexibility of synthetic ropes may work as shock absorber and reduce the maximum forces in the skylines.

The pattern of forces in the guy lines during typical yarding operations are used to simulate and calculate the movements of a tower yarder and the effect on the forces in the skyline. This paper shows how to simulate the dynamic loads on guy lines for typical ropes (wire vs. synthetic) in the lab. The test bench for this dynamic load is described and the forces in the tested ropes are compared with measurements done on real installations.

The resulting movements of the peak of a tower yarder are calculated and compared. The paper gives an outlook how the usage of synthetic ropes will influence the design procedure of standing skyline systems.

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Background

Cable Logging has a long tradition in many mountainous forest regions around the globe. Important wood resources and valuable ecosystems are located in mountainous forests. In flat or almost flat areas forestry is often competing with other land use types like agriculture, settlement or industrial use. Commercial forest plantations are mainly established in areas with moderate terrain conditions. Main reason for that is to have low priced costs for harvest and other management activities. Nevertheless forests in mountainous conditions are valuable timber resources, which are logged under this specific conditions. The UNEP-WCMC statistics (Tab1.) indicates 3 times the forest area of the USA (FAO) located in mountains. Two third of the forests in mountainous regions are temperate and boreal forests, just 30% are tropical or subtropical forests.

Cable logging has a long history in many regions. European cable logging systems are adapted to the given terrain conditions. The use of intermediate supports is common, but due to cost reasons also European yarding crews try to install single span set-up’s.

Tab. 1: Areas of different forest types occurring in 4 mountain classes (km²)
Source: IREMONGER et al. 1997

Forest Type	>=2500	1500-2500m & slope>=2°	1000-1500m & slope >=5° or local elevation range >300	300-1000m & local elevation range >300	**TOTAL**
Tropical (& subtropical)	293.093	450.221	589.328	1.541.000	**2.873.642**
Temperate and boreal forests	322.415	1.101.058	1.543.647	3.638.428	**6.605.548**
TOTAL	**615.508**	**1.551.279**	**2.132.975**	**5.179.428**	**9.479.190**

In opposite to installations in the North West, in Europe the sag of the cable is little. That results in flat cable curves with reduced payloads. The topography is one factor, others are the ownership pattern and the need to have a high lateral stability in thinning operations to avoid damages to the residual trees. The traditional long distance cable yarding installations (PESTAL) used the gravity and had just a small engine to pull the carriage uphill. This installations had 2 or more intermediate supports and reached often up to 1000 meters (~0.6 miles).

Beginning 1950, the “new mobile” short distance cable systems where introduced (PESTAL 1962). This mobile tower yarders are mainly running as uphill or downhill systems , most of all as standing skyline systems. Small equipment allows yarding distances up to 300m (~915ft), bigger ones up to 800 m (~2440ft).

Objectives

There is a long list of scientific discussions about the calculation of the exact cable curve (IRVINE 1975). The differences between parabolic curve or catenary are not discussed in this paper.

The traditional design of cable systems for forest logging in Austria used an algorithm developed by PESTAL. This algorithm is based on cable mechanics (CITARY 1962) and made some simplifications for the daily use. The formulas for the calculation are accurate enough and simple to apply. In opposite to cableways and chairlifts the cable is fixed between two anchors. For cableways and chairlifts the forces in the cable are independent from the position of the load, a balancing system keeps the forces constant.

In forest yarding systems the skyline is fixed between two anchors (this is similar to cables for suspension bridges). The forces are dependent to the position of the load, maximum forces appear when the load is in the middle of the span. Due to the rough operating conditions (carriages with 2 or 4 rollers, discrete movements, immediate stops, load touches the ground) the forces in the different cables show a high variation. This kind of strain to the cable is often visible by jumping carriages along the cableway. Fig. 1 shows a typical diagram of the forces in the guy lines and the skyline of a K-300 mobile yarder. On the right half of the diagram the unloaded phase of the yarding cycle shows moderate frequencies at a low level of forces.

Between second 53 and ~ 85 the lateral hauling shows partial stronger forces in all cables and beginning with second 85 the part of the in-hauling with high amplitudes is recorded. This high amplitudes are not very dangerous because the energy content is low related to the short time the peak's occurs. Nevertheless it is a stress to the cable which may reduce the durability of the cable (FEYRER 1991).

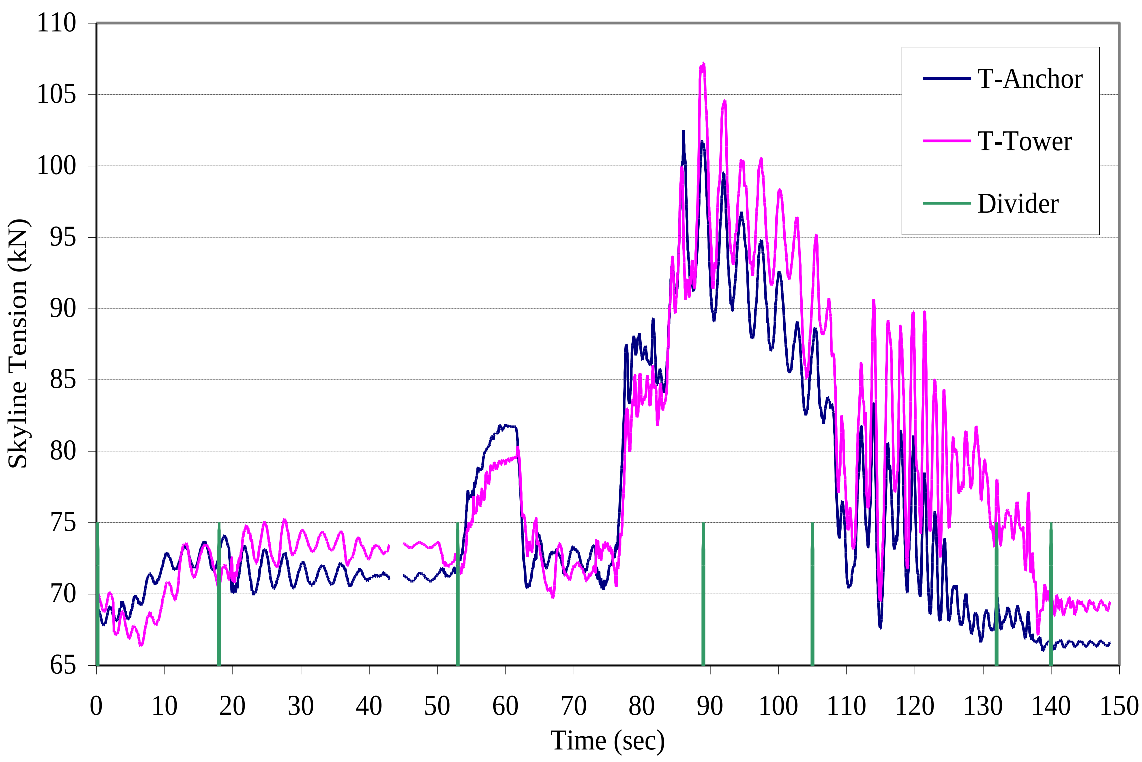
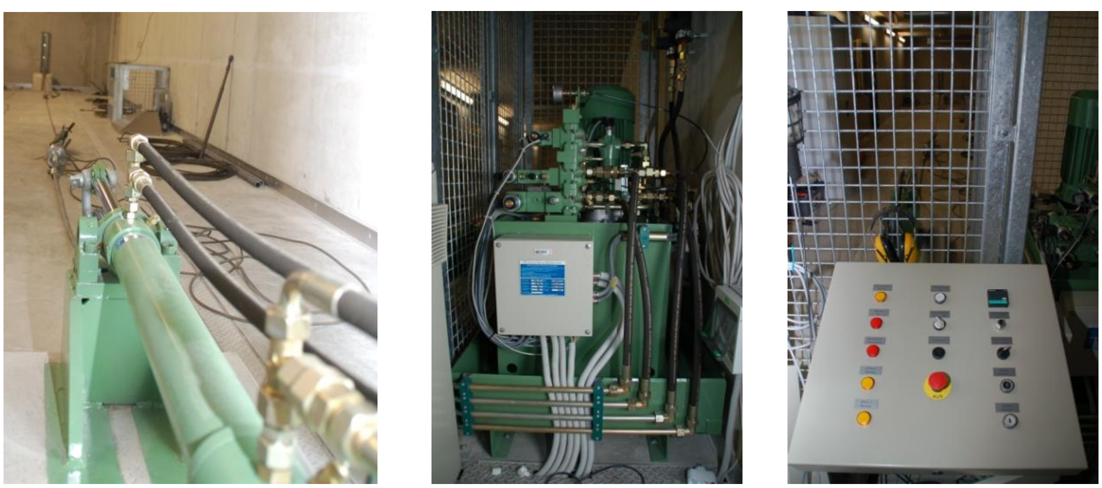


Figure 1: Forces in cables of a typical K-300 setup (PERTLIK 1993)

The traditional setup with the same type of cables for the skyline and the guy lines gives no chance to absorb the peaks of the forces resulting from the turbulent uphill running carriage. By introducing synthetic ropes this changed. Today the usage of synthetic ropes as skyline is not accepted. The main reason is the not solved problem of protection against abrasion. This problem don’t happen with guy lines. This lines are shorter, not pulled over the ground and it’s easier to inspect the surface for damages. Several forest enterprises use now synthetic ropes for their mobile yarders as guy lines. Under European conditions, fully equipped mobile yarders are often on the limits of the road traffic regulations. The save of weight by using synthetic ropes (weight ratio: steel / synthetic rope= 1/7) helps to fulfill the road traffic regulations. The ergonomic benefit for the crew’s, by handling lighter cables should contribute to a more convenient working environment.

Test bench

The test bench (picture 1) installed at the premises of the Forest engineering institute is a simple 2-way hydraulic cylinder to stretch out a cable by forth and back movements of the cylinder. A proportional directional control valve allows smooth switching and expect positioning procedures. The built in displacement transducer gives full control on the volume flow and reduces the hysteresis considerably (< 1.5 %). The valve is controlled by an programmable process control unit (SIEMENS LOGO!SoftComfort V6.1). The maximum frequency of the cylinder is 0.75 Hz (45 strokes/minute, +/- 100mm) with an maximum payload of 500 kN (150 bar). The cylinder have a maximum slideway of 800mm. The maximum volume flow of the hydraulic aggregate is 460 l/min and an external cooling circuit allow sustained continuous operation.



Picture 1: 50 kN cylinder, hydraulic aggregate and manual control unit

The process control unit controls the valve and can simulate the typical sequences of the forces in the cables of a mobile yarder (out-haul, lateral hauling, in-haul).

The Forces in the cable are measured with load cells. The actual position of the cylinder is also measured with an displacement transducer. All this is processed with an 8 channel amplifier (HBM Quantum), online displayed and stored for further analysis. Because of the risk of cable failures, nobody should be present during the tests. The room is equipped with a video monitoring system and the amplifier is integrated in the computer network of the university.

Absorber effect

In taut cable systems with both ends fix anchored, the most critical situation (PESTAL 1961) occurs in single span layout's. Therefore PESTAL advise to reduce the set-up force in such situations to 50% of the maximum design force. This results in high deflections and crews tend to ignore this recommendation to avoid intermediate supports. In multiple span layouts not specified cable length will glide into the loaded span and soften the increment of the forces, comparable to weight based tensioning systems used for chairlifts (ERNST 1959).

For the critical single span layout the values in Tab. 2 show for common length of guy lines the elongation effect under an increase of the forces in the skyline. The better absorbing effect of longer guy lines, compared to short ones is obvious (Remark: Short guy lines may under specific terrain conditions also have the effect to increase the pressure on the tower of the yarder due to inappropriate angles between the cables) .

Following the well known formula's (1), (2) and (3) the additional elongation of the guy line can be calculated as a result of the oscillating forces in the skyline.

(1) $\sigma = \frac{F}{A}$ respectively $\Delta\sigma = \frac{\Delta F}{A}$

(2) $\varepsilon = \frac{\Delta l}{l_0}$

(3) $\sigma = E * \varepsilon$

For the linear range the elongation in (3) is replace with the term of (2). For steel cables a module of elasticity is calculated with 180 kN/mm² whereas carbon fiber based synthetic ropes will have one of 120 - 140 kN7mm². For the calculations in Tab. 2 a module of elasticity of 130 was assumed.

(4) $\Delta\sigma = E * \frac{\Delta l}{l_0}$

(5) $\Delta l = \frac{\Delta\sigma * l_0}{E}$

Symbols:

F force applied to the cable

A cross sectional area

σ	tension
ε	elongation
Δl	additional length
l_0	reference length
E	module of elasticity

Tab. 2: Elongation of guy lines in meters under increasing forces in the skyline (E = 130 kN/mm²)

guyline length [m]	**Δ [kN]**									
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**55**	**60**
20	0,04	0,09	0,13	0,17	0,22	0,26	0,30	0,35	0,48	0,52
25	0,05	0,11	0,16	0,22	0,27	0,32	0,38	0,43	0,59	0,65
30	0,06	0,13	0,19	0,26	0,32	0,39	0,45	0,52	0,71	0,78
35	0,08	0,15	0,23	0,30	0,38	0,45	0,53	0,61	0,83	0,91
40	0,09	0,17	0,26	0,35	0,43	0,52	0,61	0,69	0,95	1,04

Having the reference length as a linear element in formula's (4) and (5) the absorbing effect to the skyline is roughly the ratio of the guy line length to the length of the span. For an exact calculation the angles between the skyline and the guy lines have to be accounted. On closer inspection that have to be solved as a spherical problem.

For common layouts this will be a value of 1/10 to 1/5 and reduce the amplitude of the forces in the skyline in a range of 10 to 20 %. The marked area in Tab. 2 shows for common situations the possible movements of the top of the tower, especially during the lateral hauling, when the elongation of the skyline increases the lateral deflection and is not balancing the elongation of the guy lines. That underlines also the necessity to set up the yarder following Euler buckling mode 1 (both ends pinned - hinged, free to rotate). As a result of the lower modulus of elasticity the movements of the top of the tower will increase. This absorption will lower the average and peak stress in cables and contribute to safer operations. It will be of interest if the elasticity of synthetic ropes will change during the lifetime or stay stable.

Summary

Cable yarding is the logging method for significant forest areas located in mountainous regions. The specific design with fixed anchors on both ends results in non-standard strains. The systems are not comparable to cableways or chairlifts.

A test bench to stress cables with oscillating forces is described.

The consideration of the elongation effects to the top of the tower of a cable yarder demonstrates the absorbing effect of the guy lines in general. The difference in the modulus of elasticity is boosting this effect and should find reflection in the design rules.

Synthetic ropes will be an opportunity to make the work easier but will also contribute to some safety aspects.

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THE STUDY OF THE AUTOMATIC FOREST ROAD DESIGN TECHNIQUE CONSIDERRING SHALLOW LANDSLIDES WITH LIDAR DATA OF THE FUNYU EXPERIMENTAL FOREST

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Key words: LiDAR, automatic forest road design, shallow landslide, spline interpolation, dynamic programming

Abstract: *In this study, the technique to automatically design the forest road considering shallow landslides using the LiDAR data was examined. First, in order to develop shallow landslides risk map of the Funyu Experimetal forest, the slope stability analysis by the unlimited length slope stability analysis formula was conducted. The soil depth was surveyed with simple penetration tests at 167 points and frequency distributions of the soil depth were estimated as logarithmic normal distributions. The soil depth map in the experimental forest was made using the mode values of lognormal distributions. Then, the shallow landslides risk maps in the experimental forest by the slope stability analysis were also made using these soil depth distributions. Finally, the automatic forest road design technique with high accuracy DTM and shallow landslides risk map was developed using cubic spline interpolation and dynamic programming. The program could minimize the amount of the earthwork costs avoiding shallow landslides risk areas. The program could easily design an environmentally sound low volume road automatically.*

1. Introduction

Extensive field investigations and a lot of labors are necessary for the design of the forest road. The sufficient experiences are also necessary to determine the best forest road among many alternatives. A variety of forest road design supporting techniques to reduce the workload of the forest road design have been developed using DTM (Digital Terrain Model), GPS (Global Positioning System), and similar techniques. These techniques have, however, demonstrated lack of accuracy because of the low reproducibility of geographical features. In order to improve the above-mentioned facts, Aruga et al. (2006) developed the forest road design technique using the LiDAR (Light Detection And Ranging) data that demonstrated a significant improvement in representing relatively accurate geographical features. However, the comparison with the field investigation was not done in the paper. Therefore, we developed the forest road design technique using the LiDAR data of the Funyu experimental forest and conducted the comparison with the field investigation (Saito et al. 2007a). As a result, earthwork volumes estimated using the actual measurement of the forest road and by the program using 1 m grid DEM were 3,596.48 m^3 and 3,641.51 m^3, respectively while that using 10 m grid DEM was 10,637.6 m^3. Ground surfaces produced by LiDAR data represented actual ground surfaces well and the results of the forest road design using LiDAR data were similar to the actual forest road.

However, the error occurred in the LiDAR data themselves. The vertical accuracy of LiDAR data in open sky was 0.33 m and that was 1.50 m in the forest. Tree canopies and floor vegetations might interrupt the laser. Therefore, we examined the new technique "the intersection angle method" to create more accurate ground surfaces in the forest from the raw LiDAR data (Saito et al. 2007b and 2008). As a result, the root mean square error between actual measurements and 1 m grid DEM, the intersection angle method were 1.04 m and 0.91 m, respectively. The intersection angle method reproduces geographical features more clearly than 1 m grid DEM which the aerial survey company generated using the roller method and manual filtering in Utsunomiya University Forest. Therefore, earthwork volumes estimated using the intersection angle method, 3,589.85 m^3 was closer to that using the actual measurement, 3,596.48 m^3 than that using 1 m grid DEM, 3,641.51 m^3.

Moreover, there is a problem on the forest road design technique we developed. Before using the technique, the passing nomination point and the planning height should be input into the program. Therefore, we proposed the automatic forest road design technique using the cubic spline interpolation and the dynamic programming (Saito et al. 2009a and 2009b). The forest road construction cost designed by this technique was lower than that of the forest road actually established. However, slope failure that is an important factor on actual forest road design processes and establishments in the mountainous area in Japan was not considered. In this research, the automation forest road design technique that considered the shallow landslides risk map made from the slope stability analysis was developed.

2. Study site and method

The study site is around the terminal point of the main forest road at the Funyu experimental forest of Utsunomiya University in Japan. The length of planning forest road is about 200 m. The vegetation around the study site is the mixed forest composed of pine, oak, azalea and so on. High resolution DTM was made by processing the LiDAR data using the intersection angle method (Figure 1,2).

The slope stability analysis judged the slope failure potential distributions by the unlimited length slope stability analysis formula. The areas of the safety rate *F* displayed in the following equation which becomes one or less are judged as the areas of slope failure potentials.

$$F = \frac{c + (\gamma s \cdot h - \gamma w \cdot hw)\cos^2\theta \tan\phi}{\gamma s \cdot h \cdot \cos\theta \sin\theta} \quad \cdots\cdots(1)$$

c : soil cohesion (N/m^2), *h* : soil depth (m), θ : slope angle (degree), φ : soil internal frictional angle (degree), *hw* : groundwater level (m), γs : soil density (kg/m^3), γw : water density (kg/ m^3)

The input value was determined as follows. *c, φ, and γs* were assumed to be 1,730 N/m^2, 30 degrees, and 2,000 kg/m^3 from the classification of the surface soil in the Funyu experimental forest as sandy soil. γw is 1,000 kg/ m^3. θ was calculated from 10 m grid DTM made from the 1/5,000 topographical map. *hw* was calculated using probability rainfall intensity calculated by the fair formula from the Automated Meteorological Data Acquisition System probability rainfall intensity calculation program (http://www.pwri.go.jp/jpn/seika/amedas/top.htm) and using the value of every return period. The soil depth was estimated from the values of the investigation, 167 points of simple penetration tests (Goshima et al. 2008). The soil structures were classified by Nc values beyond 20 as rock and below 20 as soil.

As for the soil depth, the large influence of the terrain factors such as the elevation, the inclination, the water catchment area, and etc. is expected. *Iida et al. 2005* pay attention to the inclination and the average depth of the water catchment area, and presume the soil depth as logarithmic normal distributions with 5 classes of slope angles and 4 classes of the average depth of water catchment area. In this study, this method was applied to the Funyu experimental forest. Figure 3 shows a comparison of the measured values of soil depth and the theoretical lognormal distribution in the inclination of 25 - 35 degrees and the average depth of the water catchment area, 0 - 20 m. Table 1 is the averages of the survey results, the mode values of lognormal distributions, and those differences each category. The soil depth comparisons are relatively consistent and can be approximated by lognormal distribution (Figure 3 and Table 1). Then, the soil depth map in the experimental forest was made using the mode values of lognormal distributions as the estimated values of soil depth (Figure 4). The shallow landslides risk maps in the experimental forest by the slope stability analysis were also made using these soil depth distributions (Figure 5).

3. The process on the automatic determination of the route

The route determination method using the cubic spline interpolation which *Tasaka et al. 1996* proposed balanced cut and fill materials and reduced the earthwork volumes. Therefore, we introduced this method to the program for the automatic forest road design technique using DTM generated from LiDAR data (Saito et al. 2009a and 2009b). In addition, the reason we introduced this method was its very short process time even at the personal computer. The procedure is the following (Figure 6):

1) A starting and terminal points are determined.
2) The contour line is generated from the starting point.
3) The nearest point *P* on the contour line from the terminal is determined.
4) The difference *h* of the elevation between the terminal point and *P* is calculated.
5) The length *l* along the contour line is calculated from the starting point to *P*.
6) The difference *h* is distributed proportionally in distance Δhi on each point *i* at an interval of 20 m along the contour line.
7) Each point moves to the point in the steepest slope direction so that the elevation of the new point becomes the same to the elevation of each point added by the elevation difference on each point, Δhi. The new point is considered as the passing nomination point.
8) Cubic spline interpolates between the nomination points at an interval of 20 m and temporary route is determined.

Next, the program searches for the minimum earthwork cost route based on the temporary route using dynamic programming (Figure 7).

1) Each curvature radius of each nomination point on the temporary route is determined.
2) Nomination points which have local minimum values of the curvature radius are determined as the base points for searching the minimum earthwork cost route using dynamic programming.
3) Candidate points are generated on both sides of the base points on the normal line at intervals of 1 m to 10 m.
4) The minimum earthwork cost route is determined using dynamic programming among the combinations of these candidate points connected with the cubic spline interpolation.

In order to calculate earthwork costs, unit costs listed in Table 2 are used. Road width was 4.0 m, fill slope was 1:1, cut slope was 1:0.8, and when the slope length became 3 m or more, the slope was assumed to be made by retaining wall of which slope was 1:0.2.

In this study, the shallow landslides risk map was overlapped to search for the route while avoiding a dangerous collapse of the forest road. The collapse was assumed to occur when the forest road passed over the shallow landslides risk areas and it was assumed to be established again. Therefore, the same amount of establishment costs for the restoration costs were assumed to be needed.

4. Result

Figure 8 shows the results of the forest road design with shallow landslide risk map generated using 50 and 100 years probability rainfall intensity. In both cases, the establishment costs of the forest road design without avoiding shallow landslides risk areas were slightly cheaper than that with avoiding the shallow landslide risk areas (Table 3). However, the restoration cost without avoiding the shallow landslide risk areas were much more expensive than that with avoiding the shallow landslide risk areas. Therefore, the total costs with avoiding the shallow landslide risk areas were lower than that without avoiding the shallow landslide risk areas. Moreover, the route with avoiding the shallow landslide risk areas generated using 100 years probability rainfall intensity became a shorter route than that without avoiding the shallow landslide risk areas (Figure 8). The program could easily design an environmentally sound low volume road automatically.

It will be necessary to examine a variety of methods to protect forest roads from shallow landslides in the future, for example, the retaining wall will be designed in the shallow landslide risk areas instead of considering the restoration cost at the shallow landslide risk areas.

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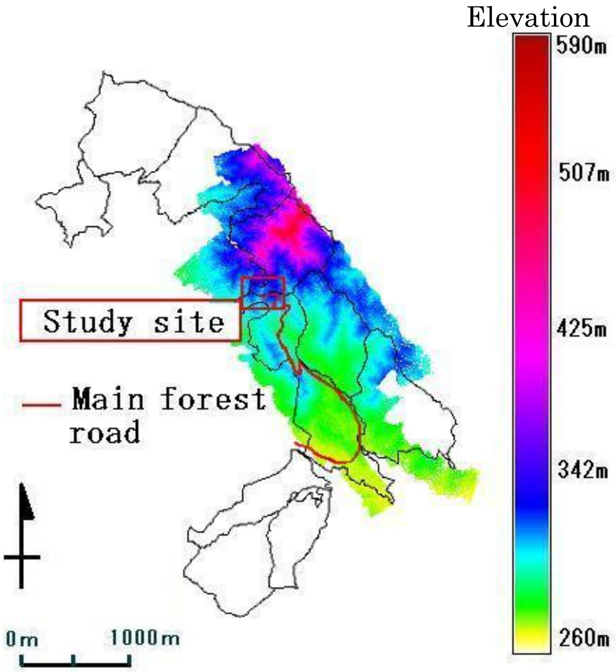


Figure 1. Funyu experimental forest of Utsunomiya University

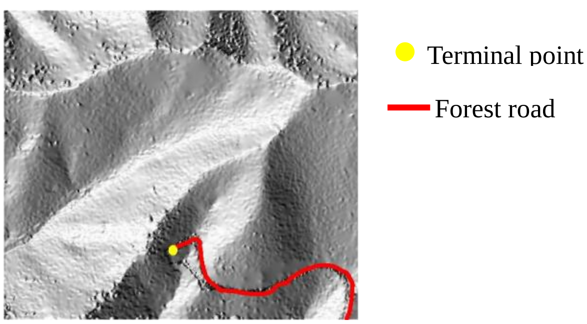


Figure 2 Study site with High resolution DTM

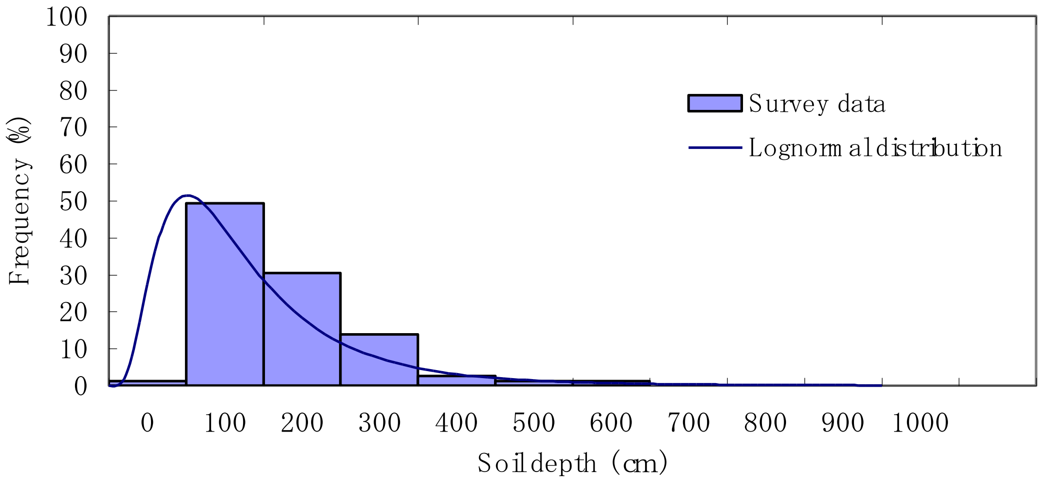


Figure3 Example of lognormal distribution and soil depth frequency distribution of survey results

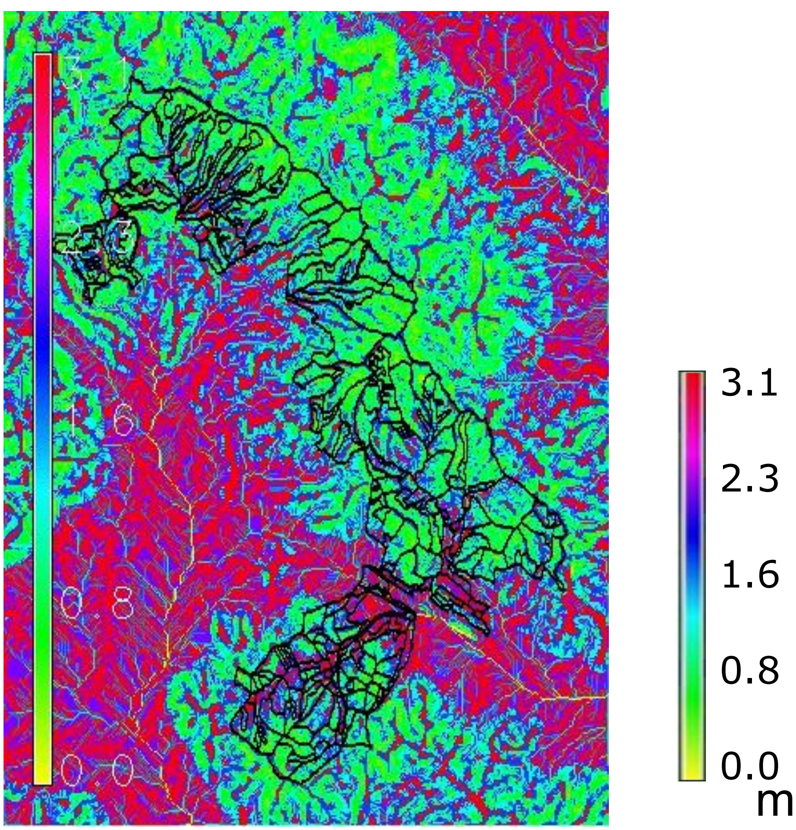


Figure 4 Estimated soil depth map

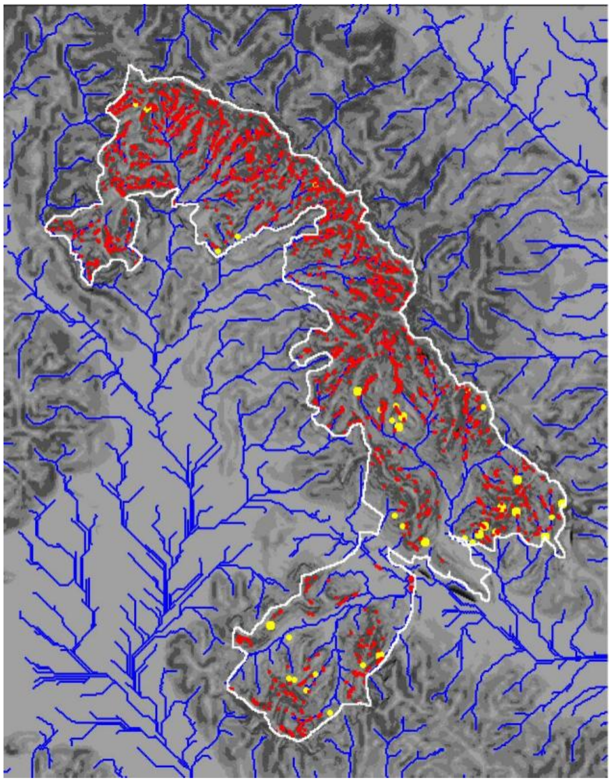


Figure 5 Shallow landslide risk map with 50 years probability rainfall intensity
(Red: Shallow landslide risk areas, Yellow: Shallow landslide areas occurred in 1998)

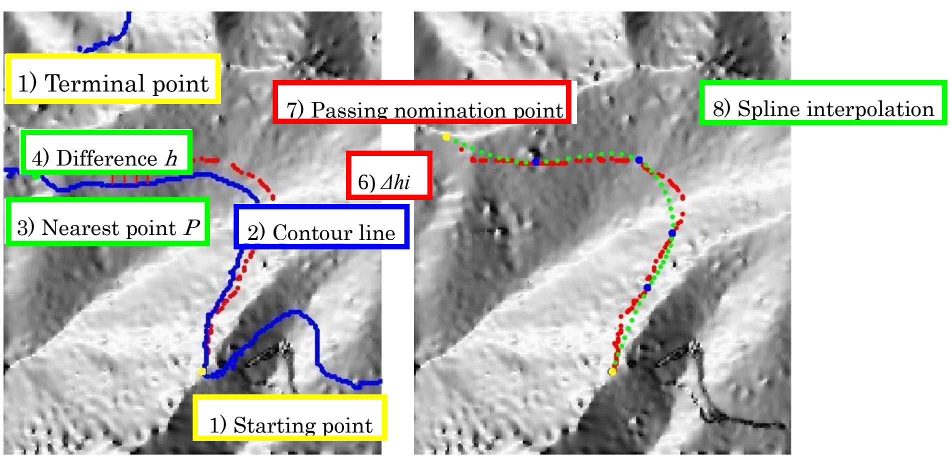


Figure 6. Process of the forest road design

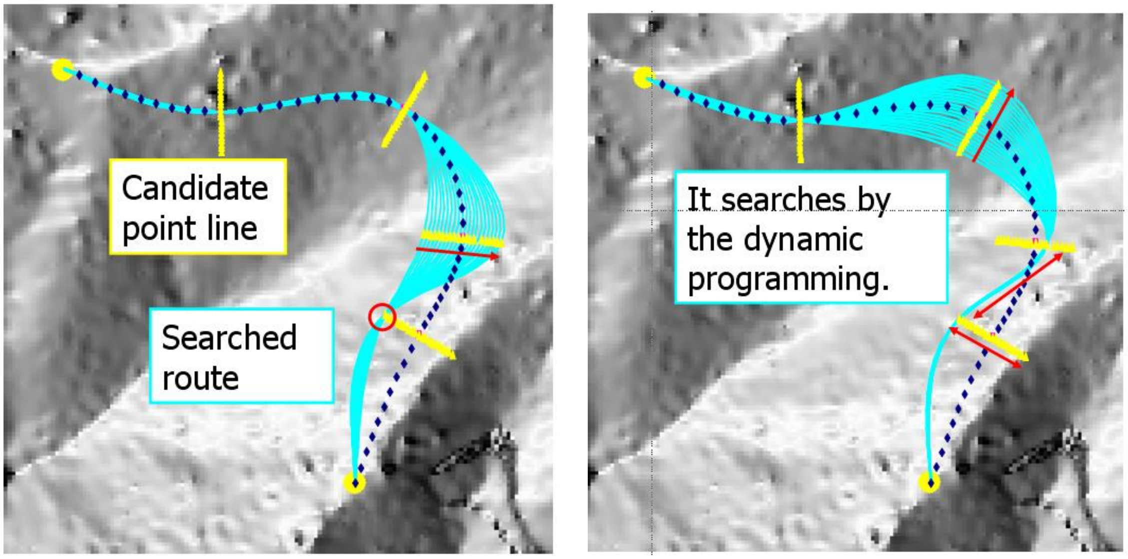
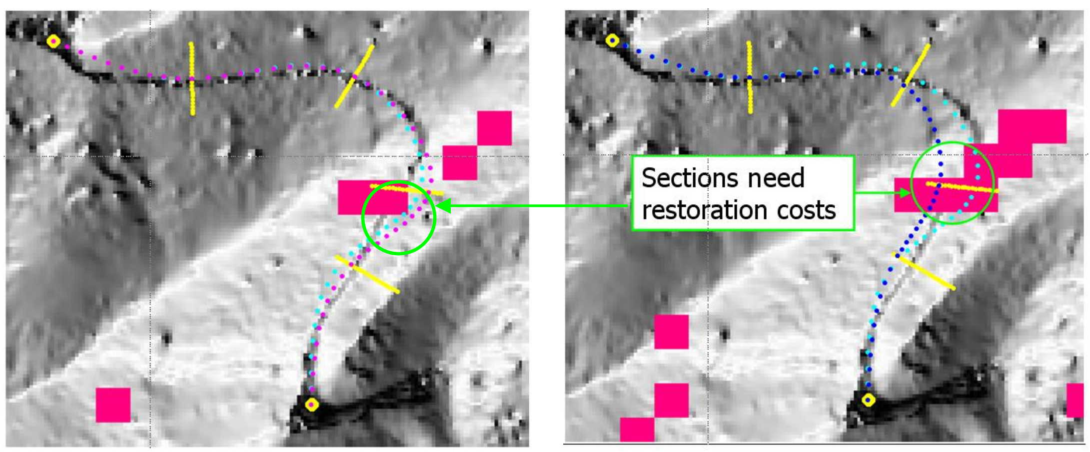


Figure 7 The minimum earthwork cost route search process



50 years 100 years

Figure 8 Result of forest road design

(Red: Shallow landslide risk areas, Light blue: Route without avoiding, Purple and Blue: Route with avoiding)

Table 1 Result of the soil depth (cm)

Average depth of catchment areas		Slope angles 0～15°	15～25°	25～35°	35～45°	45～55°
0～20m	Survey (Number)	266(16)	151.2(51)	130.8(79)	86.1(14)	(0)
	Theoretical values	311	171	101	58	32
	Difference	-45	-19.8	29.8	28.1	
20～200m	Survey (Number)	182.9(3)	79.8(6)	162.1(9)	67.1(3)	(0)
	Theoretical values	217	117	68	38	21
	Difference	-34.1	-37.2	94.1	29.1	
200～2,000m	Survey (Number)	83.1(2)	148.3(7)	159.6(6)	(0)	(0)
	Theoretical values	152	81	46	26	14
	Difference	-68.9	67.3	113.6		
2,000～20,000m	Survey (Number)	(0)	116(1)	(0)	(0)	(0)
	Theoretical values	106	55	31	17	9
	Difference		61			

Table 2 Efficiency and unit costs

Item	Machine	Efficiency	Unit Cost
Cutting	Bucket Excavator	29.7 m^3/h	8,710 yen/h
Smoothing	Bulldozer	67.8 m^3/h	9,525 yen/h
Compacting	Bulldozer	88.2 m^3/h	9,525 yen/h
Transporting	Dump Truck	5.7 m^3/h	7,306 yen/h
Fill slope greening			1,083 yen/m^2
Cut slope greening			1,860 yen/m^2
Retaining wall			16,000 yen/m^2

US$1=90 yen on Dec. 25 2008

Table 3 Result of costs

50 years	Construction cost	Restoration cost	Total cost	Length	Cost per Meter
Before avoiding	¥1,991,567	¥62,642	¥2,054,209	199.92 m	¥10,275/m
After avoiding	¥2,048,063	¥0	¥2,048,063	200.00 m	¥10,240/m

100 years	Construction cost	Restoration cost	Total cost	Length	Cost per Meter
Before avoiding	¥1,991,567	¥187,926	¥2,179,493	199.92 m	¥10,902/m
After avoiding	¥2,051,943	¥92,595	¥2,144,638	198.00 m	¥10,831/m

US$1=90 yen on Dec. 25 2008

Stump to mill logging cost program (STOMP)

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Abstract

In order to relate the change in trucking capacity to logging system costs, we developed a stump to mill harvesting cost program (STOMP). While the model results are affected by changes in trucking capacity due to average truck speed, haul distance, load weight, and truck utilization, the main feature of the model is to present the range in truck capacity across a range in probable mill unloading times. The model presents productivity, cost, and income for a range of unloading times dependent on the mill parameters selected by the user. The range times may either represent more likely (close to the median time) and less likely (farther from the median) conditions or could be used to examine the benefit and cost of current or expected mill conditions. The sample models of harvesting crews show there is usually one or more significant unloading time increases that cause significant decreases in total and net revenue. The magnitude of that decline is related to the size of the logging crew, haul distance, and other production limits (market and in-woods production). One example from a typical southern thinning crew shows the potential for a 10 to 15% decline in after tax income across a range in likely unloading times. A full range in unloading time (10 to 75 minutes) shows a drop in net income of 80% to 100% from the smallest to greatest unloading time. The models and user's manual are available at https://fp.auburn.edu/auforestops/

Introduction

The logging industry and the forest products industry have adapted and evolved in response to both internal and external financial pressure. Historically the most significant of these pressures have been the cost and productivity of labor which led to wide spread mechanization of logging which began in the 1960's and continues today. Mechanization of logging has added risk from large capital outlays and the financial impact of poorly utilized capital costs and labor expenses. As a result variables in the wood supply system that inhibit efficient utilization of capital and labor resources have immediate consequences on wood supplier businesses. The most significant impacts are the strategies the wood suppliers employ to deal with internal and external production limits and the variability in system capacity for wood. Those strategies include extending equipment life, out sourcing trucking resources, or maintaining excess capacity in either harvesting or trucking resources. While those strategies make financial sense to individual wood suppliers, in total they may lead to inefficiencies and a general erosion of wood supplier capacity.

The objective of this project was to integrate in-woods, trucking, and unloading capacities to examine how system variability affects logging productivity and costs. The resulting spreadsheet cost model uses monthly inputs for logging system capacity and productivity, annual inputs for labor and machines, and variables for mill unloading performance to determine the costs and productivity for specific logging crews. The model development was supported by the Wood Supply Research Institute (WSRI) was developed with significant interaction with the WSRI technical committee and six sessions with user groups. The project report describes the model approach and presents a scenario of a specific harvesting crew.

Model approach

System configuration

The model represents the annual productivity for a static crew with fixed annual employment, machines, and owned trucking capacity. The model allows monthly changes in shift number, available market, haul distance, machine productivity, and harvest system. Also contract trucking capacity can be changed monthly since it does not affect the calculation of fixed costs.

Production modeling

Since one of the main objectives was to examine the interaction among harvest phases, the model represents "Hot logging" conditions. All products that are harvested that day or shift are assumed to be delivered during the same shift. "Cold logging" would involve removing constraints due to machine, harvest phase, or mill capacity so that each phase operates near the maximum utilization rate. The shift limit on productivity could be the quota or market available, the in-woods production, or trucking productivity. Once the limit is identified the number of machine hours and truck miles needed to accomplish the limiting production is calculated.

In-woods production

Each machine used in the logging system has a production rate (tons per productive machine hour – t/PMH) and a utilization rate (%). Each machine is also assigned one or more harvest phases (felling, loading, processing, etc) that it can complete. The model uses the utilization rate and production rate (t/PMH) to calculate a production rate in tons per scheduled machine hour (t/SMH) for each harvesting phase. The productivity (t/SMH) available for each harvest phase is summed. The phase with the lowest production level sets the in-woods productivity. The scheduled and productive hours for the rest of the phases are calculated using the lowest production rate. The machine hours are then allocated to phases proportionally based on the hours needed in each phase and the hours available for each machine. Harvesting productivity of each phase can be adjusted monthly to represent poorer than average harvesting conditions. Phases like shoveling can be eliminated to represent seasonal changes in the harvest system (upland vs. wetland harvest). Only the phases included by the user are limiting for production. If the trucking production rate or the market (quota) is lower than the in-woods production rate, the hours used for each machine are lowered accordingly.

Trucking production

Trucking productivity is based on the number of complete round trips a truck can complete in one shift. The trucking shift can be longer that the in-woods shift reflecting the ability of truck to leave the woods with loads near the end of the in-woods shift. The round trip is composed of travel time (back and forth from the mill), loading time (in the woods) and unloading time (at the mill). Travel time is calculated with user inputs for distance from the woods to each mill and average travel speed. Loading time is a fixed number that equals the average time from when the truck arrives in the woods empty until it leaves loaded. Unloading time is determined using distributions generated from data collect by Deckard et al (2001). Inputs to the model identify mill type (pulpwood or sawtimber), unloading efficiency (benchmark or not), and inventory conditions (low, transition, and high). The model provides production and cost estimates for scenarios with unloading times across the distribution of possible unloading times. The mill turn time distributions and models are given in Appendix A.

Each combination of inventory period and mill type yields unloading times from the distribution at the 20th, 30th, 40th, 50th, 60th, 70th, and 80th percentiles. The unloading time for 20th percentile infers that 20% of the unloading times are less than the one given. Taken together the estimates for unloading times represent more likely (50th percentile) and less likely (20th and 80th) outcomes or the general range in possible outcomes given the mill and inventory characteristics. Another way to interpret the results is to examine the average mill unloading time for each outcome.

Contract Trucking

For any month that the user specifies owned trucks and contract trucks as part of the fleet, the total production available will be divided equally among the trucks specified. Building excess capacity with contract trucking will decrease the loads and miles operated by owned trucks and increase labor and fixed cost per ton. If model users rely on contract trucking only, hauling cost is a variable cost based on the loaded miles driven to deliver the loads. Trucking constraints can be lifted by adding more contract trucks on a monthly basis.

Fixed Cost

For capital equipment the model calculates the fixed costs, principle and interest payments on loan amounts, insurance cost, and market value decline. Principle and interest payments are calculated as a single annual payment dependent on term (years) and finance rate. The calculation assumes 100% financing of the purchase value. Insurance cost is a percentage of current value. Current value and market value decline are calculated using a double declining balance depreciation formula modified to represent the years of expected machine life defined by the user. If a machine is excluded from the harvest system for one month or more, the fixed costs for that machine are distributed only to the months the machine is utilized.

After tax income and cost

After tax costs are calculated given federal income tax guidelines for 2008. The depreciation calculation is simplified using only the half year convention and no consideration for Section 179 treatment. The simplification was implemented due to the likely variations in the tax code over time and individual depreciation circumstance of each machine. For depreciation road tractors are 3 year equipment and the rest of the equipment is assumed to be 5 year equipment. Formulas and assumptions related to after tax costing are presented in Appendix B. Applying the appropriate tax rate involves first entering all the production, cost, and income estimates and then observing taxable income. The tax rate is then determined based on the taxable amount. It is possible that the range in scenarios given for the same estimates might require different marginal tax rates.

Variable costs

The variable costs for machines are set by the number of productive machine hours. Maintenance costs are estimated by the user and entered directly into the spreadsheet. Fuel use is input for each machine and the monthly fuel price determines the hourly fuel cost. Lube and oil costs are estimated as a percentage of fuel costs. The model relies on users having reasonable estimates for variable costs. Overall variable costs of incidentals needed for management of a logging crew are included in the overhead cost. The overhead cost is estimated as a percent of monthly expenses.

Labor Costs

Considerable variability among logging firms exist in how labor rates are calculated for employees with numerous combinations of hourly or daily wages plus production bonuses. While in many cases these treatments are important to the analysis of labor cost as a fixed, semi-fixed or variable cost, the user input was viewed as too cumbersome to accurately express wage cost in every way possible. Since the user inputs shifts per month rather than per week, total monthly hours are divided evenly by weeks per month to develop overtime costs. This means that given the same number of shifts per month the month with fewer days will record more overtime pay. Overtime rates can be set as straight wage or overtime (time and a half) depending on the firm size. Users set the benefit rate and workers compensation rate as a percentage of total wages.

Revenue

Model users enter revenue per ton for each product for each month. Users have the option of entering the cut, load, and haul revenue as one number or splitting the hauling revenue from the cut and load revenue. There is also an option that calculates trucking revenue based on haul distance. Users enter revenue per loaded mile and a base mileage. If the estimated haul distance exceeds the base mileage, revenue increases.

Southern Thinning Crew

The equipment data presented in Table 1 represents a typical high production pine thinning crew in the southern coastal plain. We assumed that the market available for each shift was 420 tons of all products and that all trucks could carry 26 tons of each product. The average loading time for trucks in the woods was 25 minutes.

Table 1. Equipment and assumptions for cost scenario.

	Number	Make & Model	Beginning value ($)	Prod. rate (t/PMH)	Util. rate	Fuel Cons. (g/PMH)	Maint. & Repair ($/PMH)	Lube rate (% of fuel cost)
Skidder	2	John Deere 648 GIII	112531	50	78 %	5.5	8.5	26%
Knuckleboom loader w/ delimber	1	Prentice 328	54665	50	80 %	6.1	8.0	25%
Feller - Buncher	1	Prentice 2470	76531	50	80 %	7.0	9.0	39%
						mpg	$/mile	
Tractors	4		176846		95 %	5.7	0.25	
Trailers	4		53253					
Other equipment	2		21800					

The total truck cycle time shows the monthly variance due to mill unloading times and haul distance (Figure 1). The numbers in the legend represent unloading time percentiles 20 through 80. Spikes in truck cycle time are due to longer haul distances for pulp wood in January, February, July, and October. The band or range in cycle times encompassed by all the lines represents a wide range in possible conditions. A more likely range would be encompassed by the three middle lines (40-60th percentile). For April, the total range is from 1.28 to 2.01 hours per cycle and the more likely range is from 1.61 to 1.78 hours.

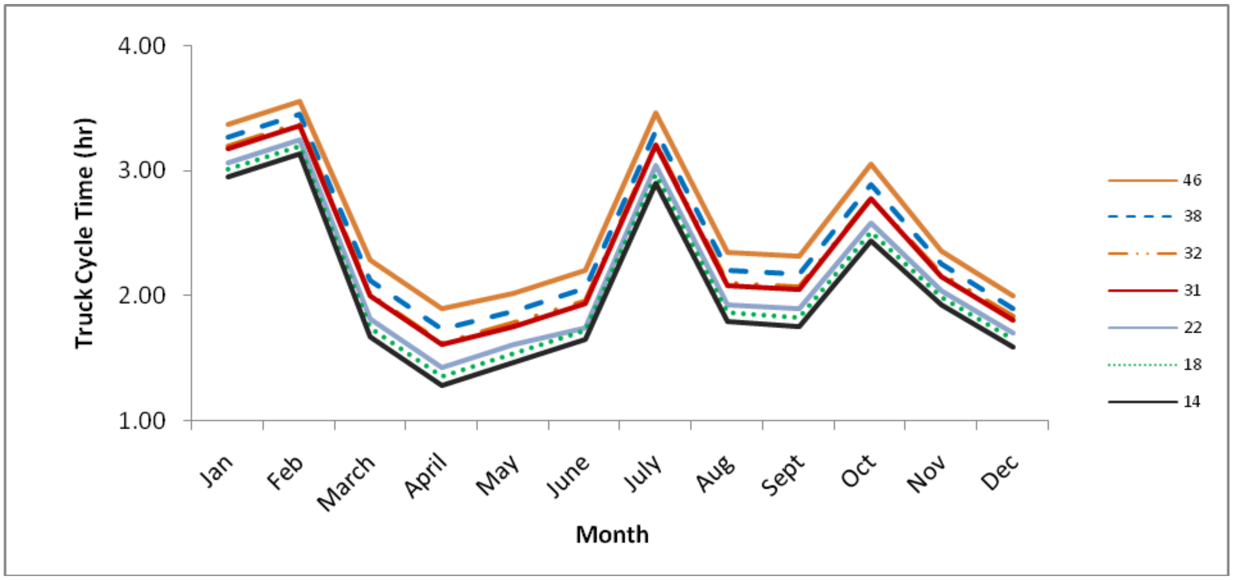

Figure 1. Monthly variation in truck cycle time for unloading time percentiles. The legend shows unloading time in minutes from the lowest (80th) to the highest (20th) times.

The model presents an annual financial summary (Table 2). The revenue used in the summary equals the before tax cost for the 50th percentile scenario and includes a 10% return to capital. Increases in total harvest are accompanied by increases in total expenses needed to harvest and haul the additional wood. Annual after tax income ranges from $74,500 to $82,800. After tax income is presented using either principle payment or decline in market value. Contractors that are able to purchase more machines with cash or use older machines (from which the loans have been repaid) should use market value decline rather than principle payment as an indicator of machine cost and after tax income. In this example, assumptions for revenue ensured that all net incomes would be positive and return to capital (19.3-21.0%) would be greater than the 10% assumption in the before tax cost calculation.

The model is designed so the user can apply additional trucking resources (owned or contract) and change the parameters (haul distance and type) of the mills and view the results on an annual of monthly basis. While this example demonstrates the relationship between net revenue and unloading time for a system balanced at the 50th percentile. The model could also show the affect on revenue of over-investment in trucking resources employed by many contractors to avoid in-woods production limits at long haul distances or long mill unloading times.

Table 2. Annual financial summaries for the unloading time percentile distribution. Costs and losses are identified by ($).

	Unloading time percentile						
	20	30	40	50	60	70	80
Unld. time (min)	46	38	32	31	22	18	14
Total sales	$1,156,868	$1,160,678	$1,173,378	$1,173,378	$1,173,378	$1,173,378	$1,173,378
Total expenses (with princ. pymt.)	($1,068,832)	($1,070,411)	($1,075,047)	($1,075,047)	($1,075,047)	($1,075,047)	($1,075,047)
Gross profit (Loss)	$88,036	$90,268	$98,331	$98,331	$98,331	$98,331	$98,331
Depreciation	($157,326)	($157,326)	($157,326)	($157,326)	($157,326)	($157,326)	($157,326)
Taxable income	$67,401	$69,633	$77,697	$77,697	$77,697	$77,697	$77,697
Federal tax liability	($13,480)	($13,927)	($15,539)	($15,539)	($15,539)	($15,539)	($15,539)
After tax income (loss)	$74,556	$76,341	$82,792	$82,792	$82,792	$82,792	$82,792
Beginning total capital value	$499,094	$499,094	$499,094	$499,094	$499,094	$499,094	$499,094
Principle payment	($136,691)	($136,691)	($136,691)	($136,691)	($136,691)	($136,691)	($136,691)
Market value decline	($114,888)	($114,888)	($114,888)	($114,888)	($114,888)	($114,888)	($114,888)
After tax net income (less market value decline not princ. pymt.)	$96,359	$98,144	$104,595	$104,595	$104,595	$104,595	$104,595
Return to capital	19.3%	19.7%	21.0%	21.0%	21.0%	21.0%	21.0%

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Efficiency and ergonomic benefits of using radio controlled chokers in cable yarding.

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Abstract

Using radio controlled chokers in cable yarding can improve both productivity and safety during the unhooking phase part of the extraction cycle. However, the additional weight of the radio controlled chokers may also increase the work load of the choker-setters on the slope. A study has been completed in Austria on the Wanderfalke yarder. The factorial study design alternated extraction corridors with and without the use of radio controlled chokers. A standard choker for this system weighs 0.34 kg and cost 11 Euro each, whereas the radio controlled chokers weighs 1.6 kg and cost 9,000 Euros for the set of four chokers. Work-load was measured by continuously monitoring the heart-rate of the workers. Results showed that was a slight productivity gain, but also an increased work-load for the choker-setter. This is reflected in the comments from the yarder crew; the yarder operator thinks it great not having to get down to unhook the turn, the choker-setter is not impressed with the extra weight and work load.

Introduction

Efficient forest management in steep terrain is mostly linked to cable-based harvesting systems. Technical developments and system optimization during the last decades targeted on more efficient, social acceptable and ecological sustainable ways to use cable yarding systems. Radio-controlled applications fostered automation of processes and enables both the yarder operator as well as the choker-setter to control the yarder (Heinimann et al., 2006). Unhooking chokers at the landing is time consuming, accounting for almost 10 to 20% of the productive cycle time, depending on the system (Baker et al., 2001). Therefore automation of choker releasing is a significant opportunity for further improvement of both productivity as well as safety.

During the 1970's the first trials of mechanical self-releasing chokers were done in Austria and Norway (Samset, 1985). Use was limited due to their unreliability. It was not until the first radio-controlled chokers were developed that the potential for efficiency improvements was recognized. However, their reliability was also limited, with one major problem being a weight of more than 4 kg (Hemphill, 1985; MacDonald, 1990). Technical developments and new materials over the last two decades have allowed the weight of a choker to be significantly reduced – as low as 1.6 kg for smaller diameter chokers.

Radio-controlled chokers have the potential to improve efficiency and work safety during cable logging operations. For operations where the yarder operator leaves his cab to unhook, the time taken to get in and out of the cab can be saved. For systems where the logs are landing either next to or in front of the yarder, the job of the 'poleman' (person who unhooks at the landing) is not required, which also reduces the yarders operational delay time (Huyler and LeDoux 1997; Biller and Fisher 1984).

The classic goal of modern ergonomics is to optimize both the systems efficiency and the working conditions. The heavier weight of the radio-controlled chokers could lead to an increase of the choker-setters physical strain. It is therefore important that an increase in productivity is not at the expense of an increase of physical strain on the choker-setter.

Acquisition costs of radio-controlled chokers are high (product information Giritzer und Fortronics), and hence the question of payback time of the investment should also be considered. Currently, there is no literature available on productivity, physical strain of choker setter, work safety, and cost effectiveness. This study examines efficiency and ergonomic impacts of radio-controlled chokers and evaluates their cost-effectiveness.

Methodology

Study layout

There are many productivity studies on cable yarding operations, whereby yarding productivity is commonly used as the dependant variable. The main source of variation is, mean volume per piece, yarding distance, as well as lateral yarding distance.

In this study the following productivity hypothesis is used:

Yarding productivity = f (tree volume, yarding distance, lateral yarding, CHOKER TYP)

A factorial layout is utilized to investigate the productivity hypothesis. Six extraction corridors with and without the use of radio-controlled chokers are alternated within one operation area.

Harvesting system

The study location is characterized by patches of wind thrown trees. The root balls of the wind-thrown trees are cut using a chain saw. The trailer mounted "Wanderfalke" yarder (company Mayr-Melnhof) extracted the whole trees to the forest road. The Sherpa U 1.5 carriage, with a maximum pay load of 1.5 tons, was used. Further processing of trees was done using a harvester head Kesla 20RH that is mounted on wheeled excavator base. A closed work chain was used, whereby through the use of radio-controlled units both the operator of the processor as well as the choker setter can control the tower yarder.

In addition to the standard manual chokers, radio-controlled chokers (Company Giritzer) were used. The radio-controlled system “Ludwig” (Figure 1) has an automatic ‘push-button’ release. The weight of each choker is 1.6 kg, with a maximum choker cable diameter of 13 mm.

Figure 1: Radio controlled choker system “Ludwig”

Study sites

The study area is located in the eastern part of the Austrian Alps. The forest consists almost exclusively of Norway Spruce (see Table 1), with an average extracted tree volume during the study ranging from 0.42 to 0.86 m^3. The age varies between 55 and 85 years. As per the study design, six cable corridors were used, with the length of the corridors ranging from 89 to 201 meters. Slope gradient ranged from 50 to 60 percent. Due to small-area windbreaks, timber volume extracted per corridor varied from 50 to 220 m^3.

Table 1: Stand descriptions

	Standard choker			**Radio-controlled choker**		
Age (J)	85	53	55	55	65	65
Tree species share (1/10)	Spruce 10	Spruce 9 BL 1	Spruce 10	Spruce 10	Spruce 9 Larch 1	Spruce 10
Av. Tree volume (m^3)	0.86	0.59	0.60	0.42	0.66	0.60
Corridor length (m)	137	102	140	148	201	89
Slope (%)	52	58	50	60	55	50
Total harvesting volume (m^3)	50.2	220.0	76.3	56.7	103.0	76.3
Harvesting volume (m^3/m)	0.37	2.16	0.55	0.38	0.51	0.86

Data collection

Time study

A time and motion study of the yarder system and choker-setter were recorded using "Latschbacher" portable-time study computers. Work was divided into work elemental tasks for system (Table 2) and the choker-setter (Table 3).

Table 2: Work task definitions for yarder system

Work task	Description
Carriage out	Carriage movement from the landing out to the choker setter
Hook-up	Rope is fed out from the carriage until load touches the carriage
Carriage in	Carriage movement from the choker setter back to landing
Landing	Lowering load and feeding in and out of the mainline
Release Choker	Operator unhooks load, includes getting in and out of the cab
Manipulation	Moving or processing trees by loader arm
Waiting	Operational delay time
Delays < 15 minutes	Delays shorter than 15 minutes
Delays > 15 minutes	Delays longer than 15 minutes
Miscellaneous	Non assignable times

Table 3: Work task definitions for the choker-setter

Work task	Description
Pull rope out	Rope is fed out from the carriage until first timber is reached
Hook-up	Load is hooked up
Lateral in	Load pulled back to carriage, until carriage is unclamped from skyline
Load preparation	Preparing work for the next yarding cycle
Chain saw work	Operating chain saw
Waiting	Operational delay time (choker setter is waiting for carriage)
Delays < 15 minutes	Delays shorter than 15 minutes
Delays > 15 minutes	Delays longer than 15 minutes
Miscellaneous	Non assignable times

For each of the six study replicates, the following response variables, factors and covariates have to be gathered or calculated at the yarding-cycle level (Table 4).

Table 4: Variable Definition for Data Sampling

Dependant variables	cycle	total time for one yarding cycle	min
	load volume	total load volume for each yarding cycle	m^3

	productivity	(load volume/cycle)*60	m^3 per PSH_0
Factor	CHOKER	(0) standard choker, (1) radio-controlled choker	2 levels
Covariates	tree volume	mean tree volume per load	m^3
	pieces	number of pieces per load (trees, tops, butts)	n
	lateral yarding	Lateral distance from skyline and felled trees	m
	distance	distance between tower yarder and stopping position of carriage	m

Heart rate

Heart rate is measured during the entire working day, including rest and lunch breaks. A Polar RS 800 G3 portable heart rate monitor is used. It consists of a pericardial heartbeat capturing-transmitting unit on a strap with electrode areas and a receiver-storage unit similar to a digital wristwatch.

The heart rate reserve (%HRR) was determined by applying the following formula:

$$\%HRR = (HRw - HRr)*100/(HRmax - HRr)$$

Where:

HRw = Working heart rate: Average number of heart beats per minute (bpm) during different working processes.

HRmax = Maximum heart rate: 220 - age

HRr = Resting heart rate: Two approaches are used to determine the resting heart rate. The average heart rate value in a sitting position for a 10 minute period in the morning or the minimum heart rate per minute for the whole working day.

Statistical analysis

Variance analysis attempts to quantify the influence of nominal or ordinal-scaled variables. The statistical analysis is carried out using SPSS 15.0 for Windows, with the statistical fundamentals as described in Stampfer (2002). The following analysis strategy was chosen:

- Estimation of significant effects of covariables and factors and analyzing of their statistical significance (variance analysis)
- Evaluation of non-linearity of covariables
- Analysis of interactions between factors and covariables
- Parameter estimation of significant factors and covariables
- Regressions analysis

- Check model assumptions (residual analysis)
- Adjustment of model

The co-variable tree volume is a major component of all production functions, but the relationship between productivity and tree volume is rarely linear. A power factor is used to transform tree volume, whereby Häberle (1984) recommends the estimation of this power value using an iterative procedure with regard on optimizing the coefficient of determination and the distribution of the residues.

Results

Table 5: Variability of the response variables and covariates

	Mean	**0.05 quantile**	**0.95 quantile**
Cycle (min)	4.64	2.61	7.97
Load volume (m^3)	0.87	0.27	1.64
Productivity (m^3/PSH_0)	12.4	3.31	26.5
Extraction Distance (m)	65.5	23.0	115.5
Pieces / turn (n)	1.3	1.0	2.0
Tree volume (m^3)	0.75	0.20	1.51

Overall, the radio-controlled chokers reduced the average cycle from 4.70 to 4.42 minutes. Much of that time saving can be contributed to the landing phase, which reduced from 0.33 to 0.12 minutes. There was no difference in the hook-up phase, and only a slight, but not significant difference in the carriage in. Interestingly, there was an increase in the carriage out phase, where the average carriage speed decreased from 2.3 to 1.6 m/sec. This was attributed to the varied choker lengths used with radio controlled chokers, and that at greater speed they would hit, and sometimes tangle in the trees lining the extraction corridor.

Overall, the statistical analysis of in total 936 cycles resulted in the following efficiency model:

$$\text{Efficiency (min/m}^3) = 0{,}960 + 3{,}495 \text{*tree volume} - 0{,}528 \text{*CHOKER} \quad (R^2=0{,}77).$$

This equation suggests that 77% of the efficiency (min/m^3) variance can be explained through the variables tree volume and CHOKER. We would normally also expect extraction distance to figure into this resulting equation. This study mainly worked with short extraction distances (average 65.5 m), and therefore this variable had no significant influence on the time consumption. Similarly, the extraction corridors typically used in Austria for full tree extraction are only 20 meters apart (Stampfer, 2002), so there is little lateral extraction and this was also not significant in the final analyses.

Figure 2 shows the productivity for cable yarding extraction dependent on tree volume and choker system. At an average tree volume of 0.6 m^3 the productivity increased from 7.10 to 7.72 m^3/PSH_{15} when using the radio-controlled choker system. This corresponds to an increased productivity of 9%.

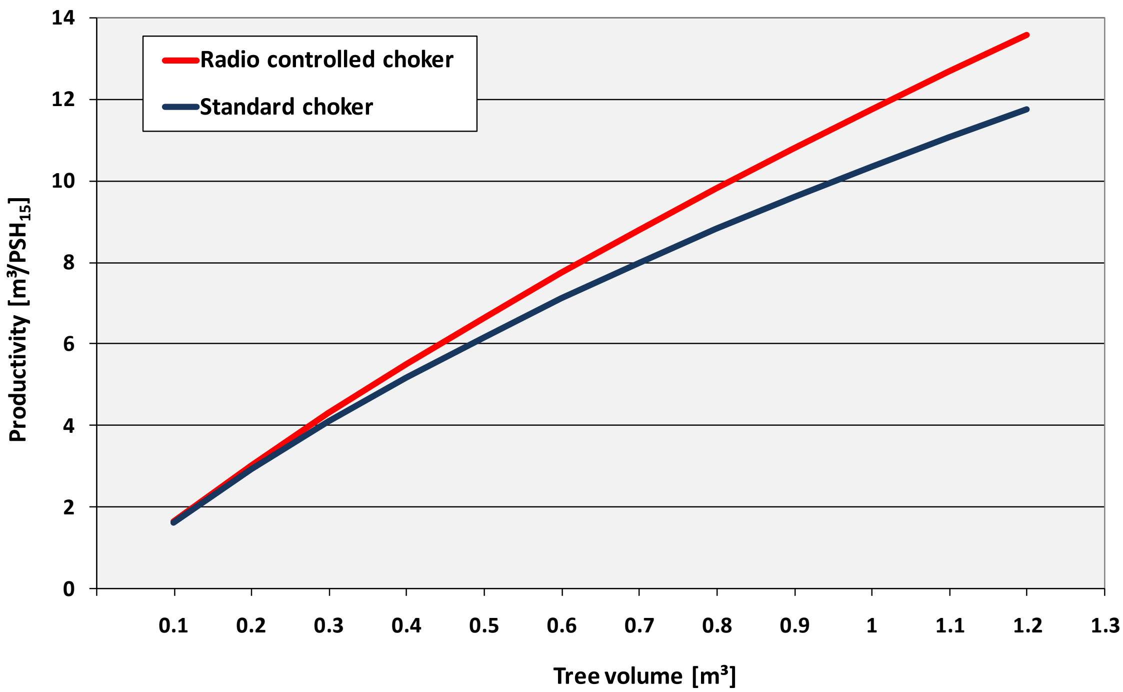

Figure 2: Productivity of the cable yarder system depending on tree volume and choker system

For comparison, in recent trials conducted at two different sites in New Zealand there was a slight decrease in productivity when using the radio-controlled chokers. This decrease was contributed to the lower average turn volume when using radio-controlled chokers. Both of these studies did show a significant time saving in the unhook phase. However, the very long extraction distances resulted in long extraction cycles, and this meant the landing phase short compared to the total cycle time.

It is possible to provide an indicative estimation of the pay-back time based on this study. The difference in productivity is 0.62 m^3/PSH_{15} with an average tree volume of 0.6 m^3. For this particular operation the felling and extraction rate 32 Euro/m^3. This suggests that using the radio-controlled chokers would increase revenue by 0.62*32=19.84 Euro per hour. If we simply divide the investment cost of 9,000 Euros by 19.84 Euros per hour, then the payback period would be approximately 450 hours (not including depreciation or repair and maintenance costs). By a harvest rate of 25 Euros/m^3 the payback period would be 580 hours.

In total 95 hours of heart-rate data was collected from the choker-setter using manual and radio-controlled chokers. A sustainable work load for a day is defined as the heart rate reserve being not greater than 40%. When using the manual chokers the work load was 40% HRR, and this increased significantly to 44% HRR when using radio-controlled chokers (Figure 3). For comparison, these values are considerably higher than those measured by Kirk und Sullman (2001). In their study of choker-setter in New Zealand the heart rate reserve ranged from 31.9 to 38.5 %HRR.

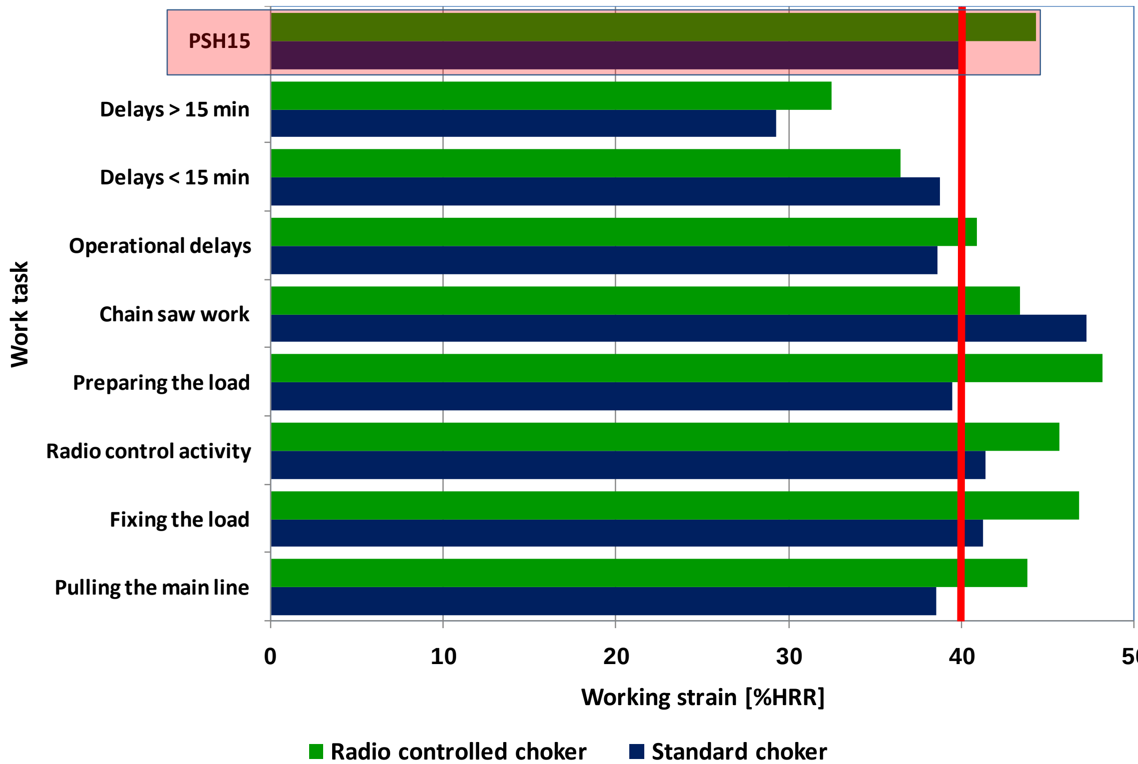

Figure 3: Working strain for the choker-setter depending on choker system

Figure 3 shows that the tasks of preparing the load, the radio-controlled activity, fixing the load as well as pulling the mainline the heart rate reserve was considerably higher for the radio-controlled chokers. Only in the 'other' activities of chainsaw work and short delays was the heart-rate higher for the manual chokers.

Discussion

While this study showed that the radio-controlled chokers can increase productivity, it also highlighted that it may have come at a cost of a higher workload for the choker-setter. It was noted that during the study the choker-setter rarely took a rest-break, and this may be attributed to the exceptionally short extraction distances, as dictated by the study area. This is also evident in the overall productivity model which showed no correlation with extraction distance. This result should therefore be considered preliminary until some additional data can be captured for longer extraction distances.

The yarder operator was particularly pleased with this new technology, and noted not only the simplification of his routine but also the additional safety around the landing. However the choker-setter did note the added difficulty associate with the varied choker lengths. The lengths were varied to avoid the chokers impacting on each other. This however caused quite wild swinging motions in the carriage out phase, resulting in the operator having to reduce carriage out time. He also noted additional maintenance of the chokers associated with the difficulty of wind-throw, as well as the reduced choking effect on smaller tree diameters. He suggested that an additional safety hook may prevent the cap from releasing early.

Overall there were only small problems associated with either the radio-control of the yarder and of the chokers: once the battery had to be replaced because it was not turned off. Otherwise there were no major problems during the study.

Conclusion

Radio-controlled chokers were studied during cable yarder extraction of wind-thrown trees in the Austrian Alps. The primary benefit associated with these chokers is in the reduced time associated with the landing of the trees (un-hooking), and the corresponding improvement in safety by eliminating this potentially hazardous task. This proved to be correct with the time study showing an overall improvement in productivity. The study also indicated that despite the relatively high investment cost associated with purchasing a set of radio-controlled chokers, that with a productivity improvement of 0.62 m^3/PSH_{15} in the pay-back time is just 480 hours. However this calculation does not include repair and maintenance costs.

To be truly considered a system improvement then the work load on the choker-setter should not increase, or at least not exceed the sustainable work rate for the day. The study however showed that the radio-controlled chokers did significantly increase the heart rate, and it did exceed the sustainable work load.

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Harvesting and Transportation of Logging Residue Logs Accumulated Along Road Side for Woody Biomass Plant in a Local Community

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Abstract

Utilization of logging residue logs is currently an important issue in the search for alternatives to fossil fuels and for business opportunities in local forestry communities. Niyodo town, a local community in the Kochi area of southwestern Japan, has recently started a government-subsidized woody biomass utilization project. The project collects logging residue logs for a processing plant using three systems: (1) a large scale logging contractor operation, (2) a medium-scale system operated by a forestry cooperative, and (3) a small scale system operated by individual forest owners. Although the expected largest and smallest sources of residue logs were large- and small-scale systems, respectively, the small-scale system procurement was the largest. We investigated system operational efficiency and carried out a cost analysis to compare advantages of systems in relation to transportation distance. The medium-scale system is not cost effective because it entails intermediate transportation. There are two types of small-scale system, and both are in large part more cost effective than the large-scale system. A subsidy for residue purchase price has an important role for profit in all of the systems. When a subsidy is applied, most of the systems are profitable over transportation distances of 30-40 km.

Introduction

Utilization of logging residue logs is currently an important issue in searches for alternatives to fossil fuels and for alternative business opportunities in local forestry communities (Richardson et al., 2002). Niyodo town, a local community in Kochi Prefecture, southwestern Japan, has recently started a government-subsidized woody biomass utilization project (Fig. 1; maps arranged and modified from Wikipedia, 2009). The project includes installation of a gasification and wood pellet production plant and implementation of a collection system for logging residue logs accumulated along road sides after conventional harvesting operations.

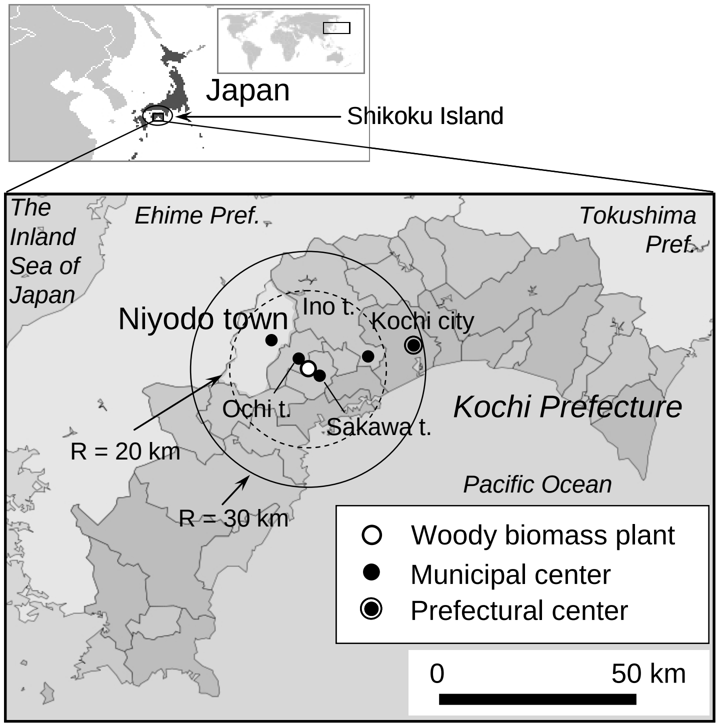

Figure 1. Location of the Niyodo-town woody biomass plant and surrounding source areas for logging residue logs

Note: Maps were arranged and modified from Wikipedia, 2009.

Three types of collection system were practiced: (1) a large-scale logging contractor operation, (2) a medium-scale system for a forestry cooperative, and (3) a small scale system operated by individual forest owners. Although the expected largest and smallest sources of residue logs were large- and small-scale systems, respectively, small-scale system procurement was the largest. While the target collection rate for green residue logs was 160 t/month (wet; water content was approximately 80-85 % of dry-mass), the mass collected by the small-scale systems exceeded 90 % of the total at the end of fiscal year 2008. Most of the residue logs were of plantation forests; the species are Japanese Cedar (*Cryptomeria japonica*) and Hinoki Cypress (*Chamaecyparis obtusa*).

One of the reasons for the relative success of small-scale operations is the additional subsidy paid to this group. The normal price for collected residue logs at the plant is US$30/t (Exchange rate is set at 100 Japanese ¥ per US$1.00; 100.12 JP¥/US$1.00 average in April 2009; Mitsubishi UFJ Research and Consulting, 2009). The town arranged a subsidy for residue logs purchased by the plant after July 2008. For residue logs collected within and around Niyodo town, the subsidies were US$30/t and US$10/t, respectively. Therefore, shippers within the town receive US$60/t of residue logs. Shippers collecting outside the town receive US$40/t.

Materials and Methods

Assessment of operational efficiency

For the large-scale system, data on operational efficiency and cost analysis were extracted from a previous report (Niyodo town, 2007). In the system studied, residue logs accumulated after cable logging operations by a contractor. Fairly wide forest roads have been prepared at the logging sites. An excavator equipped with a grapple loads the residue logs onto a 4-t truck, which directly transports them to the plant. Labor cost of the system is US$200 per man-day (Table 1). The office of the logging contractor is located in Ino town, an eastern neighbor area of Niyodo town, and its large scale operations are in Ino, Niyodo, and neighboring areas.

Table 1. Transportation system for logging residue logs

Scale of systems	Labor fee (US$/man-day)*	Loading method	In-forest transportation method	On-road transportation method
Large	200	Grapple	Truck (Payload: 4t)	
Medium	80	Forwarder-mounted grapple	Forwarder	Truck (Payload: 4t)
Small 1	0	Grapple	Medium-weight truck (Payload: 2t)	
Small 2	0	Manual	Light-weight truck (Payload: 350kg)	

Notes: * Workers in the Large-scale system are employees of a logging contractor. The Medium-scale system is organized by a forestry cooperative and the labor is provided by retirees at low cost. The labor costs of Small-scale systems are set to zero because the systems are operated by forest owners.

Logging sites of the medium-scale system are those of the Niyodogawa Forestry Cooperative; these sites have strip roads on which trucks cannot operate. A forwarder equipped with a grapple (IWAFUJI U4BG1) collects residue logs along strip roads and transports them to a terminal landing where a 4-t truck awaits. We carried out a time study of the system in December 2008. Data for machine costs were obtained from a forestry cooperative questionnaire. Because workers in the system are retired and partially volunteer people (so-called “silver-talent people”), labor cost of the system is a moderate US$80.00 per man-day (Table 1). Logging sites of the medium-scale system are within the bounds of Niyodo town.

There was no detailed information available for small-scale system shippers, except for identification data which Niyodo town office confirmed. We organized a series of questionnaires for the shippers in order to investigate their profile, operation system, distance from their logging sites to the plant, etc. Data on small-scale system residue log shipments were obtained from the town office.

Questionnaire for small-scale system shippers

Questionnaire sheets were prepared and sent to all small scale shippers (48 persons/companies) in January 2009. Although we received just 33 answer sheets (69% of total), these accounted for nearly 90% of total residue log shipments to the plant. Therefore we conclude that the questionnaire survey is representative of the small-scale system shippers.

The survey showed that small-scale system shippers have two main types of collection and transportation (Table 1). The first (Small 1) uses a grapple equipped excavator for loading residue logs from strip roadsides onto a medium weight truck (payload: 2t). The truck transports residue logs directly to the plant. In the second system (Small 2), residue logs are manually loaded and transported to the plant on a type of light truck (payload: 350kg) widely used across Japanese rural forestry and agricultural communities. These light trucks are classified in a favorable tax category in Japan.

Small-scale shipper collecting sites are spread over the Niyodo river watershed and over neighboring watershed areas of Niyodo town, Ochi town, Sakawa town, Ino town, and the rural area of Kochi City (Fig. 1). Shippers from Kochi city include members of a forestry volunteer group.

Cost analysis

Operational efficiency data were obtained for transportation distances of 30 km and 20 km for the large- and medium-scale systems, respectively. For the small-scale system, transportation distances range from 3 to 60 km (average 25.7 km). We first constructed a formula to represent the linear relationship between transportation distance (km) and collecting and transportation costs (US$/t) for each system. Using the formulae, we executed a break-even point analysis to compare system advantages by transportation distance.

For cost-distance formula construction, we obtained machine costs of the two small scale systems from related studies (Zenkoku-Ringyou-Kairyou-Fukyuu-Kyoukai, 2001; Moriguchi et al., 2004). The small-scale system labor fee was set to zero because the shippers are forest owners and thus self-employed. This certainly makes small-scale systems financially advantageous because in the other two systems there is a labor fee included in operational costs.

Profit analysis of the two small scale systems was carried out in relation to transportation distance. Profit was expressed as US$ per operation hour. When profit exceeds > zero, its value (US$/h) may be treated as compensation for the labor of a small-scale shipper.

Fossil fuel price was unstable and highest in 2008. We set two types of fuel prices for our cost analysis. One was “High fuel price” that was the average for the year 2008 in Japan, viz. US$5.04/gallon for diesel and US$5.66/gallon for gasoline. The second was “Low fuel price”, that was the current (May 2009) normal price, which was also applicable in Japan through 2007, viz. US$3.79/gallon both for diesel and gasoline.

Results and discussion

Break-even point analysis comparing all systems

Figure 2 shows relationships between collection and transportation costs for the four systems (Large, Medium, Small 1, and Small 2) and residue log transportation distance to the plant. The Small 1 and Small 2 systems had lowest costs for transportation distances ≤10-15 km and ≥10 or 15 km, respectively, depending on fuel price. Zero labor cost in these two systems accounts for their low total costs.

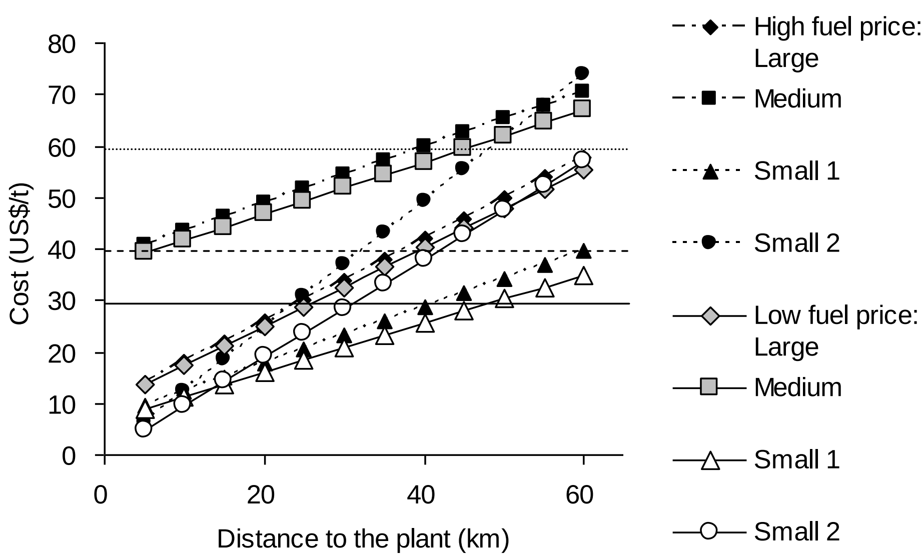

Figure 2. Break-even point analysis of the residue log collection and transportation systems
Notes: "High fuel price" indicates diesel at US$5.04/gallon and gasoline at US$5.66/gallon (Japanese average for 2008). "Low fuel price" indicates diesel and gasoline prices at US$3.79/gallon (price in May 2009, and through 2007).

The Medium and Large systems had the highest and second highest costs, respectively, with very small transportation distance effects. Labor cost of the Medium system (US$80/man-day) was lower than that of the Large system (US$200/man-day). Costs of the Medium system were >US$40/t, even when transportation distance was only 5 km. The Medium system was only profitable when there was a US$30/t residue purchase subsidy (purchase price: US$60/t) and transportation distance was <40km. The high cost of the Medium system was caused by intermediate distance transportation by forwarder on strip roads. Thus, deleting extra processes is important for cost cutting.

Fuel price variability had the largest effect on Small 2 system. This was because there were low equipment costs in the system (i.e. light-weight truck). The effect of fuel or direct cost variability on Small 2 system was proportionately greater than in any other system.

Profit analysis for the small scale systems

Figure 3 shows the relationship between profit (US$/man-hour) and transportation distance (km) for the small-scale system with residue prices of US$30, 40, and 60 per tonne. When residue price was US$60/t, both Small 1 and 2 systems made a profit if transportation distance was ≤60 km. When residue price was US$30/t, Small 1 system made a profit when distance was <50 km, while Small 2 system could not make a profit if distance was >30 km.

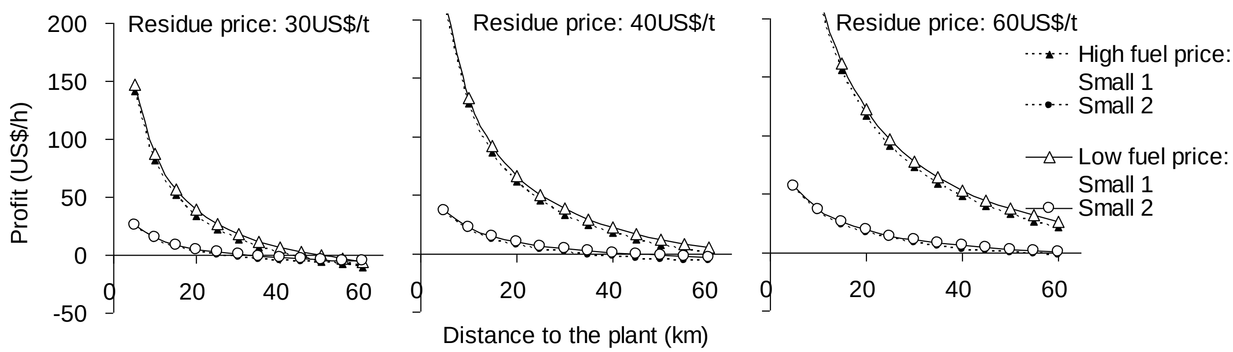

Figure 3. Profit analysis of small-scale systems in relation to transportation distance
Notes: "High fuel price" indicates diesel at US$5.04/gallon and gasoline at US$5.66/gallon (Japanese average for 2008). "Low fuel price" indicates diesel and gasoline prices at US$3.79/gallon (price in May 2009, and through 2007).

A Small 1 system shipper earned a labor profit of US$10/h when distance to the plant was <30 km, because there was a favorable balance of equipment cost (a grapple and a 2-t truck) and sufficient operational efficiency. However, a Small 2 system shipper could obtain a labor profit of US$3-5 /h or more when a subsidy was added to the residue price ($10/t or $30/t; total residue price: $40/t or $60/t) and when transportation distance was ≤25-30 km.

Conclusions

The basic purchase price of residue logs (US$30/t) is determined by cost of establishing and running the biomass plant. At this price, the medium-scale system cannot make a profit. Development of an appropriate road network would improve cost balance of the system. When a subsidy of US$10/t is added to residue log purchase price (purchase price: US$40/t), all systems except for the medium-scale could make profit when distance is <30 km. With a US$30/t subsidy (purchase price: US$60/t), even the medium-scale system can turn a profit when distance is ≤40 km.

In related woody biomass studies in Japan, transportation distances of 30-40km have frequently been taken into consideration. Moriguchi et al. (2004) performed a trial operation of residue log chipping and transportation in order to utilize logs from as far away as 35 km. Yoshioka et al. (2000, 2002, 2005, and 2006) conducted a series of field investigations and simulation analyses on woody biomass utilization. Although they discussed transportation distances between 20 and 80 km (Yoshioka et al. 2002 and 2006), the model case was analyzed for a transportation distance of 27.8 km (Yoshioka et al. 2005). Sasaki et al. (2006a and 2006b) evaluated total supply cost of wood chips in northern Japan. While they calculated costs over various transportation distances, their discussion focused on transportation distances of 30-40 km.

There is no logical reason for focusing on transportation distances of 30-40 km. Nevertheless, we will use 30 km as a working criterion in our considerations of log collection. In the Niyodo operation, 60% of residue logs were collected within 30 km of the plant, and 90% were collected within 40 km. Assuming that twisting of roads increases distance by a factor of 1.3 to 1.5, straight distances from logging sites to the plant would be 20 to 30 km. A radius of 20-30 km from the plant includes Niyodo and adjacent towns, including a part of Kochi City (Fig. 1).

Finally, our questionnaire survey showed that most small-scale operators feel subsidies have had a positive effect on their forestry activities.

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* The titles are tentative translation by the present authors.

Assessment of the Potential for Log Sort Yards to Facilitate Forest Health Restoration and Fuel Reduction Treatments

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Abstract

This paper presents preliminary results from an analysis of the potential for a log sort yard to increase the residual value (mill delivered price less handling, haul and harvesting costs) of forest health restoration treatments relative to a standard sort at landing in Ravalli County, Montana. We find that establishment of a log sort yard in Ravalli County could substantially increase the residual value of forest health restoration treatments improving potential financial returns to forest owners from treatments and expanding treatable acres that are profitable to treat. This result is robust against all model parameters except delivered log prices. A reduction in delivered log values by 30% is enough to make the present system of sorting logs into two piles at the landing more attractive than sorting at a sort yard.

Introduction

Fuel reduction and forest health restoration treatments have been widely recommended to limit the size and intensity of wildfires in the western United States (van Wagtendonk 1996). Although the importance of such treatments is recognized, log value recovery is critical to the extent and distribution of treatments (Keegan et al. 2004). Ability to treat the sizeable acreage identified as "in need" has been constrained by a combination of the small (low value) and different species composition of logs harvested in fuel reduction and forest health restoration treatments relative to traditional timber harvest operations, and land management agency budget constraints. In addition, log landings are often too narrow to provide space for extensive log sorting that may improve log value recovery. Even when more extensive sorting is possible at the landing, extra handling of logs and transportation to various markets may not be justifiable if only small log volumes per product are available at the landing. Consequently, unsorted logs are often misdirected and either consumed as lower value products or re-directed through trades between mills, resulting in extra handling and transportation costs at the mill (Sessions et al, 2005).

In the western United States, declining timber resource quality and volume, increasing diversification of log and fiber markets, and the need to recover more value from the available resource has increased interest in commercial sort yards (Dramm et al. 2002). By facilitating the stockpiling of logs that meet the unique log specifications of particular end-users, sort yards can increase value recovery and reduce misdirected log volume (Dramm et al. 2004). In addition, sort yards can provide options for effective marketing of underutilized small-diameter logs and biomass resources resulting from fuel reduction thinning operations (Dramm et al. 2002). Although several past studies indicate that costs for running a log sort yard for small-diameter logs may outweigh the revenue generated by sorting and pre-processing those logs (Sessions et al. 2005, Sedney 1992, Dramm et al. 2003), there exists potential for log sort yards to improve value recovery from small-diameter wood, especially where diverse wood product markets exist.

The US Forest Service has interest in assuring that all material associated with a timber sale is directed to its highest value use. This has, in some instances, led to stipulations in timber offerings that require winning bidders to utilize logs down to a specified size. In Montana, where requirements sometimes specify the harvest of logs that do not cover the cost of removal, this has deterred loggers from bidding at some sales, resulting in the Forest Service losing revenue through reduced bids. A sort yard could mitigate or even eliminate this problem by providing a one-stop sale yard for loggers, which reduces the burden on loggers having to find markets for small volumes of small or otherwise less-valuable logs. This may reduce the need for sales administrators to stringently enforce log utilization standards, freeing up Forest Service resources for use elsewhere, and encourage more competitive bidding by loggers at sales.

By acting as a concentration yard for niche market logs, log sort yards may encourage wood product manufacturers to buy more of their logs locally, as opposed to importing logs from outside the region, which would have positive employment and income effects locally (although this is a zero sum game at larger geographic scales).

Sort yards are likely to have net carbon emission benefits. Depending on the location of the sort yard relative to the forest and end-users, by reducing misdirected logs, sort yards may reduce log truck road miles and associated carbon emissions. Sort yards may facilitate greater utilization of small diameter logs that would otherwise be burned on site, which constitutes benefits in terms of reductions in carbon and particulate matter emissions. Sort yards may also facilitate redirection of some small logs away from short-life wood products (e.g. pulp) to longer life (and higher value) wood products.

By directing logs to their highest value market, sort yards can increase the value of timber harvested, improve the financial viability of fuel reduction and health restoration treatments and increase the willingness of loggers to bid on timber sales. This may facilitate greater implementation of fuel reduction and health restoration treatments on the landscape to achieve forest management and public safety objectives without the need for taxpayer-funded subsidization. The objective of this study is to assess whether a log sort yard can increase the residual value of forest health restoration treatments to landowners relative to a traditional sort at landing.

Data and methods

Study area

Ravalli County, Montana (illustrated in Figure 1), has a myriad of issues relevant to many other wildland-urban interface (WUI) communities throughout the inland west and northwest. As described in Loeffler et al. (2006), Ravalli County has an abundance of forestland – approximately 1.27 million acres of non-wilderness forestland. Much of this land is lower elevation, moderately to severely departed from historical fire regimes (Hardy 2001, Schmidt et al 2002), and in need of restoration treatments (Fiedler 2003, 2004). There is also an increasing WUI population. The wood processing facilities near the study area constitute a diverse range of log buyers including lumber mills, stud and plywood mills, a pulpmill, log home manufacturers, and a post and pole producer.

Virtually all logs harvested in Ravalli County are milled in five western Montana counties that are within 200 miles of Ravalli County forests, namely Flathead, Lake, Powell, Missoula and Ravalli (Spoelma *et al.* 2008).

According to the Montana Manufacturers Information System (Montana Business Connections and Bureau of Business and Economic Research 2009), there were 108 primary wood processing facilities located within these five counties in 2009, ranging from large-scale operations with annual processing capacities greater than 40 MMBF to small-scale family businesses. Log home manufacturers account for 45 of these facilities. The larger log home manufacturers import their house logs from Canada.

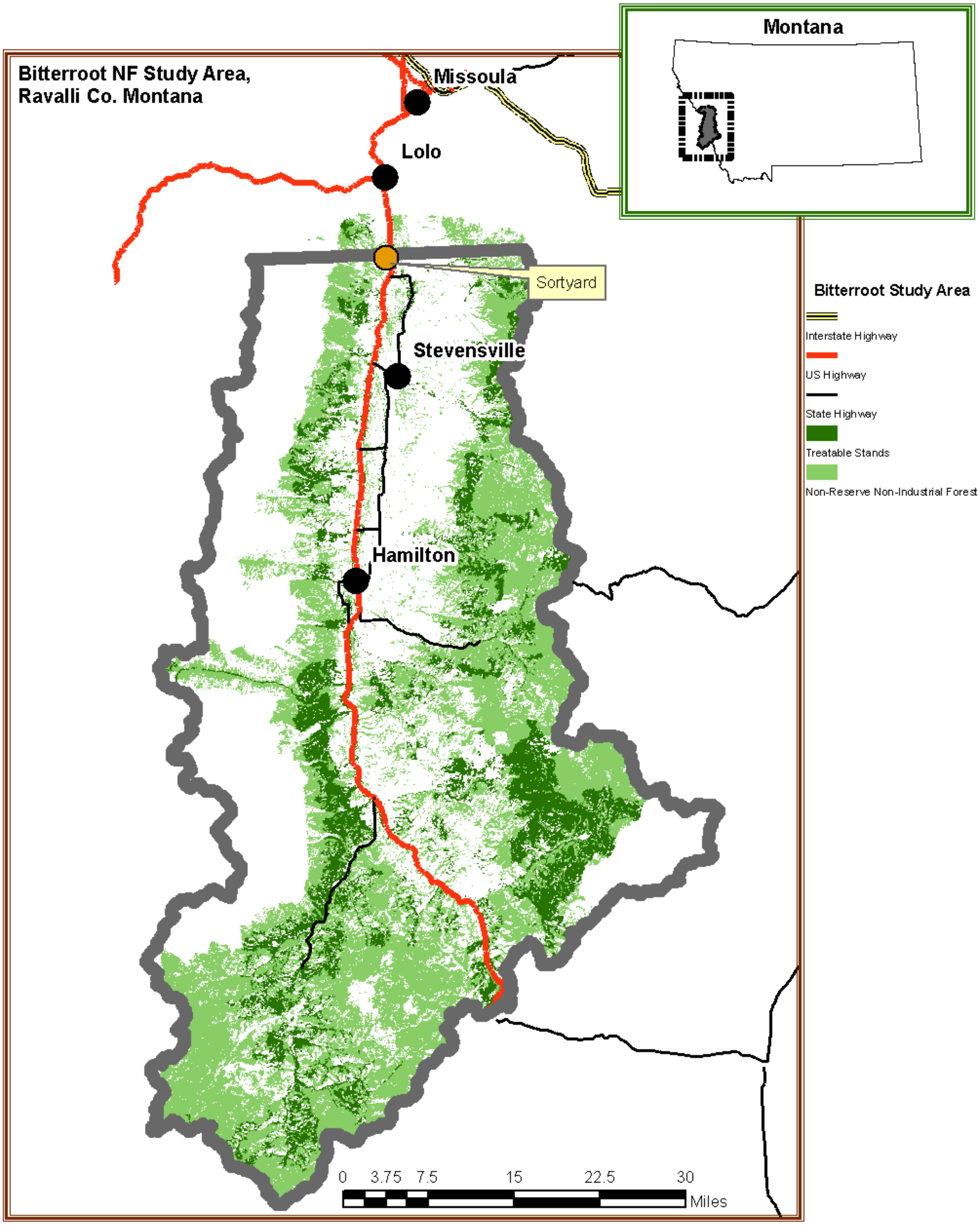
The timber industry in Montana is facing challenging times at the moment. Average log prices in western Montana fell 30% between the first quarter of 2006 and the first quarter of 2009 (Morgan 2009). During the course of this study one of the oldest and largest mills in western Montana permanently ended its 100-plus year production history.

In Montana, there are usually two log piles at the landing: sawlog and pulplog. This is for several reasons, including lack of room at the landing.
Species composition and different mills take different species
Most logging operations in Ravalli County are thinning operations that generate large volumes of small diameter material which have low values that don't warrant effort to sort at the landing.
Low harvested volumes per acre (typically less than 10 MBF) that make it challenging to accumulate at least one truck load of less common log types at a particular landing

According to data collected by the Bureau of Business and Economic Research at The University of Montana, about 1.5% of total timber harvest volume was redirected from one mill to another in 2004 (Morgan 2007).

Within Ravalli County, there are 748,700 non-reserve forested acres on federal and non-industrial private land. There are 202,300 acres of treatable forest acres.

Figure 1. Map of Ravalli County, Montana, including location of treatable acres and the potential sortyard



Forest inventory data and analysis

The central focus of this analysis was to determine if trees cut could go to higher value products via a sort yard. Forest inventory data that included not only quantitative estimates of timber available, but qualitative assessments of that timber were essential. The best publicly available data was acquired from the US Forest Service Forest Inventory and Analysis (FIA) program's Mapmaker version 2.1 database (http://www.ncrs2.fs.fed.us/4801/fiadb/fim21/wcfim21.asp). Forest inventory plots available from FIA include an array of qualitative variables in the Treelist file. Prior to silvicultural modeling, FIA plots were initially filtered using the following criteria:

1. Sampled plots were located in one of four contiguous counties – Ravalli, Lake, Mineral and Missoula – in western Montana due to the similar forest type and structure in all counties;
2. Plots were located on either non-reserved US Forest Service or non-industrial private ownership land.

Silvicultural modeling and analysis

Like most landscapes in the northwest, Ravalli County has an array of forest types, and because these forest types are structurally and biologically different, different restoration prescriptions for each forest type would be realistically applied. Therefore, we first identified various forest types in the county, and then acquired scientifically-based restoration prescriptions specific to each forest type. The forest types in Ravalli County were identified via GIS analysis of the R1-VMP forest vegetation coverage (Reference); to develop the prescriptions, Dr. Carl Fiedler (retired), a silviculturalist from the University of Montana's College of Forestry and Conservation was enlisted to provide the suite of restoration prescriptions. These steps were accomplished by first grouping the thirteen forest types identified using GIS into five broader forest type groups. Restoration prescriptions based upon what the historical structure would have likely been for each forest type group were then developed by Dr. Fiedler.

Each of the five prescriptions required a target basal area for leave in the largest standing trees, and a species preference order for trees left in the minimum basal area. Because each FIA plot was assigned a forest type and prescriptions had been developed for the forest types identified on the landscape, each FIA plot had a corresponding prescription. However, not all of the FIA plots in each forest type prescription category 'qualified' for treatment, as the plot may have not met the minimum basal area to leave. The number of FIA plots in each forest type prescription category is shown in Table X. These forest type groups and associated prescriptions are included in Appendix A.

A FIA-GIS data link was developed between the non-spatial FIA inventory data and the GIS-based R1-VMP forest type categories. The five prescriptions developed by Dr. Fiedler were each entered in the Forest Vegetation Simulator (FVS: Dixon 2003) and FVS-ready FIA plot data were then downloaded from the FIA Mapmaker database and imported into the FVS. Using the Database extension and a series of Compute keywords, FVS output files were exported to a database. Each of the five FVS Treelist output files were then imported separately into the R1-VMP Stand Classifier program (Berglund and others 2008), which categorizes FIA plots into R1-

VMP (Brewer et al. 2004) forest type categories using the FIA stand Treelist file. The Stand Classifier program is based upon the same algorithms used to forest type R1-VMP polygons.

Because FVS-ready files are pre-packaged to run exclusively in the FVS model, selecting and importing qualitative FIA Treelist variables and importing into FVS is not an option, thus a join of the FVS Treelist and the FIA Treelist was necessary. The FVS and FIA Treelists, as well as the R1 Stand Classifier output file, were imported into the MS Access database software. A series of queries were then conducted to join the files such that each FIA plot, having been output from FVS, contained plot level information developed with the Compute keywords, and assigned a R1 Stand Classifier forest type group, thus contained plot level and tree level information. Plots which did not have any volume removed during prescription modeling were removed from the FIA plot data set.

Harvest cost modeling

We estimated harvest costs using the Compute keywords from FVS as variable inputs for the tractor skidding cost equation in Keegan et al. (2002). Dollars per green ton harvest costs are estimated using average diameter at breast height (inches), volume per acre removed (tons), and average skidding distance (feet). Ground based harvest cost estimates were thus produced for each FIA plot 'qualifying' for a treatment. The average cost per acre and standard deviations for each forest type are presented in Table X.

The table reports harvest costs per MBF, which is Harvest cost is harvest cost per acre from Keegan *et al*. (2002) inflated to 2007 dollars divided by the sum of sawlog and pulplog volume harvested per acre.

GIS analysis

Treatable acres and haul costs were determined using Geographic Information Systems (GIS) analysis. Spatial data, both raster and polygon, from Ravalli County were acquired and then a set of data filters were applied to identify appropriate study area acres by selecting or removing the following acres from the larger spatial data sets:

1. All non-treed acres removed (Brewer et al. 2004);
2. All non-reserved USFS and non-industrial privately owned acres in Ravalli County (USFSa 2007, NRIS 2007);
3. All acres with median slope less than or equal to 40% (USGS 2007);
4. Acres burned in 2000 by high and medium fire severity removed (NRIS 2007);
5. All inventoried roadless removed (USFSa 2007);
6. All polygons that have their center within 2,000 feet of a road (USFS 2007b)

Following the identification of total treatment candidate acres in Ravalli County, a subset of the total number of acres would be used to spatially place a realistic amount of annually treated acres across the study area. Several steps were required to accomplish this:

1. The average number of acres treated annually between 2003 and 2006 on both Forest Service and privately owned lands were estimated (USFSc 2007, MT DNRC 2007):
    a. 1,032 Bitterroot National Forest acres;
    b. 5,111 privately owned acres;
2. The average number of acres treated annually were prorated across the forest types so that the proportion of acres treated was constant across forest types;
3. A sample of GIS polygons was selected randomly by forest type such that the sampled acres approximated the prorated acres for each forest type;

Product haul costs were then estimated from the forested polygons randomly selected across the study area to represent a typical annual harvest on the five forest types. We used a GIS road network data layer covering the study area that was previously developed by the Human Dimensions Program of the US Forest Service Rocky Mountain Research Station housed at the Forestry Sciences Lab in Missoula, Montana (USFS RMRS 2007). This road layer contains road segments classified as either paved or unpaved road. We estimated the round trip haul cost at $2.60 per mile for paved road segments and $5.80 for unpaved road segments based on an average cost of $90 per hour for owning and operating a logging truck and an average speed of 35 mph on paved and 15 mph on unpaved road.

The harvested acres is the average number of acres that have been cut in the recent past

These GIS road data, average per mile haul costs, and average harvest volumes for each of the forest types were entered into MAGIS, a spatial decision support system for scheduling vegetation treatments and routing haul through road networks (http://www.fs.fed.us/rm/econ/magis/). MAGIS was used to simulate applying the treatments designated for each of the forest types, loading the logs created by the treatments onto the road network in the vicinity of the randomly selected polygons, and routing the loaded trucks through the road network over the most cost-effective paths. For the Sort Yard Option, the logs were routed to the designated sort yard location. For the Landing Option, the sawlogs were routed to a common point several miles north of the study area. Logs hauled to each of the candidate sawmills in the Landing Option must travel through that common point. Pulpwood for both the Sort Yard and Landing Options were routed directly to the paper mill. Logs were routed separately for each forest type, and the average per acre haul cost was computed and entered into the master spreadsheet. The additional haul costs associated with the two options were added in that master spreadsheet. For the Sort Yard Option, that included the cost of hauling of the sorted logs to the processing mill that provides the highest net economic return for the sort yard. For the Landing Option, it included adding the haul cost from that common point north of the study area to each of the candidate mills for receiving the sawlogs from each forest type.

Acres by forest type are shown in Table X.

Table X. Summary information of randomly distributed forest types.

Forest type	Acres Represented	FIA plots (n)	Mean Harvest Cost ($/acre)	Standard Deviation
Douglas fir (DF)	2,396	245	$672	$465

Englemann spruce-subalpine fir (ESAF)	579	91	$498	$429
Lodgepole pine (LP)	860	94	$764	$525
Dry mixed conifer (DMC)	799	94	$1,021	$630
Ponderosa pine (PP)	1,413	59	$455	$361
Total	6,047	583	--	--

End-user log specifications and delivered prices

In the autumn of 2007, telephone and in-person interviews were held with 12 purchasers of logs from Ravalli County to acquire their log specifications and delivered log prices. A summary of the specifications and delivered prices is provided in Table X, although it should be noted that every end-user has different specifications and delivered prices, which have been preserved for realism in the analysis. Log prices have decreased significantly since the autumn of 2007 when this information was collected. These 12 processors are among the largest and most diverse log processors in western Montana and are capable of utilizing the log volume projected to be cut given the silvicultural prescriptions employed in this analysis. They consisted of one pulp mill, three log home manufacturers, one posts and poles operation, one plywood manufacturer, three sawmills and two studmills.

Table X – Log specifications and delivered prices by product type

Log type	Log specifications					Delivered price ($/MBF)
	Species accepted	Max led (inches)	Min sed (inches)	Max length (feet)	Min length (feet)	
House logs	Dead or dried DF,ES, LP		8		12	$550 - $1,700
Peeler logs	DF, WL	30	7.5	35	17.5	$530
Sawlogs	All coniferous species		5	41.5	16	$275 - $490
Posts and poles	LP	8	3	21	17	$477
Stud logs	LP, DF, ES, AF,WL, PP	30	4.5	35	8.5	$375 - $440
Pulp logs	All coniferous species	28	2.5	45	12	$240

Note: Species codes are: DF, Douglas fir; ES, Engelman spruce; LP, lodgepole pine; WL, western larch; AF, alpine fir; and PP, ponderosa pine.

Simulating the log sorting process

Critical to this analysis was developing a method in which to ‘sort’ logs by species, total log length, and large and small end diameters, to acquire the highest value possible from each tree assumed cut in this analysis. FIA has a Treelist which records information for every tree sampled and the FVS cut treelist clearly identifies all cut trees These two lists were joined together by tree ID, thus, making available all possible information about each cut tree would for use in estimating a single tree's highest potential value. Additionally, "a collection of the standing tree volume estimators used by the Forest Service" kept in the National Volume Estimator Library and housed at the USDA Forest Service Forest Management Service Center (USFS 2006) were utilized to estimate variable log diameters and volumes per log segment in many of the cut trees. That is, when a large tree is felled, more than one potential product may come from that tree. For instance, a logging rule of thumb is that, beginning at the stump, the first section of the tree can yield a peeler log, the second (middle) section can yield a sawlog, and the top section may be a pulp log. This rule of thumb is a direct result of the product's specification, i.e. species, small end diameter, and length, for large trees. However, not all the cut trees were large enough to produce three products. Many were large enough to produce only one product, and some could product two products, all of which were essentially determined by the combinational mix of tree species, size, height (log length) and potential product values. Variables required for the Basic Functions in the Library, which were used to estimate log lengths at varying diameters, and board foot volume are:

Table X. National Volume Estimator Library equation variables and definitions used in to merchandise cut trees.

Variable	Definition	Source
Region	Forest Service Region number	NVEL Appendix
Forest	Forest Service Forest number	NVEL Appendix
VolEquNum	Volume Equation Number	NVEL Appendix
Dbh	Diameter at Breast Height (4.5 feet from the ground)	FVS Treelist
TotalHt	Total tree height measured from the ground to the tip.	FVS Treelist
TopDia	Minimum top diameter for calculating the main stem volume.	FVS Treelist

Landing option

Pulplogs for all scenarios are directed to the pulpmill in Frenchtown. In the landing option the sawlogs could be directed to one of the four sawlog mills in Seeley Lake, Columbia Falls, Pablo, or Deerlodge.

It was assumed that in the landing option, whichever sawmill/pulpmill combination yielded the highest net value for the logs produced from each of the five prescriptions would receive all sawlogs while the pulplogs were always directed to the pulpmill. The net value was calculated as the delivered value of the logs to a sawmill and the pulpmill, less all harvest and haul costs (Equation X). Table X lists the variables used in this calculation.

$$LNR_{ft} = N_{ft} * (Rev_{sm,ft} + Rev_{p,ft} - HarvCst_{ft} - HaulCst_{sm,ft} - HaulCst_{P, ft})$$

Table X. Equation X variables and variable definitions used to estimate Landing option net revenue.

Variable	Definition

$\hat{LNR}_{ft}$	Estimated net revenue from forest type *ft*
N_{ft}	Number of acres in forest type *ft*
$Rev_{sm,ft}$	Revenue per acre from sawmill *sm* from forest type *ft*
$Rev_{p,ft}$	Revenue per acre from pulpmill p from forest type *ft*
$HarvCst_{ft}$	Mean harvest cost per acre from forest type *ft*
$HaulCst_{sm,ft}$	Mean haul cost per acre for sawlogs from forest type *ft*
$HaulCst_{P,\ ft}$	Mean haul cost per acre to pulpmill from forest type *ft*

To calculate the value each cut tree has at each mill, the FVS cut treelist from each prescription was entered into a spreadsheet where the log attributes were analyzed using a series of Excel "IF" statements, the NVEL functions, and mill specifications. This process was conducted for each of the four sawmills in this option, for each forest type prescription. Cut trees were analyzed to fit into highest value product possible – a sawlog – and then the lesser valued pulplog. If a tree was large enough to yield a sawlog, that portion of the tree to the minimum small-end diameter accepted at the sawmill was removed from the total tree length and placed in the sawlog deck. The remaining portion was then analyzed to fit a pulplog. If the remaining portion yielded a pulplog, that portion of the tree to the small-end diameter accepted at the pulpmill was removed and placed in the pulplog deck. If a tree did not initially yield a sawlog, it was evaluated for a pulplog. Trees the yielded sawlogs but were not a species purchased by a sawmill were placed in the pulplog deck. Figure X displays the log sorting procedure employed.

Sort yard option

For the sort yard option we also assumed that there is only room at the landing for two piles of logs – logs destined for the sort yard and pulplogs. Pulplogs are sent directly from the landing to the pulpmill while all other logs are sent to a centralized sort yard for sorting into highest value products, which are then sent to particular end-use locations. At the sort yard, the logs can be placed into one or more of the following end-use categories, listed in descending order of value per MBF:

1. Log home manufacturer – three locations
2. Plywood mill
3. Post & pole manufacturer
4. Sawmill
5. Studmill – two locations
6. Pulpmill – tops of higher valued trees

We recognize that regionally there exists a greater number of end-uses for logs, including log furniture, railings, viga/latillas, fuel pellets and engineered wood products. However, in 2004 only 1.36% of wood volume harvested from Ravalli County was sold into a market not covered by the six categories listed above (Bureau of Business and Economic Research 2007). Therefore, the range of end-use destinations we specify are the most likely consumers of the majority of merchantable timber harvested in this analysis.

Five of the end-use mills we identify can generate higher revenue for a log than if the log had simply been directed toward a sawmill, as in the Landing option. Other than the pulpmill, only the two studmills pay less for delivered logs than sawmills.

Similar sorting logic from the Landing option was employed in the Sort Yard option. However, instead of the two potential end-uses described in the Landing option, the Sort Yard option has nine potential end-uses for cut trees. All merchantable logs are examined for their highest value product potential. The same FVS cut treelist was entered into a set of spreadsheets containing systems of "IF-THEN" statements that identified the highest value of the first segment of log, removed it from the tree bole and apportioned that highest identified value to the first segment. Following this, the remaining segment(s) of the log were then similarly analyzed and directed towards that highest value end-use, and so on in descending order of value, until the log bole could not produce any other products. The lowest value considered was a pulplog. It is important to note this was not an exercise in optimal bucking, which is in itself a uniquely different experiment, but an attempt to begin from the base of a cut tree and identify highest value of log segments moving upward.

The following equation shows our method for estimating net revenues in the Sort Yard option; equation variables are described in Table X:

$$SYNR_{ft} = N_{ft} * (Rev_{sm,ft} + Rev_{p,ft} - HarvCst_{ft} - HaulCst_{sy,ft} - HaulCst_{P,ft})$$

$$- \sum_{m=1}^{M} Vol_{m,ft} * (HandCst_{sy} + ProdHaulCst_{m})$$

Table X. Equation X variables and variable definitions used to estimate Sort Yard option net revenue.

Variable	Definition
$\widehat{SYNR}_{ft}$	Estimated net revenue from forest type *ft*
N_{ft}	Number of acres in forest type *ft*
$Rev_{m,ft}$	Revenue per acre from end-user mill *m* from forest type *ft*
$Rev_{p,ft}$	Revenue per acre from pulpmill from forest type *ft*
$HarvCst_{ft}$	Mean harvest cost per acre for forest type *ft*
$HaulCst_{sy,ft}$	Mean haul cost per acre from forest type *ft* to the sort yard
$HaulCst_{P,ft}$	Haul cost per acre to pulpmill from forest type *ft*
$Vol_{m,ft}$	Volume in MBF going from the sort yard to end-user mill *m* from forest type *ft*
$HandCst_{sy}$	Mean sort yard handling cost per MBF
$ProdHaulCst_{m}$	Product haul cost per MBF from the sort yard to end-user mill *m*

There is a preference for standing dead air dried trees because less exposure of the logs to snow sitting on the log. A selling feature that some log home manufacturers use is that they explain to clients that the trees were standing dead, not a live tree that has been killed. House logs could be air dried, but they tend to get blue to black stains if left lying on the gorund. Need to be up on stickers and stacked on top of each other end over end. You would want to debark the logs. Hand crafter log home manufacturers do presently buy green logs and let them dry. Benefit of green wood is that you can use close to 100% of the volume. Standing dead trees often have areas of rot.

Method to estimate net value change

Potential net change in stumpage value can be used to assess whether a sort yard could increase the residual value of forest health restoration treatments to landowners, and thus also the potential for a sort yard to expand treatable acres that are profitable to treat, relative to a traditional sort at landing. Potential net change in stumpage value can be estimated for each forest type as:

$$\Delta SV_{ft} = SYNR_{ft} - LNR_{ft}$$

If ΔSV_{ft} is greater than zero, the sort yard increases total surplus in the timber market and the investment is socio-economically sound. However, if ΔSV_{ft} is less than zero, the sort yard is a poor investment from society's perspective. We describe this as potential net change in stumpage value, because whether a net increase in stumpage prices would actually arise in the log market will depend upon the level of competition throughout the wood products supply chain and the relative negotiating skills of agents involved in transactions from the forest owner to the final milling destination. However, in assessing the socio-economic efficiency of investment in a sort yard, which party actually pockets the increase in surplus is irrelevant.

Results

Tables A and B report by forest type the harvested acres, harvest costs, harvested volume by product type, delivered prices by product type, round trip haul costs by product type and the residual value of logs when sorted at the landing and sorted at the sort yard, respectively. Harvest costs are the same in the sort at landing and sort at sort yard scenarios since the silvicultural prescriptions for each forest type is the same for the sort at landing and sort at sort yard scenarios. Delivered prices are reported for the end-user to which the logs were sold in the model. Delivered prices for pulplogs reflect the willingness of the pulpmill taking logs from the study area to pay more for logs as haul distance increases. Weighted average delivered price has been calculated by weighting the price paid for each log type in accordance with that log type's contribution to total harvested volume. Round trip haul costs in Table B are the sum of haul cost from the forest to the sort yard and haul cost from the sort yard to the end user. Weighted average harvest, haul and sort yard cost has been calculated by weighting these costs for each log type in accordance with that log type's contribution to total harvested volume.

In this case study, total harvested volumes under the sort at landing and sort at sort yard scenarios are almost identical. This is not surprising, because the pulpmill in the study area will take logs that meet their minimum length down to a top-end diameter of 2.5 inches, so total merchantable volume is unlikely to vary between the sort at landing and sort at sort yard scenarios.

Total annual residual value in the study area across all forest types with a sort at landing is estimated to be $5.431 million, compared with $6.480 million with a sort yard. Thus, the sort yard is estimated to increase the residual value of logs in Ravalli County by $1.049 million or 19.3%. However, the benefit of the sort yard varies substantially by the forest type from which logs are harvested.

Table A. Prices, costs and residual values of logging operations in Ravalli County with a two-pile sort at the landing

Item	Forest type				
	Douglas fir	Ponderosa pine	Dry mixed conifer	Lodgepole pine	Engelman spruce and alpine fir
Acres harvested per annum	2396	1413	799	860	579
Volume harvested					
Sawlog (MBF/acre)	4.55	3.47	2.84	3.92	1.58
Pulplog (MBF/acre)	0.99	1.67	6.71	2.84	3.87
Total (MBF/acre)	5.54	5.13	9.54	6.75	5.45
Delivered prices					
Sawlog ($/MBF)	375	490	490	490	490
Pulplog ($/MBF)	230	216	230	243	230
Weighted average ($/MBF)	349	401	307	386	305
Harvest and haul costs					
Harvest cost ($/MBF)	121	89	107	113	92
aul to sawmill ($/MBF)	130	93	111	123	109
Round trip haul to pulpmill ($/MBF)	70	51	69	81	67
Weighted average harvest and haul ($/MBF)	241	168	189	218	171
Residual value					
$/MBF [a]	108	233	119	168	135
$/acre [b]	600	1196	1132	1132	733
Total per annum ($ millions) [c]	1.438	1.690	0.904	0.974	0.425

Notes: a. Residual value in $/MBF is weighted average delivered price less weighted average harvest and haul cost.
b. Residual value in $/acre is residual value in $/MBF multiplied by total harvested volume in MBF/acre.
c. Total residual value per annum is residual value in $/acre multiplied by the number of acres harvested per annum.

Table B. Prices, costs and residual values of logging operations in Ravalli County when logs are sorted at a sort yard

Item	Forest type				
	Douglas fir	Ponderosa pine	Dry mixed conifer	Lodgepole pine	Engelman spruce and alpine fir
Acres harvested per annum	2396	1413	799	860	579
Volume harvested					
Standing dead houselog (MBF/acre)	0.00	0.01	0.10	0	0.03
Green houselog (MBF/acre)	1.77	0.49	2.23	0.23	0.93
Peeler log (MBF/acre)	1.01	0.28	1.38	0.00	0.00
Sawlog (MBF/acre)	0.06	3.23	1.13	1.10	0.56
Posts and poles (MBF/acre)	0.05	0.04	1.17	4.45	0.03
Stud logs mill 1 (MBF/acre)	2.00	0.57	1.27	0.09	0.37
Stud logs mill 2 (MBF/acre)	0.18	0.00	1.49	0.28	2.87
Pulplog from landing (MBF/acre)	0.25	0.23	0.51	0.43	0.30
Puplog from sort yard (MBF/acre)	0.21	0.28	0.46	0.20	0.39
Total (MBF/acre)	*5.53*	*5.13*	*9.74*	*6.78*	*5.47*
Delivered prices					
Standing dead houselog ($/MBF)	1000	1000	1000	1000	1000
Green houselog ($/MBF)	672	672	672	672	672
Peeler log ($/MBF)	530	530	530	530	530
Sawlog ($/MBF)	490	490	490	490	490
Posts and poles ($/MBF)	477	477	477	477	477
Stud logs mill 1 ($/MBF)	440	440	440	440	440
Stud logs mill 2 ($/MBF)	375	375	375	375	375
Pulplog from landing ($/MBF)	230	216	230	243	230
Puplog from sort yard ($/MBF)	202	202	202	202	202
Weighted average ($/MBF)	*486*	*453*	*465*	*435*	*404*
Harvest, haul and sort yard costs					
Harvest ($/MBF)	122	89	105	113	91
Roundtrip haul cost to sort yard ($/MBF)	50	30	49	61	46
Sort yard ($/MBF output)	76	76	76	76	76
Round trip haul to log home manufacturer ($/MBF)	24	24	24	24	24
Round trip haul to veneer manufacturer ($/MBF)	112	112	112	112	112
Round trip haul to sawmill ($/MBF)	62	62	62	62	62
Round trip haul to post and pole manufacturer ($/MBF)	33	33	33	33	33
Round trip hail to stud mill 1 ($/MBF)	112	112	112	112	112
Round trip hail to stud mill 2 ($/MBF)	80	80	80	80	80
Round trip haul to pulpmill from sort yard ($/MBF)	20	20	20	20	20
Round trip haul to pulpmill from landing ($/MBF)	70	51	69	81	67
Weighted average harvest, haul and sort costs ($/MBF)	*314*	*251*	*284*	*281*	*269*
Residual value					
$/MBF [a]	172	202	181	154	135
$/acre [b]	951	1036	1766	1043	739
Total per annum ($) [c]	2.279	1.465	1.411	0.897	0.428

Notes: a. Residual value in $/MBF is weighted average delivered price less weighted average harvest and haul cost.

b. Residual value in $/acre is residual value in $/MBF multiplied by total harvested volume in MBF/acre.
c. Total residual value per annum is residual value in $/acre multiplied by the number of acres harvested per annum.

Discussion

Comparison of Tables A and B indicates that the sort yard greatly increased the residual value of logs harvested in Douglas fir and dry mixed conifer forest types by facilitating the separation of substantial volumes of green houselogs and peeler logs, and the upgrading of pulplogs to studlogs and posts and poles. Together, these redirections of logs increased the weighted average delivered price for these forest types by more than the weighted average harvest, haul and sort yard costs increased.

There was effectively no difference in residual value of logs harvested from the Engelman spruce and alpine fir forest type between the sort yard and sort at landing scenarios. The separation of almost 1 MBF/acre of houselogs and the upgrading of pulplogs to studlogs increased the weighted average delivered price by just enough to cover the increase in   increase in Engelman spruce and alpine fir forest type can be found

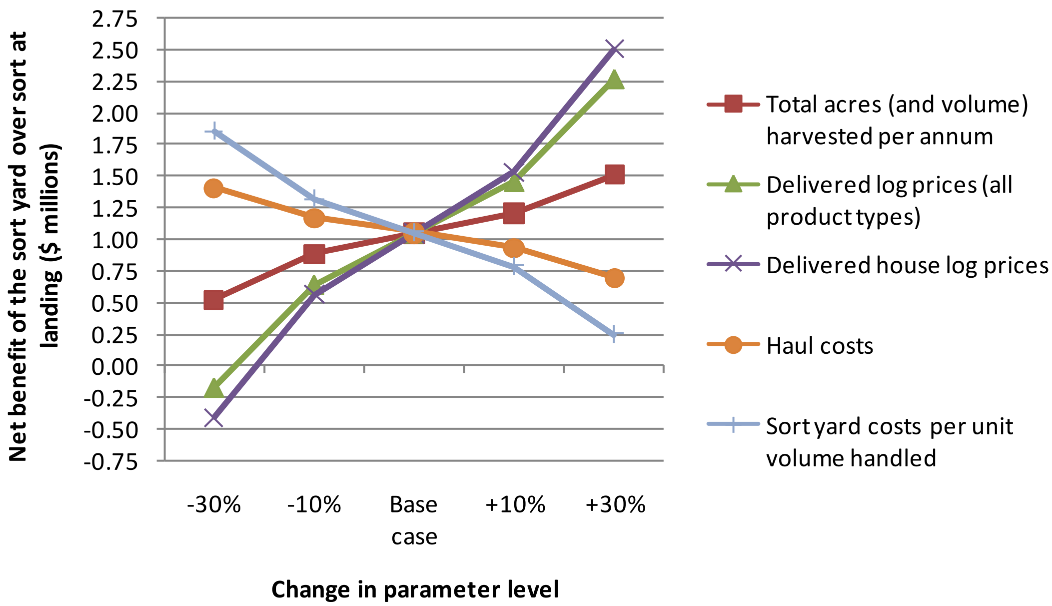
The sort yard decreased the residual value of logs harvested in ponderosa pine and lodgepole pine forests. For the ponderosa pine forest type, most logs in the sawlog pile in the sort at landing scenario were also in the sawlog pile at the sort yard. Most of the sawlog volume from the lodgepole pine forest type was upgraded to the post and pole pile at the sort yard because of a small increase in delivered value net of haul costs. In both forest types, there was a substantial volume of pulplogs upgraded to other low value log types, but little upgrade of sawlogs to houselogs and peeler logs. Overall, the increase in the weighted average delivered price in these forests types was not enough to offset the increase in the weighted average harvest, haul and sort yard costs.

These observations highlight that the potential to separate high value logs at a sort yard is a critical determinant of whether a sort can increase the residual value of forest. It is also clear that there could be a substantial payoff to sort yard operators and forest owners to assess ahead of a sale whether there is a payoff to sorting the logs at a sort yard. Given data used in this study, the residual value of logging operations in Ravalli County will be maximized by sorting logs from Douglas fir, dry mixed conifer and Engelman spruce and alpine fir forest types in a sort yard, while sorting logs from ponderosa pine and lodgepole pine forest types at the landing. This scenario has not been evaluated in this study.

Since merchantable volume in the sort at landing and sort at sort yard scenarios are virtually identical, a sort yard in Ravalli County is unlikely to reduce the level of in-woods burning of forest residue and the associated particulate matter and carbon emissions. However, the sort yard did substantially redirect volume away from the pulpwood market. The sort at landing scenario generated 14,776 MBF of pulplogs per annum, compared with 3539 MBF/year in the sort yard scenario. The redirection of logs to longer life products does constitute a carbon storage benefit.

Figure 2 summarizes the sensitivity of the net benefit of the sort yard to changes in modeling parameters. The net benefits are highly sensitive to delivered prices for all log types, but particularly to house log prices. Delivered log price reductions of less than 30% is sufficient for the residual value to be maximized by sorting at the landing rather than in a sort yard. The high sensitivity of sort yard net benefit to house log price is due to there being no offsetting reduction in delivered log prices for the sort at landing scenario, since only sawlogs and pulplogs are marketed. In contrast, when all delivered log prices change, prices change for both the sort at landing and sort at sort yard scenarios.

Figure 2. Sensitivity of the net benefit of the sort yard to changes in modeling parameters



In this case study, average haul distances (and costs) are greater in the sort yard scenario. Consequently, increases in haul costs (e.g. diesel prices) decrease the net benefits of the sort yard. However, the directing of logs to various end users to maximize residual value was performed assuming particular haul costs per mile on paved and unpaved roads, and some logs may be optimally redirected should haul costs rise or fall. Consequently, sort yard net benefits may be underestimated for reduced and increased haul costs. Given the relatively high diesel prices used in this analysis, net benefits of the sort yard appear to be robust against changing haul costs.

The sort in sort yard scenario assumed the presence of a sort yard that had been configured to handle 37,000 MBF per annum. Permanent changes in volume handled at the sort yard would be addressed by changing the configuration of the sort yard. Short-term changes, including fluctuations associated with normal business cycles, are likely to be addressed by altering levels of variable factors of production such as labor and energy, which is addressed in the sensitivity analysis of net benefits of the sort yard to change in total acres harvested (and total volume handled). Change in total acres harvested affects the net benefit of the sort yard by changing total delivered log revenue and by changing sort yard costs per unit volume. For example, a decrease in acres and volume harvested reduces total delivered log revenue for the sort yard and sort yard variable costs, but increases fixed costs (including the return on capital invested) per MBF handled at the sort yard. The overall effect is a decrease in the net benefit of the sort yard over the sort at landing scenario. However, even at a 30% reduction in volume, the sort yard still has net benefits of $0.5 million over sort at landing. Increases in acres and volume harvested improve the performance of the sort yard relative to a sort at the landing, because increases in total delivered log revenue and decreases in fixed costs per unit volume handled at the sort yard outweigh increases in variable costs at the sort yard. Thus, the sensitivity analysis suggests that net benefits of the sort yard are robust against changes in acres harvested.

There is uncertainty about optimal configuration of sort yards, which affects their costs of operation. In this case study, configuration was driven by expert opinion and a sort yard financial model, which suggested total (fixed and variable) costs of $76/MBF. Anecdotal information acquired from managers of log sort yards suggested $40/MBF might be more appropriate, although it is unclear whether this estimate covers the total costs of the operation. Net benefits of the sort yard are more sensitive to sort yard costs per unit volume handled than to haul costs or acres harvested. However, net benefits of the sort yard are robust against changes in sort yard costs.

Concluding comments

The analysis suggests the establishment of a log sort yard in Ravalli County could substantially increase the residual value of forest health restoration treatments to forest growers, improving potential financial returns from treatments and expanding treatable acres that are profitable to treat. This finding is robust against all parameters except delivered log prices. A reduction in delivered log values by 30% is enough to make the present system of sorting at the landing into two piles more attractive.

There are two notable limitations of this study that will be addressed in future work. First, the assumption adopted in this study that annual acreage treated by forest type is proportional to that forest type's presence within the treatable landscape may result in a harvest volume composition that is substantially different from the composition of harvests in recent years. Second, the sort at landing scenario assumed sawlog and pulplog piles only in all forest types. Given anecdotal information about harvesting operations in the study area, this seemed appropriate. However, upon analyzing the cut tree lists by forest type, it became clear that greater residual value from a two pile sort at the landing could have been obtained by assuming alternative pile combinations in some forest types. For example, the lodgepole pine forest type could have yielded a greater residual value with a posts and poles, and a pulplog pile at the landing. The Engelman spruce and alpine fir forest type could have yielded a greater residual value with a studlog and a pulplog pile at the landing.

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Integrating biomass recovery operations into commercial timber harvesting: the New Zealand situation.

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Abstract
In most countries biomass recovery from existing timber harvesting operations is recognised as an important component of any bio-energy program. At present, there are very few biomass recovery operations in New Zealand, despite the very large amount of residue generated by large-scale harvesting operations in plantation forests. Much of this residue is readily available post-harvest at landings, with a major concern being the contamination. Currently, residue constitutes a problem for both processing as well as the subsequent planting. A research project has commenced to help assess what an optimal residue recovery system may be. The paper considers what strategy could be employed to successfully integrate biomass recovery into NZ logging operations, with the integration of biomass recovery into the harvesting operation being key. Based on both international literature as well as extensive field visits three favourable options are established. Productivity and cost estimates are provided: with both the post-harvest residue recovery from the landing using a tub grinder, as well as using off-road trucks to transport the residues to a secondary landing for comminution estimated at 34 NZ$/ton. Whereas the post-harvest option provides for easier logistics, the concurrent recovery option will yield both greater quantity as well as quality biomass. Using a bundler to accumulate slash, and then comminute at the power plant is expected to increase the cost to 44 NZ$/ton. Finally, limitation and future research considerations are also discussed.

Introduction

In most countries biomass recovery from existing timber harvesting operations is recognised as an important component of any bio-energy program. Biomass recovery adds to the complexity of forestry operations, but also offers opportunities to increase efficiency, raise value recovery and reduce harvesting and management costs (Björheden 2000). At present, there are very few biomass recovery operations in New Zealand, despite the very large amount of residue generated by large-scale harvesting operations in plantation forests. These present a concentrated opportunity for low-cost biomass recovery.

Ninety-five percent of NZ plantation forests (Pinus radiata and Douglas Fir) are grown on a rotation that targets recovery of veneer, clear wood and or sawlogs. Potential residue recovery as a by-product is therefore very much secondary to the main harvest, which generates the largest revenue. Nearly all operations are whole-tree extraction, where trees are generally processed at the landing or eventually also at a central processing yard. Regardless of the site of processing, logging residue constitutes hindrance to harvesting and processing, as well as the subsequent restoration activities (Figure 1). Therefore biomass recovery also offers an important benefit in terms of easier operation and forest management.

Figure 1: Typical yarder landing showing the biomass discarded 'over the side'. Such biomass piles are becoming larger as the market for pulpwood decreases

A number of woody biomass studies have already been carried out in NZ to help define the problem and opportunity (i.e. Jack and Nielsen 2008; Hall and Evanson 2007; Hall et al. 2001; Kimberly and Manley 2006). The NZ government is trying to promote biomass use through targeted subsidies; for forestry mainly in the form of a 40% capital subsidy on equipment (EECA 2008). To develop a biomass recovery industry, contractors should have access to detailed operational information about machines and systems that are most cost effective.

A project has commenced at the University of Canterbury, funded by the Energy, Efficiency and Conservation Authority (EECA) that aims to determine such cost-effective biomass recovery systems through a series of intensive field studies, as well as the development of a set of Biomass Recovery Guide for Contractors.

Internationally, the biomass 'industry' is quickly developing with new machinery and new systems continually becoming available. The general goal of this paper is: 1) consider strategy options for integrating biomass recovery into forest operations; 2) to present different options for recovering the logging residue; 3) to provide a reasoned estimate of the recovery cost for each option; 4) to indicate the technical limitations of these systems; 5) to address the gaps in our knowledge of these systems, and especially the uncertainties about their transfer to NZ conditions, pointing the direction of future research on the subject.

1. Biomass Recovery Strategy

Currently, there are no product subsidies or any form of renewable energy guarantee. A biomass recovery industry cannot succeed without being integrated into the forest industry as a whole. The first step of this project was to review international literature that would help develop a strategy that may strengthen a newly developing market in NZ:

1. Combining roundwood and energy wood production optimisation: An integrated approach to full tree utilisation revenues and processing costs. At the moment we refer to biomass waste or residue, but in fact it is a commercial by-product. This allows us to consider higher efficiency value chain systems such as whole-tree chipping for lower quality trees.
2. Integration of the biomass recovery system into the harvesting operation. Tend to focus on post-harvest biomass recovery, but have not considered to volume losses associated with pushing this material off the landing, and then pulling it back on.
3. Payment (or at least evaluation) by mass and moisture content, and or energy content of product. We tend to base our evaluation on green tons, resulting in very low quality biomass being delivered. We need to focus on product value depending on end-use.
4. Differing volumes of residues depending on harvesting and landing configuration. With a number of operations now two-staging, or processing at a CPY, we need to recognise the impact on not just the changing volume, but also the raw material type. For example, at a CPY the residue is primarily in the form of short but large diameter off-cuts and bark.
5. Drying effect – quality of fuel and optimisation of transportation. Transportation of dryer biomass has clear advantages in terms of return, but dry biomass is (more) difficult to comminute, and there is also an energy loss associated with natural decomposition that are not well understood.

2. Residue recovery options

The recovery of logging residue can be carried out with a number of different systems, depending on where the residue is made available and on whether the current operation planning can be aptly modified. While large volumes of biomass are also left on the cut-over, the focus is on landing because its disposal is particularly problematic, and there is a much higher potential for cost-effective recovery.

Concerning place, this residue can be recovered at:

- the conventional landing (skid),
- a ‘superskid’, which is a processing area that services a number of smaller landings (typically called ‘pads’) to concentrate the log-making, cross-cutting, sorting and loading activities, whereby stems are often forwarded off-road by a two-stage type machine
- at a larger central processing yard (CPY), with more automated processing, whereby stems are transported by either off-road, or on-road trucks.

CPYs are still relatively rare. The sheer volume of biomass that is generated at CPYs, and their convenient location close to a mill, means that these residues are already being recovered by a permanent, or semi-permanent comminution machine on-site (Figure 2).

Figure 2: Tub grinder working at the CPY in Kawerau. This CPY processes over 500,000 m3 of wood annually

Recovery from conventional landings and super-skids is the key issue. The options available depend on whether it can be performed concurrently with the main harvesting operation, or post-harvest. Recovering logging residue post-harvest is perhaps simpler to organize, but presents important disadvantages related to the contamination of the residue and the difficulty in reaching it. Normally, operators use a skidder or a bulldozer to push the residue off the landing, or throw off-cuts off the landing with the loader. Regardless of the technique, the result is very similar: the residue gets contaminated, entangled and difficult to reach. As a consequence, the eventual recovery operation will need to include an excavator (or bulldozer?) for retrieving the residue back onto the landing. Furthermore, the entangled and dispersed residue is likely to decrease the productivity of retrieval, making it comparatively expensive. The repeated handling of the residue is likely to cause a high incidence of breakage and contamination, both of which favour the use of a sturdy tub-grinder, one of the few machines capable of comminuting contaminated short-wood.

These disadvantages can be largely avoided if the residue is salvaged as harvesting progresses, which has already been demonstrated as a more effective strategy (Grushecky et al. 2007). This requires a higher planning effort, since the main harvest operation will need to adapted and accommodate the concurrent recovery activity. As loader and dozer operators already spend much time and effort trying to get rid of the residue, perhaps a convenient trade-off could be eventually worked out. If biomass recovery is concurrent with the main harvest, different options can be explored:

1) adding a chipper to the operation and chip the residue as it reaches the landing (Westbrook et al. 2007). The chip can be blown directly into chipper vans or in roll-on roll-off containers, or it can be discharged onto the ground for later reloading;
2) move the residue to a separate collection point – possibly an older landing located nearby. Residue can be stored from multiple landings, and eventually chipped and delivered by an

industrial operation, when the storage site contains enough material to justify it, and when this material is dry enough to provide a high-quality fuel (Ranta and Rinne 2006);

3) use a truck-mounted bundler that will move between multiple active landings. It will compact and stack the accumulated residue for later collection and transport by standard log trucks to the user plant (Johansson et al. 2006, Stampfer and Kanzian, 2006). In this respect, it is important to consider the quality of the residue to be processed: most commercial bundlers may have considerable difficulty in manufacturing coherent bundles from a residue composed mainly of short wood pieces, especially if a comparably large amount of branch material is not available. In this case, it may be worth checking the performance of new "compaction box" bundler prototypes, recently appeared in Sweden (Lindroos et al. 2008).

3. Influencing factors

A number of factors will affect the feasibility and the results that can be obtained from each alternative option. In particular: the amount of biomass available at each landing, and its accumulation rate; the space available at the landing; the distance of the eventual collection point; the size and the form of the residue.

Typical productivity for NZ operations range from 200 to over 400 tons per day. Significant amounts of branch and top wood is left on the cutover as a consequence of felling and dragging breakage. However, the NZ value recovery (log-making) procedure produces larger volumes of mid-stem off-cuts. The estimated biomass to log weight ratio is about 1:10 (Hall 1994). The residue produced by the average operation would amount to about one to two truckloads per day, which is too limited for justifying the presence of a full-scale chipping operation concurrent to the harvesting operation. This restricts the choice to either a smaller stand-by chipping set up, or to concentration at a separate storage point, with or without bundling.

A survey of NZ landings showed that the average period of use varies between one and 12 weeks, with a median value of 3 weeks (Visser et al. 2009). This would correspond to the accumulation of 15-25 truckloads (about 375-625 t) of biomass per landing at the end of the harvest. Conversely, a super-skid may be in operation for 3-6 months and can accumulate over 10,000 tons of residues.

Exploring the option of stacking the residue on the landing, we can calculate the space this would take up, if properly stacked. Assuming 100 kg m^{-3} as the bulk density of loose logging residue, the 400 tonnes accumulated at a landing would represent 4,000 m^3, and organized in 3 m tall stacks (considering 3 m as the maximum height at which a loader can comfortably stack such material) would occupy a surface of 1,200 m^2. The landing survey indicates that the average landing area in excess of 4,000 m^2. Such surface could easily accommodate the biomass stack, the chipping operation and the transport vehicle, but only after the main harvest operation has been completed and the equipment relocated to a new site. Therefore, both space requirements and accumulation rate prevent the set up of an industrial chipping operation alongside the main harvest rig, whereas the utilization of old landings as biomass storage and processing sites seem feasible.

Distances between the landings in the same forest were also measured in the landing survey. As the large plantation forest mature evenly, it is not uncommon to have 3 or 4 operations working in close proximity. The distance between active and inactive sites can range between few hundredths meters and few kilometres, so that a collection point can generally be found within 2-3 km from any of the other landings – active or inactive. Hence, loose residue could be moved at a comparatively low cost, even if its low bulk density does not allow utilizing the full payload capacity of the transportation vehicles. Such short distance makes bundling redundant, unless the purpose of bundling is actually to allow storage at the original landing and direct transportation to the end user. In this case bundling could still make sense, as it would allow for using a highly efficient stationary chipper at the user plant. Bundles could be removed by standard log trucks every time a full load is ready, or they could be stored at the landing, since their bulk density is 3 to 4 times higher than that of loose residue (Spinelli and Magagnotti 2009) and therefore the 3-m stack coming from a single landing would occupy between 300 and 400 m^2. With its average gross productivity of 7 tons per hour (Kanzian 2005), a truck mounted bundler could serve 2 operations working in the same forest. Covering a third and/or fourth operation may require longer shifts. Such machines often work double shift in their Nordic countries of origin (Kärhä and Vartiamäki 2006).

Finally, the size and shape of the residue can impose significant constraints on the technology used for recovery and processing. A significant proportion of the residue accumulated at NZ landings consists of slovens and offcuts, whose large diameter may prevent the use of light chippers, thus precluding the standby chipper option. The short length of these pieces also requires that the infeed opening of any equipment used for processing them is fitted with an extended lower lip or table, and favours the use of tub-grinders. Bundling is also possible, on condition that there is enough branch and top material to build coherent packs. For this same reason, it is advisable to manufacture short bundles, with a length between 2.5 and 3 m.

Based on these considerations, we remain with three options for recovering logging residue from NZ landings, and namely:

Option I - Retrieving the residue post-harvest with an excavator, and process it with a mobile tub-grinder; transporting hog-fuel to the user plant with chip vans;

Option II - Moving the residue to a nearby collection point using a truck with a large-size bin, while the main harvest proceeds (no need for pushing the residue off the landing); chipping the residue at the collection point when enough residue has been accumulated to justify an industrial chipping operation; transporting chips to the end user with chip vans;

Option III - Bundling the residue at regular intervals as the main harvest proceeds; transporting the bundles to the user plant with standard log trucks; chipping at the plant with a stationary chipper. Again, this option is limited to those cases where residue includes a significant amount of slash, to fill up the space between log offcuts and build a coherent bundle.

4. Productivity and cost

Note: All costs are in New Zealand dollars, whereby 1 NZ$ is approximately 0.5 Euro.

It is important to try and estimate a rough landing-to-boiler cost for the different options, in order to assess their feasibility. In the absence of proper experimental data, such comparisons are not conclusive, and should rather be taken as a general indication. Such estimates should be transparent, thus enabling readers to substitute their own figures and repeat the calculations as more detailed information becomes available.

Table 1 shows the estimated machine rates for the range of equipment considered in our study. Such rates have been obtained with the method described by Miyata (1980). The basic operating cost has also been increased by 25 % to account for overheads, relocation and profit. The rates shown in the table do not include labour costs, that have been added separately, at a rate of 20 $/h for the forest machine operators and 14 $/h for the truck drivers. The resulting figures are compatible with those reported by Forme (2008), which however only provides information for the loader, but not comminution, bundling and transport machinery.

Table 1 – *Machine rates and calculation assumptions (excluding operator)*

Machine		Loader	Mobile grinder	Mobile chipper	Stationary chipper	Bundler	Truck-loader	Truck-trailer	Chipvan
Investment	$	300,000	800,000	800,000	700,000	850,000	300,000	350,000	320,000
Service life	yrs	5	5	5	7	5	5	5	5
Usage	h / yr	1750	1750	1750	2000	1750	1750	1750	1750
Fixed cost	$ yr^{-1}	64,320	171,520	171,520	124,400	182,240	64,320	75,040	68,608
Variable cost	$ / SMH	29.3	101.6	96.7	55.8	38.9	29.3	32.0	25.8
Total cost	$ / SMH	83	249	243	148	179	83	94	81
Total cost	$ / 8h	661	1996	1947	1180	1430	661	749	650

Productivity estimates are somewhat more complex, but can be obtained from relevant literature.

Concerning Option I, the operation may consist of three units: a 350 kW mobile tub-grinder and two 20-t excavators, one for retrieving the residue and the other for feeding the grinder. The productivity of such operation is limited by the grinder, and is in the range of 20 tonnes per scheduled machine hour (SMH), all delays included. Such figure is slightly lower than that presented by Hall and Evanson (2007), but is taken as a conservative estimate of long-term productivity, meant to include operational, mechanical and personnel downtime. Thus, processing the 400 t available at the average landing will take approximately 20 hours. Residue retrieval may proceed twice as fast, taking 7-8 hours per landing (Hall 1993), also because the excavator only needs to treat part of the biomass – that at and over the landing edge.

The excavator can be equipped with a second clam bucket for loading trucks. This way, the grinder can dump the hog fuel on the ground when no trucks are available, dramatically reducing the large operational delays that cripple the efficiency of roadside chipping operations (Spinelli and Visser 2009; Stampfer and Kanzian 2006). In this specific case, discharge on the ground is unlikely to increase significantly the contamination of an already contaminated fuel, and the 4%

losses indicated by Hall (2008) might be reduced when dealing with large quantities. Overall, this operation requires two operators – one on each loader.

The operator on the loader that feeds the grinder will also steer the hog through a remote control placed in the cab. The total cost of this operation is equal to 455 $/SMH, or 22.7 $/t. The hog fuel is then hauled to the plant using chip vans, with a volume capacity in the range of 90 m^3. A simple deterministic model has been developed for estimating transport productivity and cost, and is presented in Table 2. Based on this model, transport cost will amount to 11.1 $/t on the average one-way hauling distance of 40 km. For Option I, the total delivered cost will then amount to about 34 $/t (Table 3).

Table 2 – *Basic assumptions, productivity and cost of transport*

Transport option		**Hogfuel**	**Chips**	**Bundles**	**Slash**
		Basic assumptions			
Payload	t	25	27	27	8
Speed - forest road	km / h	15	15	15	15
Speed - public road	km / h	50	50	50	50
Loading	Min	50	50	40	20
Scale and unloading	Min	20	20	30	10
Delays	Min	10	10	10	5
		Productivity and cost calculation			
Turn time - 2 km	Min	-	-	-	51
Productivity	t / SMH	-	-	-	9.4
Hourly cost	$ / SMH	-	-	-	97
Unit cost	$ / t	-	-	-	10.3
Turn time - 40 km	Min	176	176	176	-
Productivity	t / SMH	8.5	9.2	9.2	-
Hourly cost	$ / SMH	95	95	108	-
Unit cost	$ / t	11.1	10.3	11.7	-

In Option II, the residue is moved to an older inactive landing using an off-road truck, equipped with large size bin and independent loader. The bin can be enlarged to a volume of 40 m^3 (2.5 x 6 x 3.2 m), which on 3-axle truck would leave just enough space for the loader. Average load, loading and unloading times, and moving speed are shown in Table 2. Assuming a one-way hauling distance of 2 km on forest road, such unit could move slightly more than 9 tons per hour, at a cost of 10.3 $/t. The material is then chipped with a powerful mobile chipper, fed by an excavator-based loader. This operation requires one worker only, since the loader operator can also steer the chipper through a remote control placed in the loader cab. Long-term chipping productivity can be estimated in the range of 25 t/SMH (Spinelli and Hartsough 2001) - slightly higher than the grinder, due to the more efficient comminuting device (Asikainen and Pulkkinen 1998). What's more, dirt-free chips will present a higher quality, possibly fetching a better price than hog fuel (Eriksson and Björheden 1989). Due to their more regular shape, chips also pack better than hogfuel and can form denser, heavier loads on the chip vans, which explains the lower transportation cost. Overall, Option II achieves almost the same financial result as option I, but offers a better product, with a potentially higher market value.

Option III is based on a truck-mounted bundler, regularly visiting active landings to pack and stack the residue. The machine is manned by one operator and can produce about 7 tonnes per hour, at a unit cost in the range of 28 $/t. The bundles are then moved directly to the user plant with a self-loading log truck, or loaded out with the regular excavator loaders used in the harvesting operation. The bundles are chipped with a stationary chipper at the plant, capable of processing about 40 t of biomass per hour (Spinelli et al. 2007). Compared to a mobile chipper, the stationary unit is more efficient and much cheaper to acquire and operate, since it does not require a carrier, runs on electric power and uses a much simpler and more durable transmission. Overall, the cost of Option III is significantly higher than that of the alternatives, due to the very high cost of bundling. This assumes that the bundler models currently on the market can handle a residue largely consisting of short, stubby elements. The future availability of new and more versatile bundling units could prove to be the simplest recovery chain to organize, requiring the addition of only one specialised unit to a conventional logging set up.

Table 3 – *Costing the three main options for the recovery of landing residue*

Operation	Option I	Option II	Option III
Moving, $ / t	-	10.3	-
Bundling, $ / t	-	-	28.4
Grinding, $ / t	22.8	-	-
Chipping, $ / t	-	13.8	-
Transporting, $ / t	11.1	10.3	11.7
Chipping, $ / t	-	-	4.2
Total	**33.9**	**34.5**	**44.4**

Superskids

The differences between a skid and a superskid is substantial, since the latter offers a larger amount of residue material, more space for accommodating processing and loading equipment, and possibly also some stationary or semi-stationary infrastructure to increase the efficiency of all operations. For example a highly efficient stationary chipper could be used for converting all residue into a higher quality and value energy co-product, turning a disposal problem into an opportunity for additional income. In this case, one can assume the same chipping cost as for Option III (stationary chipper) and the same transport cost as for Option II (chipvan), for a total delivered cost in the range of 14.5 $/t.

Once in place, the comminution line could be fed with landing residue, transported to the CPY with enlarged load space off-highway trucks, similar to those described for Option II, but with the addition of a trailer. Such units could reach a payload of 15 t, and proceed at the same 15 km/h speed as the basic truck version. Informal interviews with companies estimate the average distance between active skids and the CPY approximately 10 km. This figure has been used for calculating the turn time of an off-highway truck and trailer rig, after extending loading and unloading time proportionally to the payload increase. The resulting figure amounts to 135 minutes for a payload of 15 t. Assuming a machine rate of 100 $/SMH (operator included), the cost of delivering landing residue to the CPY is in the range of 15 $/t. Adding the 14.5 $/t previously estimated for the cost of chipping and transport to the user plant, returns a total delivered cost of 29.5 $/t, which is still very favourable.

5. Future research

Biomass residue recovery from landings is still relatively unexplored in New Zealand, and there is an urgent need for reliable information on a number of different operational aspects, including: quantity and quality of the biomass, possible markets, long-term productivity and cost of the proposed systems, and possibility for their further improvement.

Estimates presented in this paper are based either on European data, or on data obtained in NZ from comparatively short-term studies. Neither can offer an accurate prediction of long-term productivity under typical NZ conditions. It is important to validate through field trials and extended time and motion studies. In their absence it will be very difficult to develop accurate estimates of delivered costs, and to draw reliable comparisons between alternative systems.

It is also important to determine the actual amount of residue produced at typical landings, since the data available so far are based on ballpark figures - and although such methods are still acceptable and are frequently used or mentioned (Rummer 2008), they offer a very basic accuracy level.

One of the main hurdles to the development of a NZ forest energy sector is the present limited demand of wood fuel: without a market capable of absorbing significant amounts of biomass at a reasonable price, it is very unlikely that operators will develop modern and effective biomass production chains. The drivers behind the development of a forest energy sector can be many, both public and private in character (Björheden 2006), and the possible growth of bioenergy in NZ is not exclusively dependent on national policies against climate change.

Market development must proceed with product specification development, as different markets will require products with different quality. It would be important to better understand fuel quality obtained from different situations. In particular, it is important to determine the level of contamination and the moisture content of the biomass salvaged from old landings.

From a technical viewpoint, one could also explore the many variations of the main three options presented above. For instance, Option II could be made more efficient by using roll-on roll-off bins, parked at the landing and periodically recovered by a dedicated shuttle truck. This solution is likely to decrease loading time. Another example is offered by the transport of residue to CPY: in this case, the residue may consist of whole tree tops, rather than branches, slovens and offcuts. Whole tree tops could be transported with standard log trucks, and could be loaded, unloaded and chipped more efficiently. In this case, one may even explore the profitability of separating different product streams from the same tops, such as pallet logs, pulpwood, pulp chips and fuel biomass.

This report has only considered the recovery of residue accumulated at landings, excluding the cutover residue that is particularly abundant especially after a ground-based operation. The management of this residue is also expensive, since the slash is often windrowed with an excavator before establishing a new crop. Thinning operations offer a further opportunity for fibre recovery. At present, radiata plantations are generally thinned to waste. The size of cut trees is large enough to make recovery feasible.

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Finding the 'Sweet-Spot' of Mechanised Felling Machines.

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Abstract

Understanding how stand and terrain parameters impact the productivity of harvesting machines is important for determining their optimum use. Productivity studies in forest operations are often carried out on new equipment, or on equipment being used in new conditions. Such information is normally presented as a productivity or efficiency function; that is, a regression equation that best represents the data. Most studies establish that piece size is the dominant predictor that impacts overall productivity. A common concept, know as the 'piece-size law', is that productivity increases at a decreasing rate with increasing piece size. What is not well understood is the upper limit to this piece-size law. That is, as the trees get 'too' large, the machine starts to struggle and we can expect a decrease in productivity. Four different mechanised felling machines were studied in New Zealand radiata pine plantations. Using more complex non-linear equations it was possible to identify an 'optimum' piece-size for maximum productivity, whereby this 'sweet-spot' piece size for all machines is considerably smaller than their maximum. Unexpectedly, productivity tended to decrease gradually, not drop off suddenly beyond the optimum. Using more complex statistical functions when correlating piece size to productivity will help identifying the 'sweet-spot'.

Introduction

In forestry, harvesting machine productivity is impacted by stand and terrain variables. Understanding these impacts is important for determining their optimum use. Therefore, productivity studies in forest operations are often carried out on new equipment, or on equipment being used in different conditions. The empirical models derived from such studies can be used for many purposes, including wood-flow planning, predicting machine or system productivity (Holtzscher and Langford 1997; Spinelli et al. 2009), and costing models (Adebayo et al, 2007; Bolding et al, 2007). However, at a more fundamental level it allows us to understand the behaviour of harvesting machines and/or systems under varying stand and terrain conditions.

A large number of variables can impact harvest machine productivity. We can attempt to group them as stand and terrain variables. Typical stand variables include piece size (e.g. Evanson and McConchie 1996; Wang and Haarla 2002; Visser and Stampfer 2003; Nurminen et al. 2006), stocking density and or thinning intensity (Eliasson 1999), type of cut and total volume (Suadicani and Fjeld 2001). However, for specific studies, variables such as tree form (Evanson and McConchie 1996), branch size (Glode 1999), pruned status, selection criteria of trees to harvest (Eliasson and Lageson 1999) and/or degree of wind-throw can also significantly influence productivity. There are also stand parameters that interact with the harvest system, including the felling pattern and number of logs to extract. Typical terrain variables include slope, extraction distance, trafficability, and terrain roughness. Again, there are parameters that interact with the harvest system, include rutting, as well as the layout of skid trails and landings. Although slope can readily be measured either onsite or from maps, the impact of slope is very much dependant on the harvest system. While, in general, increasing slope decreases productivity for ground-based systems, a certain level of slope is desirable for cable yarding systems, but then again only if that slope if concave! While most parameters have a ratio scale, variables such as terrain roughness require a nominal scale using categories, or composite variables such as percent deflection for slope with cable yarding systems.

The impact of stand and terrain variables can also be significantly affected by the human operator. Operator performance can result in a 20-50% variation in machine productivity (Bergstrand 1987; Murphy and Vanderberg 2007). To overcome such variation, productivity models should be based on large samples (Nurminen et al. 2006). For operator variation alone, Bergstrand (1987) suggested that to achieve a confidence level of 95% approximately 400 operators would have to be included in the study. Machine productivity determined in short-term time studies is typically also higher than found in follow-up longer-term studies (Siren and Aaltio 2003). Kuitto (et al. 1994) suggested using common coefficients from combined studies, and such coefficients based on combined series of studies are already available for specific time study elements, such as delays (Spinelli and Visser 2008).

We often simplify the problem associated with the over-abundance of predictive variables in our harvesting studies by selecting the dominant factors to measure in the study, and then again when evaluating the data by assuming basic relationships to the response variable. For example, the impact of extraction distance on productivity is easily understood – and the relationship is mono-directional. That is, the longer the average extraction distance the lower the productivity. However, some variables are clearly not mono-directional.

Most studies establish that piece size is the dominant variable that impacts overall productivity. A common concept, know as the ‘piece-size law’, is that productivity increases at a decreasing rate with increasing piece size (Figure 1). Some papers use a linear (Nakagawa et al. 2007, Sirén and Aaltio 2003), or even a quadratic (Nurminen et al. 2006, Karha et al 2004) relationship with piece size. Most common is a power function, whereby in a range of applied machine studies a power factor of approximately 0.6 describes the productivity to piece size relationship very well (e.g. Jirousek et al, 2007). Because of the mono-directional nature of these functions, when used for productivity prediction the ‘optimum’ productivity is always at the maximum piece size.

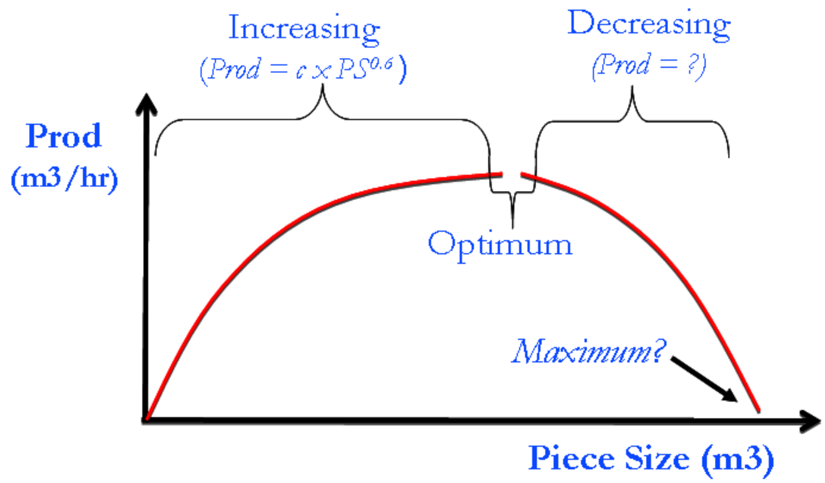

Figure 1: Graph showing the basic relationship between piece size and productivity. The graph has three phases: the 'increasing' phase reflecting the 'Piece-Size Law', the optimum or sweet-spot phase, and a decreasing phase beyond the optimum.

The raw data of some published studies exhibits a tendency to decrease at the upper limit. This simply means that the increase in time is greater than the increase in piece size. This effect is masked when assuming mono-directional relationships. If this is common, we should be using more complex non-linear functions to evaluate the effect of piece size in our productivity studies. This would not only increase the accuracy of the model, but it would also help us define an optimum that is not necessarily at the maximum piece size.

To improve our understanding of the piece size to productivity relationship, especially in the optimum and decreasing phases, this study focuses on studying a series of machines working with a relatively large piece size. For this purpose, we have chosen to focus on mechanised harvesters working in forest stands with above average-sized trees.

Methodology

Four mechanized felling, and/or felling and processing, operations were chosen to study the effect of piece size on productivity. Mechanised felling is used where possible in New Zealand as it increases productivity and cost effectiveness, but can also reduce the occurrence of stem breakage and increase personal safety (McConchie and Evanson, 1995). The machines studied were all harvester heads attached to an excavator base.

All studies were conducted on clearfell operations in New Zealand radiata pine plantations. The study included operations using the following harvester heads on excavator bases:

1. Waratah 622 in Bottlelake Forest (Figure 2) – flat terrain with sandy soils
2. Waratah 624 in Lowmount Forest – rolling terrain with silty sandy soils
3. Satco 630 in Ashley Forest – rolling to steep terrain
4. Woodsman in Tarawera Forest – rolling terrain with volcanic ash soils

The first three study sites are in the Canterbury region of the South Island, the last is in the Bay of Plenty region of the North Island.

Figure 2: The Waratah 622 harvesting head in Bottlelake Forest.

A classic time and motion study was conducted at each site. The work tasks used for the study are shown in Table 1.

Table 1: Work task definitions for the mechanised harvester study

Work task	**Description**
Fell	Felling and bringing the tree to the ground
Delimb	Delimbing the whole tree
Bunch	Pre-bunching stems for extraction
Move	Repositioning between trees or rows
Clearing	Moving slash and or tops for either moving or felling
Delays	All operational and mechanical delays

In a suitable section of the stand, working ahead of the harvester, the DBH of each tree was measured and recorded, and the trees either flagged (Figure 3) with tape or painted. The Satco head is just a felling head and so did not complete the delimbing work task. The felling and delimbing work tasks were combined for the Waratah and Woodsman heads, as operator typically commences delimbing before the tree has hit the ground.

Figure 3: Waratah 622 with pine clearfell in Bottlelake Forest. Note that all trees are marked with unique colour-bands prior to felling.

Post-felling, approximately 20 trees were scaled by measuring diameter at 5 meter intervals along the stem, as well as a top length and diameter. A simple tapered cylindrical volume equation was used to arrive at the volume of each segment, and summed to arrive at a close approximation of the volume of the tree. A simple exponential regression was used to correlate DBH to tree volume.

Productivity information (m^3/PMH) was calculated based on the time it took the processing head to fell and process different piece sizes. Note that the productivity information shown in this study is for productive machine hours (PMH) only, and only includes the felling and delimbing phase. Combining all four studies, approximately 40% of the time was felling and delimbing, the remaining 60% with bunching, clearing, moving or in some type of a delay.

Results

The Woodsman (piece size range 0.7 to 3 m^3 – Figure 4) and the Satco head studied in Ashley Forest (piece size range 1 to 5.3 m^3) are typical of many productivity studies, in that the sweet spot is not obvious. The data collection, through lack of large enough trees, did not extend far enough beyond the optimum.

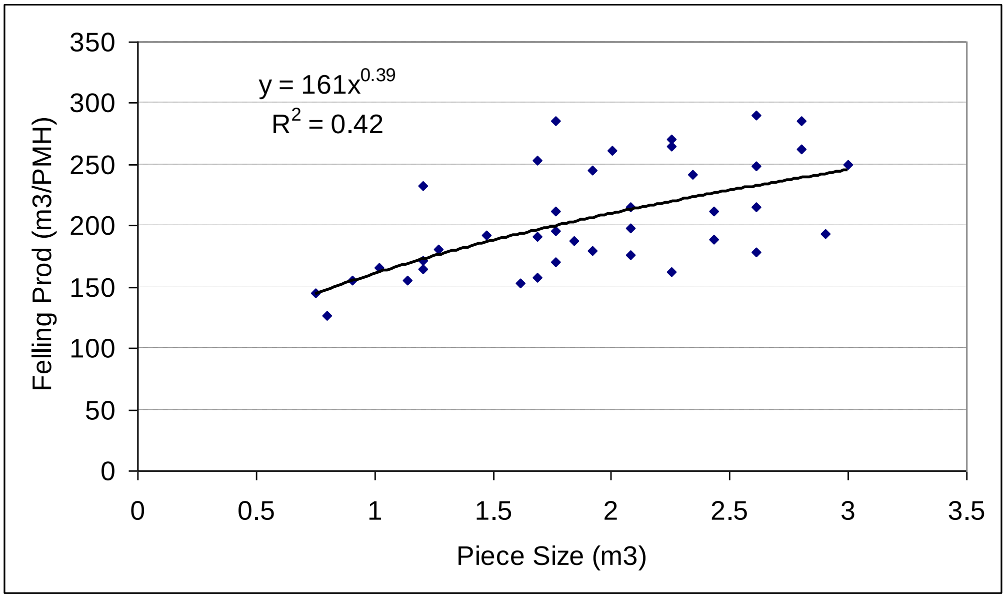

Figure 4: Woodman harvester head productivity (felling and delimbing only) and pieces size (m3)

The most common productivity type function to use for evaluating the effect of piece size appears to be a power function, in the form of

$$\text{Productivity (m3/hr)} = a\ PS^{b}$$

Where PS is the piece size, and both a and b are coefficients determined by the regression analyses. For the above example (Figure 4) the regression yields:

$$\text{Prod} = 161 \times PS^{0.39} \qquad (r^2 = 0.42)$$

It appears to provide an adequate relationship between Piece Size and Productivity – although only explaining only 42% of the variation. Note that it is also possible to work with efficiency as the response variable, whereby;

$$\text{Efficiency (min / m3)} = e^{-a\ PS},$$

The problem of the mono-directional relationship remains the same.

In two of the studies we did succeed in collecting enough data to clearly show the declining productivity phase. For example, the Waratah 624 (felling and delimbing) data is shown in Figure 5.

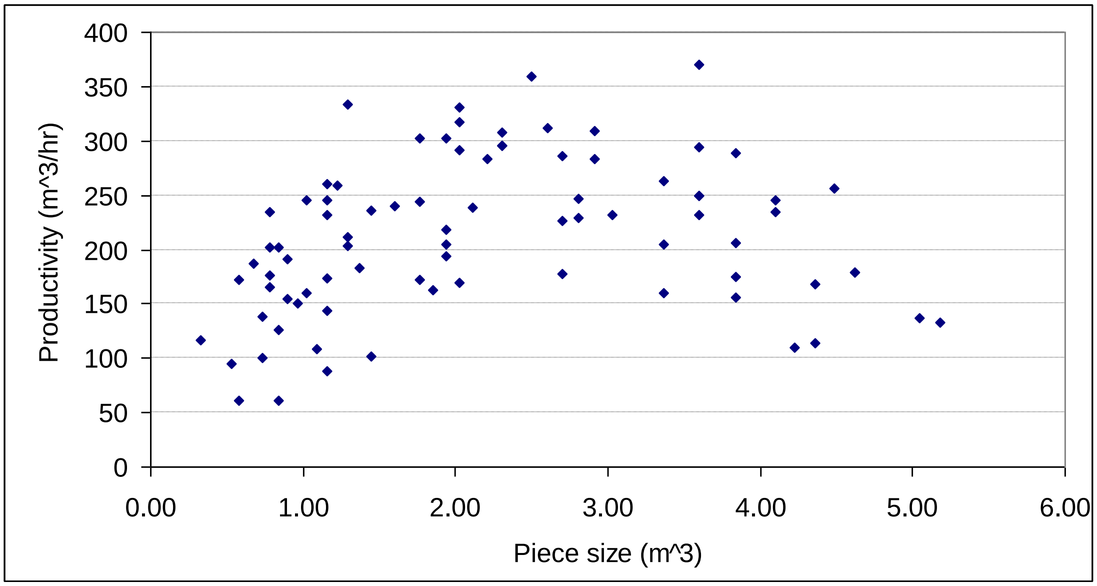

Figure 5: Productivity (felling and delimbing only) vs. Piece Size for Waratah 624 harvesting head in Lowmount Forest.

The declining phase can be attributed to a number of factors. While technically the bar is longer than the DBH, operator experience indicates that the bar is likely to pinch, or jam, with larger diameters. They therefore use a back-cut, move the head around the base of the tree, and then complete the cut. Extra time is also required for delimbing the larger branches, as well as for manipulating a heavy stem.

The shape of the data set for the smaller Waratah 622 study in Bottlelake forest was similar. The trees sampled ranged in piece size from 0.3 to 3.8 m^3, whereas in the 624 study it ranged from 0.3 up to 5.2 m^3. We note that it would be unreasonable to attempt to fit a mono-directional function to the Waratah data sets. It is possible to use a quadratic function to the data:

$$\mathrm{Prod} = a \times PS + b \times PS^2$$

A quadratic function assumes that the decreasing phase is identical to the increasing phase, and that the optimum is exactly in the middle. Quadratic functions are rarely preferred in statistics. For this data set it yields the equation:

$$\mathrm{Prod} = 200 \text{ x } \mathrm{PS} + 35.9 \mathrm{\ PS}^2$$

The optimum (sweet-spot) for the Waratah 622 was 2.2 m^3, whereas the Waratah 624 was 2.8 m^3. The specification sheets for these two machines indicate a maximum delimbing diameter of 65 and 76 cm respectively. For these studies the sweet spot was with 48 and 55 cm DBH trees respectively. Figure 5 indicates that as the piece size approaches 6 m^3 the productivity will drop to zero, whereby this was just 4m3 for the Waratah 622. This matches up well with the published maximum diameter as specified by the manufacturer.

The increasing phase of the productivity curve was almost identical for the two different Waratah head sizes. This is consistent with Iwaoka et al. (1999) and Ovaskainen et al. (2004) who suggest that lighter harvesters can operate at approximately the same productivity of medium size machines. When considering the higher operating costs of larger harvester heads, then smaller harvester heads are more cost effective in smaller piece size (Jirousek et al, 2007).

A more complex non-linear equation can be used that provides an opportunity to identify an optimum, as well as allowing different shapes for the increasing and decreasing phases of the productivity relationship. Two functions, each using just two coefficients, were preferred;

$$\Pr od = \frac{PS}{a + b \times PS^2}$$

$$\Pr od = a \times PS \times e^{b \times PS}$$

The behaviour of these two functions is very similar. Allowing the program R (software) to run an iterative optimising algorithm it yields:

$$\Pr od = \frac{PS}{0.0048 + 0.00058 \times PS^2}$$

$$\Pr od = 289.6 \times PS \times e^{-0.418 \times PS}$$

These equations were adequate for re-evaluating the first two data sets, and it did find an optimum that was not the maximum piece size. It was noted that neither of these functions was able to bring the declining phase down quickly enough to match the data for the Waratahs. The latter equation was modified with an additional co-efficient, c.

$$\Pr od = a \times PS \times e^{b \times PS^c}$$

Again using R, the iteration yielded a= 203.2, b=0.136 and c=1.655. Figure 6 plots the quadratic, as well as both the two and three coefficient exponential functions over the Waratah 624 data set. The 3–coefficient exponential function is the best fit with the lowest residual.

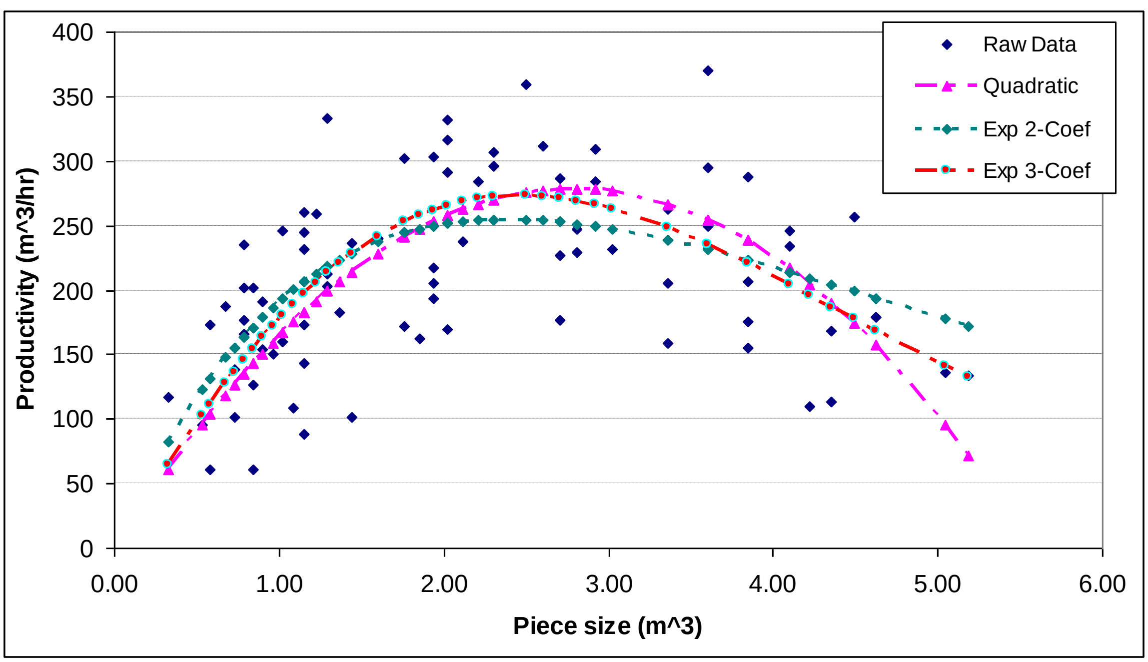

Figure 6. Graph showing the Waratah 624 productivity data, as well as the quadratic and two exponential regression approximations.

Conclusion

Time studies are a great tool in forest engineering to understand the impacts the many stand and terrain variables can have on machine and harvest system productivity. While many variables exhibit a mono-directional relationship with productivity, this study has shown that piece size does not. Logically, there should be an optimum piece size where productivity is greatest that is not automatically the maximum piece size. For future studies consideration should be given to using a more complex function when relating piece size to productivity.

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Masticators for fuel reduction treatment: equipment options, effectiveness, costs, and environmental impacts.

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Abstract
As a tool to reduce fire hazards, mastication changes the structure and size of fuels by shredding standing small trees and downed woody materials and leaves a mat of shredded wood on the soil surface. Here, we reviewed the literature and report on interviews with forest professionals to synthesize the existing information on mastication equipment options and costs for various fuel types and work conditions as well as environmental impacts from mastication treatments. There are two basic types of masticators commonly used that are distinguished by their masticating heads (rotary head or horizontal drum) that are further differentiated by their base machines (integrated or boom-mounted). The rotary head masticator requires low horsepower and energy consumption while the horizontal drum masticator effectively cuts fuels closely to the surface. The costs of running these machines are highly variable, ranging from \$100 to 1395 per acre, and are dependent on slope, residual tree density, fuel type and amount, and operator experience. The environmental impacts of mastication are relatively low. Nutrients remain on site and soil compaction is minimal. Sedimentation insignificantly or only slightly increased after mastication due to the thick layer of mulched wood. Mastication is a viable alternative for fire hazard reduction when the treatment area cannot be burned, mechanical removal of excessive fuels is cost prohibitive, or impacts on soil and sedimentation are of concern.

Introduction

Mastication is a desirable fuels treatment method when there are concerns about stand fire resistance, smoke, public property or safety (Berry and Hesseln 2004). Thinning becomes a less favorable fuel treatment alternative when either soils are too sensitive or available forest products markets don't exist. Mastication reduces fire hazard by changing the fuel orientation and size through grinding and shredding shrubs, standing small trees, and downed woody material (called activity fuels hereafter), leaving a mat of shredded wood on the soil surface (USDA Forest Service 2004). Mastication is often more costly than prescribed burning, and mechanical fuel reduction thinning operations may be less costly than mastication if the harvested wood can be sold to offset the cost of the operation (Rummer et al. 2003). Mastication changes the fuel; it does not remove it (Jain et al. 2007). Negative impacts on soils and residual trees may occur and vary based on equipment choices, intensity, and introduction of fire (Windell and Bradshaw 2000). It is difficult to predict burn intensities in masticated areas using fire modeling programs such as Behave Plus and FOFEM (Glitzenstein et al. 2006, Knapp et al. 2006, Kreye 2008).

The objectives of this paper are to synthesize published literature and report on interviews with forest professionals. This synthesis examines mastication equipment options and costs for various fuel types and work conditions as well as effectiveness and an overview of the environmental impacts from mastication treatments.

Equipment Options

Mastication machines are equipped with two major forms of masticating heads: rotary (vertical shaft) and horizontal drum (horizontal shaft). Ryans and Cormier (1994) and Windell and Bradshaw (2000) refer to the masticating heads as either vertical shaft or horizontal shaft. Halbrook et al. (2006), Moghaddas and Stephens (2008) and Kane et al. (2009) did not use the same terms to describe the masticating head but instead refer to vertical shaft and horizontal shaft as rotary and horizontal drum, respectively.

Masticating Heads

The names of masticating heads (attachments) imply their physical appearance (Table 1). The vertical shaft, or rotary disc (further referred to as rotary), masticator can be either a boom-mounted attachment or an integrated attachment (USDA Forest Service 2004). What distinguishes a masticator as rotary is a vertical drive shaft that is attached to a bar or disk; this bar or disk contains the cutting apparatus which can be fixed or free-swinging teeth or blades (Fig 1). The horizontal shaft (further referred to as horizontal drum), can also be either boom-mounted or integrated. The drive shaft, which is often horizontally oriented, contains several rows of the cutting apparatus (Fig 2). Both types of masticating heads have their own advantages and disadvantages as (Table 1.)

Table 1. List of characteristics, descriptions, advantages and disadvantages for the two types of masticator, differentiated by the type of masticating head (Mckenzie and Makel 1991, Ryans and Cormier 1994, Windell and Bradshaw 2000, Coulter et al. 2002, USDA Forest Service 2004, Hammatt 2009).

	Rotary head	Horizontal drum

Base machines	Wheeled or tracked
	Two types
	• Integrated
	  ○ Purpose built carrier
	• Boom-mounted
	  ○ Excavator, feller-buncher, harvester, backhoe
		Wheeled or tracked
		Two types
		• Integrated
		  ○ Purpose built carrier, front end loader, drive-to-tree feller-buncher, skid steer
		• Boom-mounted
		  ○ Excavator, feller-buncher, harvester, backhoe

Horsepower requirements	Lower horsepower requirements	Higher horsepower requirements
Head/ cutting devices	Vertical drive shaft • Disk or bar with attached cutting devices • Cutting devices may either be fixed teeth or free swinging knives	Horizontal drive shaft • Cutting devices attached to horizontal shaft or “drum” • Cutting devices may either be fixed or free swinging teeth (hammers) or free swinging knives
Fuel type best suited to treat	Standing stems are treated with greater productivity and at lower costs than horizontal drum type	Activity fuels are more easily treated as this masticator type cuts closer to the ground and provides more of a mulching action
Operational advantages	• High kinetic blade energy ○ Cuts even when dull • Low energy consumption per ton of mulch	• Good operator visibility • Large bearing surface resulting in less wear • Cuts close to ground
Operational disadvantages	• Low blade life • Leaves high stumps • Poor operator visibility	• Low kinetic blade energy ○ Cuts poorly with dull blades • Blades are difficult to change

Figure 1. Rotary head masticator (boom mounted)

Figure 2. Horizontal drum masticators: boom mounted (left) and integrated (right).

<u>Base Machines</u>

There are two basic divisions between the base machines based on how the masticator is attached to the machine. The first carrier type encompasses integrated machines, where the attachment is either part of the design of the machine or attached to the front end of the machine. The second type is the boom-mounted carrier, where the attachment is located at the end of a hydraulic boom.

There are operational advantages associated with the different base machines. The boom mounted masticator allows treatment where the machines cannot traverse such as deep ditches and steep embankments using a long boom (Ryans and Cormier 1994). Tracked machines are often used to work on steeper slopes and on soils with a low weight bearing capacity. The wheeled machines are generally faster and less expensive to operate (Windell and Bradshaw 2000, Coulter et al. 2002, USDA Forest Service 2004).

There are restrictions and limitations associated with combining each of the masticating heads with prospective base machines. The base machine must be compatible with the masticating attachment; some masticating heads are unable to be paired with certain base machines. Many masticating head/base machine combinations are listed in both Windell and Bradshaw (2000) and Ryans and Cormier (1994). Hydraulic attachment hardware and lack of sufficient hydraulic pressure often limit base machine/ masticating head combinations. Addition of a hydraulic system powered by a small diesel engine can remedy this problem (Ryans and Cormier 1994, Coulter et al. 2002, Halbrook et al. 2006, Benson 2009).

Effectiveness

Masticators chunk, shred, grind, break, or in other ways reduce the size and character of standing and down material (Jain et al. 2007), and thus alter the size, distribution, and depth of fuels, affecting fire behavior (Weatherhead 1977, Rothermel 1983, Kane et al. 2006). Mastication may increase surface fire hazard for 2 to 3 years as the small fuels that are produced are easily ignited because of their large surface area-to-volume ratio (Weatherhead 1977, Kane et al. 2006, Jain et al. 2007, Hartsough et al. 2008). Despite this, mastication reduces the hazard of catastrophic fire and potential for canopy ignition by raising canopy base height, increasing resiliency to fire, and may reduce flame height and fireline intensity (Coulter et al. 2002, Glitzenstein et al. 2006, Kreye 2008).

The longevity of a fuels treatment is an important factor to consider, especially with respect to economic constraints. Anecdotally, forest professionals estimate the longevity of mastication treatment to be anywhere from five to ten years. Fire modeling programs such as HA (Hough and Albini 1978) predict a rapid return to hazardous fire conditions following mastication but programs such as these are limited in their predictive abilities in masticated areas (Glitzenstein et al. 2006).

The effectiveness of mastication treatment is highly influenced by the equipment used. Rotary cutting heads, especially integrated attachments, are less likely to shred severed stems that can fall over after being cut only once (Ryans and Cormier 1994). Masticators that use knives are better suited to treating small diameter materials (<3 inches) and those that use fixed teeth are better suited to treating material greater than six inches in diameter (Coulter et al. 2002). Anecdotally, we have observed that the intensity of mastication affects resprouting and fuelbed depth, both factors that increase treatment efficacy and longevity.

Costs

<u>Masticator costs</u>

Mastication can be considered when other treatments' restrictions and limitations are prohibitive. Mastication is often more expensive than prescribed burning and results in higher costs than a fuel reduction thinning operation that produces forest products to offset the cost of the operation (Rummer et al. 2003). Treatment costs for masticators are highly variable, ranging from $100 to 1395 /ac (Weatherhead 1977, Coulter et al. 2002, Rummer et al. 2003, Fight and Barbour 2005, Halbrook et al. 2006, Burgess 2009, Forest Service 2009, Hammatt 2009, Herold 2009, Schatz 2009; Table 2).

Table 2. Summary of maximum and minimum cost per acre with associated machine types and references.

Machine Type[1]	Cost ($/ac) Maximum	Cost ($/ac) Minimum	Citation
Rotary			
Boom-mounted	862	431	Coulter et al. 2002
Boom-mounted	550	330	Coulter et al. 2002
Boom-mounted	805	403	Coulter et al. 2002
Boom-mounted	583	547	Coulter et al. 2002
Boom-mounted	1395	335	Halbrook et al. 2006[3]
Horizontal Drum	659	440	Coulter et al. 2002
Boom-mounted Integrated	868	479	Coulter et al. 2002
Unknown[2]	1000	100	Rummer et al. 2003
Unknown	506	506	Fight and Barbour 2005[3]

[1] Masticating heads are either mounted on a boom or "integrated," meaning attached to the front of the machine.

[2] "Unknown" represents cost data where information on masticator type was not included.

[3] Fuel loading was reported in two papers (Rummer et al. 2005, Halbrook et al. 2006) ranging from 20 to 61 ton/ac.

Variables affecting cost

Important variables that appear to affect the cost of treatment include slope, residual tree density, diameter of the material to be treated, fuel loading and operator experience. Steeper slopes and greater residual tree density increase the treatment cost (Coulter et al. 2002, USDA Forest Service 2004, Halbrook et al. 2006). Increased time required to treat larger diameter materials yields decreased production and therefore higher costs (Fig. 3). If the fuels being treated are incompatible with the machine, the result will be higher treatment costs due to low treatment productivity (Table 1). Fight and Barbour (2005) found that for mechanical treatments, the cost of treatment increased by 1% for every additional ton per acre of fuel loading. Though costly, masticators can be used when prescribed fire and thinning are less desirable choices due to environmental and operational constraints.

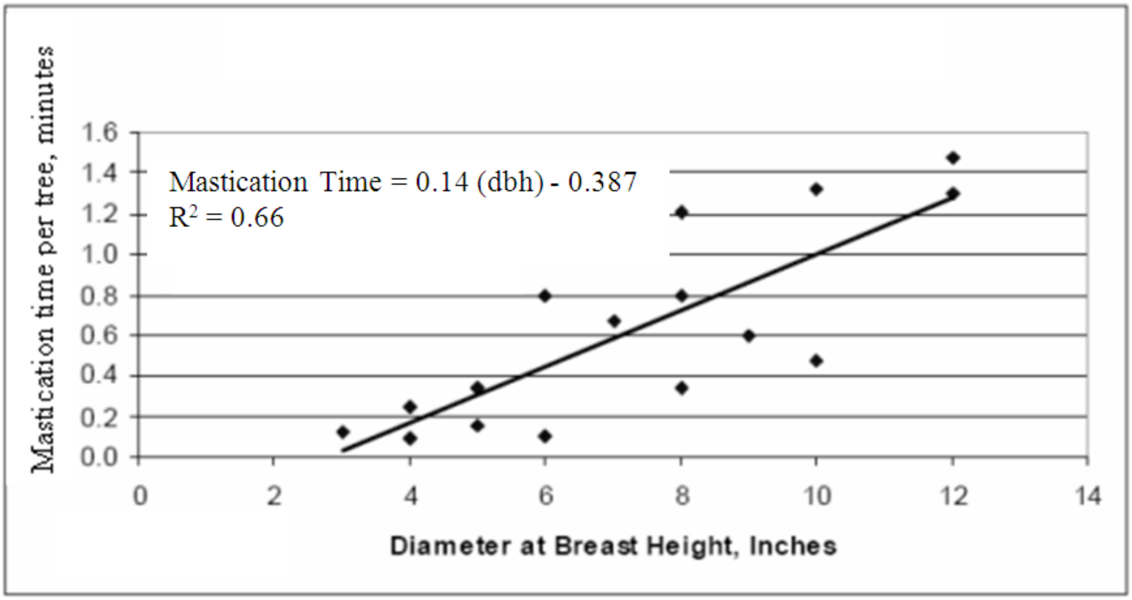

Figure 3. Increased time is required to masticate larger diameter material yields decreased production and higher cost. These data represent mastication times for a boom mounted rotary head masticator (adapted from Coulter et al. 2002).

Environmental Impacts

Mastication is a viable fuel hazard treatment option in environmentally sensitive areas because masticators cause minimal environmental impacts (Coulter et al. 2002, Hatchett et al. 2006, Kane 2007). This machine is a viable option where soil disturbance, smoke and the wildland-urban interface are a high priority (Coulter et al. 2002, USDA Forest Service 2004, Halbrook et al. 2006). The environmental impacts that are potentially resulting from mastication treatments have been placed into three categories: sedimentation, soil damage and stand damage.

In the published literature, erosion resulting from mastication treatment has been shown to be slight to insignificant (Hatchett et al. 2006, Burgess 2009). Hatchett et al. (2006) observed no runoff in masticated sites in the Sierra Nevada under normal rainfall rate (2.9 inches per hour). The tracks from the machine pass are covered in a layer of woody mulch, reducing bare soil exposure and erosion (Hatchett et al. 2006, Moghaddas and Stephens 2008). Levels of soil disturbance will vary and are associated with operator experience and the selected steering path (Hatchett et al. 2006).

Soils are sensitive to heavy equipment operations and removal of woody biomass from the site (Han et al. 2006). Mastication retains biomass in the forest, thus site nutrients are conserved (Jain et al. 2007). Soil compaction is a crucial management indicator for forest site productivity and should be considered when evaluating mechanical forest treatments (Poff 1996, Powers 1999, De Vos 2005). Mastication has been shown to have little effect on soil bulk density in dry summer conditions (Moghaddas and Stephens 2008, Burgess 2009). In a study conducted in the Sierra Nevada, Moghaddas and Stephens (2008) found no significant difference in soil bulk density between areas of machine travel and the control. Low compaction caused by masticators is partly due to the relatively light ground pressures of these machines (1.9-

10psi; Windell and Bradshaw 2000, Halbrook 2006, Burgess 2009). Additionally, the masticator only passes once over any given area walking on a mat of mulch thereby buffering compaction (Han et al. 2006, Jain et al. 2007, Moghaddas and Stephens 2008 Hammatt 2009, Burgess 2009).

Stand damage may occur from direct machine impacts or tree mortality following treatment wounding. Mechanical damage to trees resulting from mastication depends on the machine operator's skill, but anecdotal evidence suggests that stem damage is minor (Burgess 2009, Forest Service 2009, Hammatt 2009, Herold 2009, Schatz 2009). Burning light fuelbeds (<3 inches) deep will not lead to increased residual tree mortality, but burning heavy fuelbeds resulting from mastication is known to cause substantial tree mortality (Knapp et al. 2004, Busse et al. 2005, Bradley et al. 2006, Kobziar and Stephens 2006, Hartsough et al. 2008, Burgess 2009, Gibson 2009, Forest Service 2009).

Conclusion

This study synthesizes published literature and forest professional interviews regarding various aspects of masticators used for fuel hazard reduction. The available equipment options, effectiveness, costs and associated environmental impacts have been aggregated to aid land managers considering the use of masticators for fuel hazard reduction. Mastication is an alternative for fire hazard reduction when the treatment area cannot be burned, mechanical fuels removal is cost prohibitive, or impacts on soil or sedimentation are of concern.

Many types of masticators, operating at various costs, are available to effectively lower the hazard of crown fire. Whereas rotary head masticators are capable of treating standing stems with greater productivity and at lower costs, the horizontal drum type treats activity fuels more easily as it provides more of a mulching action and cuts closer to the soil surface. Mastication costs vary and are inflated with increased slope, fuel loading, residual tree density and diameter of treated materials. Mastication tends to be a costly treatment method but is effective at reducing the hazard of crown fire for five to ten years.

Mastication is a viable option where concerns about sedimentation, soil compaction and residual stand damage constrain fuel treatment methods. The resulting mat of mulched wood substantially reduces sedimentation and compaction in masticated sites. No nutrient depletion occurs from mastication as no biomass is removed from the forest. Mechanical damage to residual trees is minimal and mortality due to the introduction of fire varies upon mulch depth. Mastication may see increased use in the future to reduce fire hazard, especially on the growing wildland-urban interface where many concerns are present at once.

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Effects of Soil Compaction on Individual Tree Growth in the Central Appalachian Hardwood Forest Region

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Abstract

A field study to measure impacts of ground-based skidding traffic soil compaction on residual tree growth was carried out on a 20-acre tract of the West Virginia University Research Forest located in central Appalachia. Skid trails were laid out in 170' – 200' sections, which allowed for one 50'treatment and two 50' replications of each treatment over the total skid trail. Treatments were arranged in a 3x3 factorial with three payload sizes of unloaded, half capacity, and full capacity and the number of loaded machine passes set at 1, 3, and 5. Three skid trails underwent no skidding activity in order to serve as control treatments. Measurements included soil type, pre-treatment and post-treatment soil bulk density and soil moisture, understory vegetation, and site slope and aspect. Merchantable hardwood trees within a 30-foot range of the centerline were randomly selected and measured for DBH, total height, merchantable height, grade, crown size, and growth rate. The comparison of initial and subsequent tree and soil measurements will be used to examine residual tree growth and soil compaction recovery. Initial measurements were taken in 2005, while post-treatment measurements were taken during the same time period in 2007. Bulk density decreased on sections with one pass (.27 pcf), sections with two passes (.16 pcf), and sections with three passes (3.79 pcf) from 2005 to 2007. Moisture content increased from 2005 to 2007 on all the trails ranging from .46% to 3.14%. Also, total height and merchantable height increased an average of 4 and 2 feet, respectively. Sample plots were also taken in the skid trails for regeneration. The amount of greenbrier and huckleberry decreased, but some hardwood species increased in numbers. Diameter growth averaged .13 inches between the summer of 2005 and 2007.

Introduction

Soil compaction due to timber harvesting has been studied for more than 50 years in most regions of the country (Foil and Ralston 1967; Lull 1959; Mace 1970; Steinbrenner and Gessel 1955; Weaver and Jamison 1950; and Kuennen et al. 1979). Best management practices (BMPs) compliance and effectiveness have become the focus of many soil compaction studies due to the effects of timber harvesting as a silvilcultural activity on erosion and sedimentation (Kochenderfer et al. 1997, Briggs et al. 1998, Egan et al. 1998). These BMPs can be altered in order to address new technology and reduce impacts on timber harvest sites. All harvesting operations cause some compaction, but the degree of compaction varies with harvesting equipment, techniques, intensity, and soil properties, especially moisture content and texture (Reisinger et al. 1988, Reisinger and Aust 1990, Aust 1994). Previous studies compared the area disturbed by conventional logging with a tractor or skidder to a skyline system. A skyline system reduces the amount of equipment and repetitions that are necessary to travel over the landscape in order to remove the stems. A study in Western Montana noted significant differences in compaction of volcanic ash and clay soils (Cullen et al. 1991). Differences were noted in several horizons based on the amount of machine traffic an area received during harvesting operations. Steinbrenner and Gessel (1955) studied tractor harvested areas in western Washington and found 26 percent of the total area to be occupied by tractor skid roads. Wooldridge (1960) compared soil disturbances by skyline-crane harvesting with those by conventional tractor skidding. In the tractor-harvested area, 29.4 percent of the ground surface was disturbed, while only 11.1 percent was disturbed in the skyline area. Dyrness (1965) stated the tractor-harvested unit had approximately three times more area in the compacted disturbance class than did the high lead unit. Dickerson (1976) reported that 21% of the soil on a clearcut stand was disturbed compared to 14% for an area with a selective cut. Dickerson also found twice as much severely disturbed soil (barred, rutted, and compacted) on the clearcut operation. Soil disturbance averaged 17% in selection cuts and 28% in strip and patch clearcuts of northern hardwoods (Nyland et al. 1977).

The forest floor has been found to be very susceptible to disturbance by harvesting operations (Turcotte et al. 1991). Soil compaction and loss of organic matter from the forest floor had a direct influence on the weathering rates of minerals, nutrient mineralization and consequently plant growth. Mechanical disruption of the forest floor might have an adverse impact on site productivity because the forest floor was a major source of nutrients for shallow rooted spruce and fir seedlings (Hoyle 1965, Shaw et al. 1987). However, soil compaction also increases water holding capacity, which can favor tree growth (Gomez et al. 2002). Studies have shown that compaction potential is increased when soil moisture levels are between field capacity and saturation (Froelich et al. 1980).

Timber harvesting methods in central Appalachia have become more mechanized in recent years. However, chainsaw felling and rubber-tired cable skidding is still the dominant system in the region due to terrain limitations and other constraints surrounding hardwood species. The soil bulk density changes associated with conventional manual and mechanized harvesting systems have been studied (Wang et al. 2005 and 2007). In this study, we wanted to quantify and document how traffic intensity and payload of a typical rubber-tired cable skidder affected soil compaction and the residual stand growth in the region. The study site was initiated in 2005 and follow up measurements were completed in 2007. This paper will report on the residual effects of soil compaction after a two-year time period.

Materials and Methods

Site and Skid Trails

The field data collection was carried out on a section of the West Virginia University Research Forest from May to July in 2005 and the site was selected as a representative sample of the central Appalachian hardwood region with respect to tree age and species composition. The study area was 20 acres in size, relatively flat, and of the same general southwestern aspect with the elevation of approximately 2000 feet (610 m) (Figure 1). The soils of the area are comprised of three associations. The Dekalb-Buchanan-Lily and Hazelton-Dekalb-Buchanan associations make up the majority of Research Forest, and are generally gently sloping to very steep, well drained and moderately well drained, acid soils; found on uplands and foot slopes. A smaller area of the Gilpin-Wharton-Ernest association is found in the northwestern portion of the Forest, and this association is more alkaline than the other two soils. The major species composing the WVU Research Forest are red oak *(Quercus rubra)*, yellow-polar *(Liriodendron tulipifera)*, red maple *(Acer rubrum)*, chestnut oak *(Quercus prinus)*, and black cherry *(Prunus serotina)*. Other species found within the forest are cucumber tree *(Magnolia acuminata),* scarlet oak *(Quercus coccinea)*, black gum *(Nyssa sylvatica)*, sassafras *(Sassafras albidum)*, and American beech *(Fagus grandifolia)*.

Skid trails were laid out in 170 to 200 foot sections, which allowed for one 50-foot treatment and two 50-foot replications of each treatment over the total skid trail (Figure 1). There were 12 total skid trails, each with one treatment and two replications. The skid trails were laid out in such a way that skidder traffic traveled west to east, and generally on a slight uphill grade (0%-10%) on all trails. The design also called for three trails to be laid out end to end from west to east, and this pattern was continued to the south until all 12 trails were laid out. Traveling west to east, there was a 100 foot gap between the end of one trail and the beginning of the next. Traveling north to south, there was a 100 foot buffer from the centerline of one trail to the centerline of the next trail. All skidder traffic, other than the treatments, was confined to the area outside of the buffer zone and within the 100 foot gap between the end of one trail and the start of the next in order to preserve the area where the growth trees were located. A GPS unit was used to assist in the mapping of each skid trail in the study area.

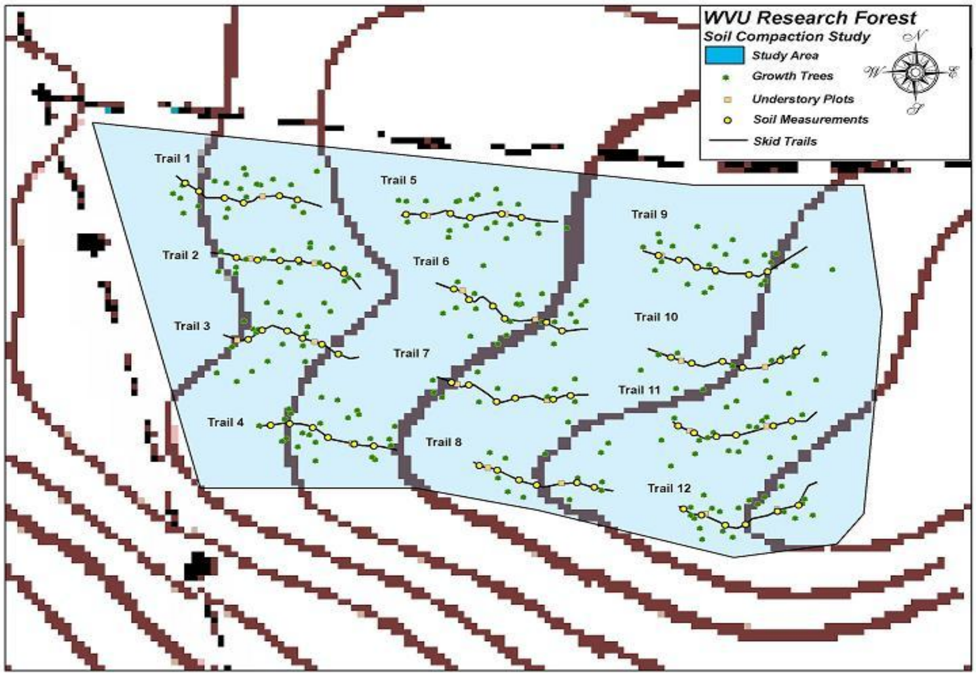

Figure 1. Skid trail layout, growth trees, understory plots, and soil measurement locations.

After the skid trails were laid out, a Caterpillar D3G tractor was used to clear the woody debris, standing understory trees, and some of the surface material (upper layer organic matter) from the skid trails in order to utilize the Troxler 3440 density and moisture gauge. No overstory trees were removed during the preparation phase. A John Deere 640G III cable skidder was employed for extraction operations with three levels of assigned loads: no load, ½ load, and full load. Full load was 798.6 board feet (BF) Doyle Scale and was formed by four yellow-poplar logs of 33 feet in length and varied in diameter while ½ load meant the skidder operated pulling two logs of 415.3 BF. No load meant that the skidder operated on the trails without any logs. The same two logs were used for the ½ load size during each cycle, and both were marked on the ends with high-visibility orange tree marking paint enabling distinct recognition.

Field Measurements

Understory sampling was conducted on two replications of each skid trail for a total of 24 sample locations. A 3'x12' cross section of the skid trail was laid out for each sample before any skidding activity took place. Regeneration and understory vegetation under 4' in height was counted by species within the sample area. A photograph was also taken of the plots for comparative purposes. A GPS unit was also used to assist in the mapping of each understory plot.

Trees were selected from the overstory canopy (dominant and codominant) on the basis of size and species. Only trees of sawtimber size were sampled (DBH 11.0 inches or above), and species were selected on the basis of local merchantability. Sample trees had canopies that were within 30 ft of the skid trail, and no more than five trees per replication per side of each trail were sampled. The total number of trees sampled was 225, providing an average of approximately 19 trees per skid trail.

Trees were labeled in a unique fashion with high-visibility, wet-coat orange tree marking paint based on the skid trail number, the replicate number, the tree number within the replicate, and the corresponding side of the skid trail when facing east. Tree measurements included species, diameter at breast height (DBH), total height, merchantable height in 8' sections, crown diameter, grade, distance from the side of the skid trail, and whether or not the tree was damaged during the skidding operation. All sample trees were measured for the past 10-years of growth by extracting a sample with an increment borer and then counting growth rings and measuring the cores in the lab. All increment boring was done on the southern side of the tree (azimuth = 180˚) and was restricted to approximately 2.5 inches in depth.

Each replicate within each skid trail was measured in two locations for initial soil density and moisture content for a total of 72 cross sections over the 12 skid trails. Soil measurements were made on a cross section of skid trail, starting 1' from the edge of the trail, and then every 2' across the 12' wide trail for a total of 6 measurements per cross section. The total number of initial soil density and moisture content measurements was 432. The measurements were made at a depth of 6" with a Troxler Labs 3440 soil density and moisture gauge. The cross sectional measurements were then averaged to calculate a cross sectional mean density and moisture content.

The nine skid trails that had undergone skidding treatments (skid trails 2, 3, 4, 6, 7, 8, 10, 11, and 12) were measured for post-treatment soil density and moisture using the same process as the initial measurements. A total of 54 cross sections (which were placed in the same initial measurement locations) were measured across the nine skid trails. The total of post-treatment soil density and moisture measurements was 324.

Data was collected again in July, 2007 using the same methods and equipment. Data collection points were located using GPS data taken during the initial sample in order to effectively assess differences on the site. This sample allowed for a complete comparison of changes during a two-year time period under normal conditions. There was no further harvesting activity on the between field measurements.

Data Analysis

A t-test was used to test if significant differences existed in bulk density changes. The general linear model (GLM) was applied to the data to examine the impacts of individual factors as well as their interactions on soil bulk density and moisture content in the skid trails.

$$Y_{ijk} = \mu + P_i + L_j + P_i * L_j + \varepsilon_{ijk}$$
$$i = 1, 2, 3$$
$$j = 1, 2, 3$$
$$k = 1, 2, 3$$

Where Y_{ijk} represents the k^{th} observation of the soil density or the soil moisture content and μ is the overall mean of the response variable. P_i is the effect of i^{th} number of machine passes (1, 3, and 5 loaded machine passes). L_j is the effect of j^{th} payload size (no load, half load, and full load). ε_{ijk} is an error component that represents all uncontrolled variability.

Results

Understory species composition did change during the two year time period (Table 1). The overall number of understory stems found increased from 104 to 128. However, there were generally fewer species found in each plot during 2007. One species that was not found in 2005 was yellow-poplar, but this species was prevalent in 2007. This could be due to the likelihood of this species to be a pioneer in sprouting after a disturbance. The number of sassafras sprouts increased, while red oak sprouts decreased over the two year time period. Additionally, the count of black cherry sprouts decreased and this is generally a pioneer species as well.

Table 1. Understory species by year.

Species	2005	2007
Black gum		1
Black cherry	14	7
Chestnut oak	11	12
Fern	1	2
Greenbrier	18	17
Hickory	1	
Huckleberry	6	10
Red maple	23	22
Red oak	20	12
Sassafras	3	20
Sourwood	5	3
White oak	2	2
Yellow poplar		20
Total	104	128

Red oak (36%), yellow-poplar (24%), chestnut oak (19%), black oak (9%), scarlet oak (8%), and red maples (4%) were the major overstory canopy with less than 2% of other species recorded. The total average height ranged from 83 to 99 in 2005 to 88 and 103 feet in 2007 for the major species, with merchantable height showing an overall average increase of 3 feet during the two year period (Table 2). Crown diameter averaged 32.25 feet ranging from 30.87 to 36.49 feet in 2005 for the dominant and codominant trees measured. The average crown diameter was found to be 35 feet in 2007, which is nearly a 3 foot increase. The average 10-year growth rate was 0.82 in 2005 compared to 0.89 inches in 2007. This represents an average growth of 0.07 inches over the two year period. White oak showed the least growth with 0.6 inches in 2007 compared to black oak with 1.3 inches. Average distance of these sampled trees to the centerlines of skid trails ranged from 13.95 to 19.28 feet.

Table 2. Statistics of sampled trees along the skid trails by species.

Species	THT (ft)		MHT (ft)		Crown Diameter (ft)		10-yr Growth (in)		Distance to Trail (ft)
	2005	2007	2005	2007	2005	2007	2005	2007	
Black oak	86.20	89.45	39.20	40.83	32.20	34.65	0.54	1.32	13.95

Chestnut oak	85.10	89.40	44.29	43.57	30.95	34.50	0.78	0.88	14.10
Red maple	86.11	89.11	35.56	39.22	32.22	34.78	1.00	0.97	21.22
Red oak	90.47	94.53	44.31	45.65	36.49	39.73	0.89	0.96	15.36
Scarlet oak	82.18	84.22	40.82	42.39	34.44	37.83	0.64	0.79	19.28
Yellow-poplar	98.66	102.57	58.42	60.96	30.87	34.92	0.89	0.94	17.55
Others	83.5	87.5	32.00	44	28.50	30.5	1.03	0.38	14.50

The average DBH in 2005 was 16.69 inches and increased an average of 0.4 inches in 2007. Heights, crown diameters, 10-year growth, and distances to the skid trail centerlines were all summarized by DBH class (Table 3). The total height ranged from 89.46 to 100.33 feet, an average increase of 3 feet in 2007. Merchantable height varied from 38.49 to 54.83 feet as DBH changed from 14 to 24 inches in 2007, which was an average increase of 2 feet. Crown diameter also increased from 27.88 to 30.90 and 41.31 to 45.45 ft. as the DBH changed from 14 to 24 inches for the two sample years. The average 10-year growth rate increased from 0.67 inches for the 14 inch DBH class to 1.15 inches for the 24 inch DBH class. Trees measured were located 15 to 24 feet away from the centerlines of skid trails.

Table 3. Statistics of sampled trees along the skid trails by DBH class.

DBH Class (in)	THT (ft)		MHT (ft)		Crown Diameter (ft)		10 yr Growth (in)		Distance to Trail (ft)
	2005	2007	2005	2007	2005	2007	2005	2007	
14	84.10	89.46	36.62	38.49	27.88	30.90	0.67	0.79	15.25
16	89.00	90.97	48.18	46.88	30.98	34.27	0.77	1.01	15.78
18	90.91	94.82	46.86	48.86	34.34	36.52	0.88	0.87	18.31
20	93.31	95.58	50.39	51.39	36.39	40.61	0.89	1.00	12.47
22	97.76	100.33	54.33	54.83	41.24	40.98	0.93	1.09	15.67
24	96.13	99.85	51.73	54.30	41.31	45.45	1.15	1.06	23.38

A t-test was used to test the statistical differences of soil moisture content and soil bulk densities between the two sample periods (Table 4). Moisture content decreased significantly from 2005 to 2007 for the treated segments. Soil bulk density also decreased from the treatment period to 2007. However, the bulk density decrease was not significantly different.

Table 4. Soil moisture content and bulk density in treated skid trails.

	Treatment	Treated	t-value	p-value

	Before (2005)	40.99	1.19	0.2363
Moisture content (%)	After (2005)	31.58	7.29	<0.0001
	After (2007)	29.86	-4.78	<0.0001
	Before (2005)	69.99	-0.3	0.7633
Soil bulk density (lb/ft^3)	After (2005)	76.06	-4.75	<0.0001
	After (2007)	74.65	-0.12	0.9045

An ANOVA test was also used to test significant differences of load capacity and number of passes (Table 5). There were significant differences in the segments with 3 and 5 loaded passes showing decreases in moisture content during the two year time period. Three loaded machine passes showed the greatest decrease in moisture content (F = 12.08; df = 3, 2.18; P = <0.0001). Significant differences were seen in soil bulk density in 2005 (F = 967.93; df = 3, 537.0; P = <0.0001). However, bulk density showed no significant differences with number of loaded machine passes in 2007. One loaded machine pass showed the greatest recovery in terms of soil bulk density during the sample periods. Payload size carried by the machine also proved to significantly impact both moisture content and bulk density in 2005. Each payload size was significantly different with respect to moisture content immediately after treatment in 2005 (F = 29.72; df = 2, 72.68; P = <0.0001). During the 2007 assessment only no payload showed a significant difference in the three classes. Soil bulk density showed the same results in both years with no and half payload sizes being significantly lower than full payload size.

Table 5. Means and significant levels of soil bulk density and moisture content in skid trails[a].

		Moisture Content (%)		Soil Bulk Density (lb/ft^3)	
		2005	2007	2005	2007
No. of loaded machine passes	1	31.04A	31.62A	75.47B	71.38A
	3	33.22A	28.94B	74.66B	75.32A
	5	30.47A	29.01B	78.06A	77.27A
Payload size	no	37.82A	25.12B	72.54B	75.58B
	half	31.44B	32.82A	74.49B	70.87B

	full	25.47C	31.62A	81.16A	77.51A

[a] Means containing the same letter in a column of a group are not significantly different at the 5 percent level with Duncan's Multiple – Range Test.

The 2005 soil bulk density readings were consistently higher with fully loaded machine passes (Figure 2). The greatest number of machine passes with no load was slightly higher compared to the same passes with half load. This could be due to slightly wetter soils or a small change in soil content.

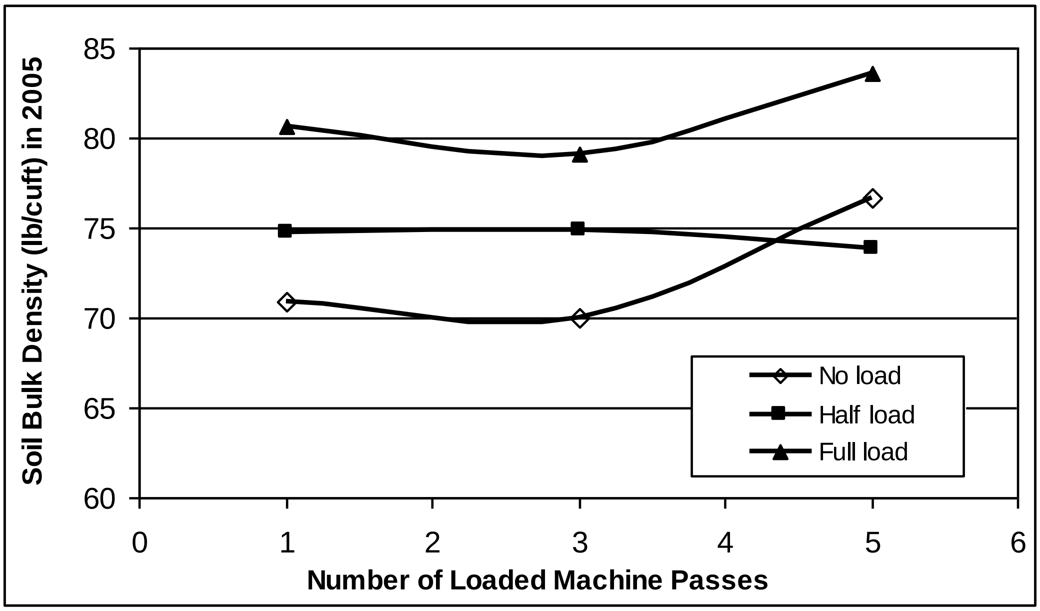

Figure 2. Soil bulk density changes by loaded machine pass and payload size.

In 2007 soil bulk density recovered in reference to fully loaded machine passes (Figure 3). Similarly half loaded machine passes also showed recovery with each class of machine passes. The machine passes with no load did not show the same recovery, which could be due to the lack of compaction caused during the treatment in 2005.

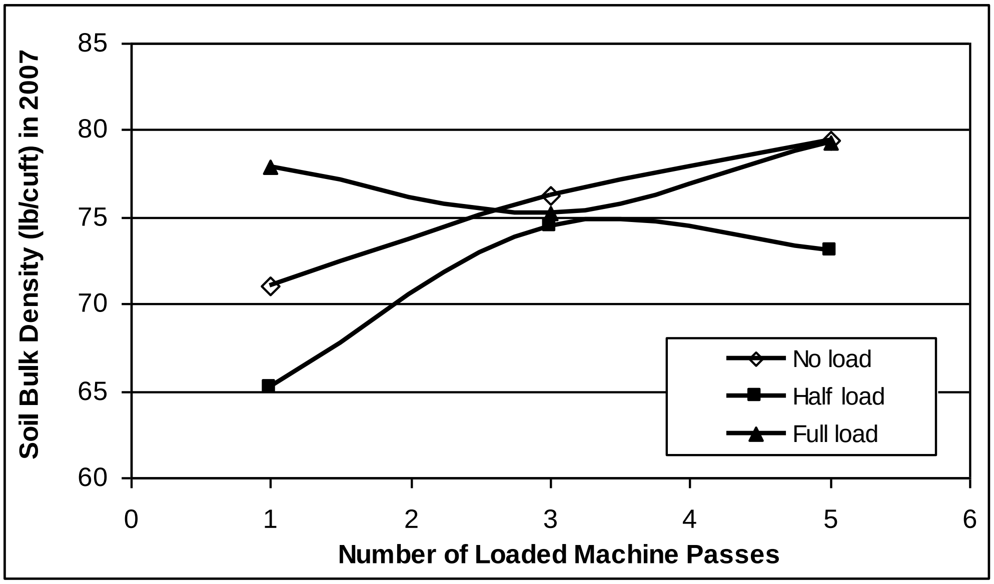

Figure 3. Soil bulk density changes by loaded machine pass and payload size.

Conclusion and Discussion

Analyzing soil recovery rates is necessary to determine harvesting effects on forest land. This study shows results for a two year time period after treatment with varying machine passes and load combinations. Data collected from the site included tree information for sample trees within 30 feet of the skid trails. This data was collected to analyze effects on growth of the residual trees. Tree growth was found to show diameter growth of 0.07 inches. This could mean that the effects of soil compaction did impact the sampled trees, with such small growth. Tree growth was also seen in reference to height. Total and merchantable height increased during the elapsed time period. It should be noted that there was crown and top damage in the stand due to a snow storm that occurred in 2006. This storm did break some of the tops, which resulted in a decrease in heights of some sample trees. This storm could also explain some of the growth due to an opening of the canopy and allowing some trees to flourish.

Understory species were also sampled in the trails themselves prior to treatment and again in 2007. The overall number of stems increased, but the number of stems per species was different. Yellow-poplar was not found prior to treatment and was very prolific in 2007. This is a pioneer species and was able to sprout from seed after the forest floor was disturbed and some understory removed due to skidding treatments.

Both soil bulk density and moisture content decreased slightly during the two year time period. The bulk density data reveals that the soil is recovering from compaction especially on the trails with the highest number of passes and load combinations. The results for moisture content show that it is recovering slower than bulk density. This could possibly be explained by certain precipitation events in conjunction with the sampling time periods. A heavy precipitation event or lack thereof can affect measurements for moisture content. Significant differences were found to be decreasing in 2007 for moisture content. In 2005 each payload size was significantly different and only no payload was significantly different in 2007.

Our results show that soil bulk density is decreasing on this site over time. A final data collection replication will be completed during the summer of 2009. This sample will provide four years of data and will allow us to review the effects of skidding on soil bulk density and moisture content in Appalachia. The results will be used to provide recommendations for state BMPs to focus skidding to a few well developed preplanned designated skid trails and minimize trafficking across the general harvest area to protect soil (and water) resources. The findings from this study suggest that under certain conditions (1) most bulk density increase on skid trails occurs after the first three loaded machine passes, (2) preplanned skid trails may minimize bulk density increase across the overall site, and (3) emphasis should be placed on the amount of trail constructed through careful planning. After the final data collection replication we will analyze understory data, effects on tree growth, and soil recovery rates after skidding.

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Influence of regeneration method on soil strength in a Sierra Nevada mixed conifer forest

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Abstract

The cumulative effect of forest operations has potential to enhance or diminish various soil properties. The choice of regeneration method (e.g. single tree selection v. clearcut) distinctly influences the frequency and severity of harvest-related disturbances that in turn influence forest soils. Of particular importance is the long-term effect of operations on soil productivity. Soil strength (i.e. resistance to penetration by roots) is an integrative measure of soil productivity that can be used to assess the sustainability of forest operations. We measured soil strength at the stand level to see if differences could be detected between different regeneration methods (single-tree selection, group selection, overstory removal, clearcut, and a no-harvest control). Two stands per regeneration method were sampled using a recording cone penetrometer at Blodgett Forest Research Station, CA. Single tree selection and group selection stands had higher-frequency, lower-severity harvest histories, while clearcut and overstory removal stands had lower-frequency, higher-intensity harvest histories. We could detect an overall influence of regeneration method on soil strength within the top 0.5 meters of soil. Between-treatment analyses indicated that the clearcut and overstory removal stands tended to have greater soil strength when compared to the control, but not when compared to single-tree selection or group selections stands. For all regeneration methods, soil strength within the top 0.5 meters of soil was usually less than 2000 kPa, a threshold of soil strength above which root stress can increase substantially. These results follow 20+ years of harvest histories, but much more time is needed to evaluate soil properties on the same temporal scale as a rotation age. Experimental studies such as the North American long term soil productivity study that link soil strength differences with productivity will also be important for further evaluations of whether forest operations enhance or diminish metrics of soil sustainability.

Introduction

Maintaining the sustainability of forests is a goal shared by all stakeholders, including the state and federal governments, the forest product industry, forestry professionals, and environmentally oriented non-governmental organizations (e.g. in California: Dicus and Delfino 2003, CDF 2003, Pacific Forest Trust 2004, SAF 2004, USDA Forest Service 2004). Schemes for assessing sustainability vary widely, with different opinions on what values should be sustained (i.e. *criteria*) and what metrics of sustainability should be measured (i.e. *indicators*). Consistently, however, conservation of soil resources is among the standard requirements of a sustainable forest. Of particular importance in forests where operations occur (e.g. for timber extraction or fuel reduction) is the influence of operations on soil compaction. Increased compaction may in some cases diminish productivity (Heninger et al. 2002) and in others enhance it (Powers and Fidler 1997). Whatever the influence of compaction, it must first be measurable in order assess its impact.

We attempted to measure soil compaction, to see if we could detect differences at the stand scale in a forest where repeated operations have consistently been applied for over 20 years. We used the basic contrast of regeneration methods (clearcut, single tree selection, group selection, overstory removal, and no-harvest) to provide a gradient of harvest frequencies and intensities. We had two questions: 1) Are differences in soil strength detectable between regeneration methods? 2) What are the implications for productivity, if any?

Methods

The study area lies within Blodgett Forest Research Station (BFRS), located between 1220 and 1310 m on the western slope of the central Sierra Nevada mountain range in California. The climate is montane Mediterranean with dry, warm summers (14 to17 °C) and mild winters (0 to 9 °C). Annual precipitation averages 166 cm, most coming from rainfall during fall and spring months. The soil developed from granodiorite parent material and is productive for the region. Vegetation at BFRS is dominated by a mixed conifer forest type, composed of variable proportions of five coniferous and one hardwood tree species. Native conifer tree species include white fir (*Abies concolor* (Gord. & Glend.) Lindl. Ex Hildebr.), incense-cedar (*Calocedrus decurrens* Torr.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. menziesii), sugar pine (*Pinus lambertiana* Dougl.), and ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.).

Stand sizes used for this study averaged 20 ha. All stands (including the no-cut reserve) regenerated from a harvest circa 1910. The 1910 harvest removed most commercially valuable trees and left about 15 trees per hectare as seed trees. Stands used in this study developed following this harvest with minimal intervention for approximately 60 years. The experimental treatments were different regeneration methods that were used across BFRS between 1970 and 2000. Regeneration methods included clearcut, single-tree selection, group selection, overstory removal (a.k.a. diameter limit cutting), and a no-harvest reserve. Two stands from each regeneration method were selected for sampling. All stands except the no-harvest reserve used conventional falling with tracked skidders to yard cut-to-length logs. Operations occurred in mid- to late-summer, when soils were mostly depleted of water. Harvest slash was left on-site. The clearcut stands were regenerated with clear-fell harvesting in 1984 (21 years prior to sampling). Cultural treatments in clearcut stands included site preparation (pile and burn), planting, herbicide spraying, and a precommercial thin with a tracked excavator with a masticating head. The clearcut stands therefore had two entries involving heavy equipment.

The single tree selection stands each had 3 entries over the 30 years prior to sampling. In general, these harvests created diverse structures by removing trees of all size classes. Harvests removed 20-50% of standing volume. The group selection stands also each had 3 entries over the 30 years prior to sampling. Each entry regenerated 10% of the stand area within dispersed ~0.4 ha openings that were clearfelled. Between openings, the stands were commercially thinned from below to target residual densities that were approximately 50% of maximum stand density. Overstory removal stands each had 2 harvest entries over the 30 years prior to sampling. These harvests removed the largest trees available, removing 40-70% of standing volume. No-harvest areas have not been entered with any equipment since the initial harvest circa 1910.

To assess compaction, soil strength was measured with a recording cone penetrometer. Measuring soil strength with a penetrometer is a relatively sensitive and integrative method for measuring changes in soil compaction as related to tree growth (Landsberg et al. 2003). The penetrometer is pushed by an operator down into the soil. Resistance to the downward pressure through the soil is measured continuously as it passes through the soil profile. Sampling points were distributed on 120 x 120 meter grid across stands. Skid trails were not excluded. At each sampling point, a square grid of 25 points were used to collect soil strength measurements. The measurements were averaged to the plot level, then averaged across the stand. Stand averages of soil strength are the experimental unit for statistical analysis.

Soil strength (expressed in kilopascals) integrated across the top 500 mm of soil was compared between treatments using ANOVA and followed by Tukey's honestly significant difference tests for between treatment comparisons. Differences are judged to be significant with p-values less than 0.05.

Results and Discussion

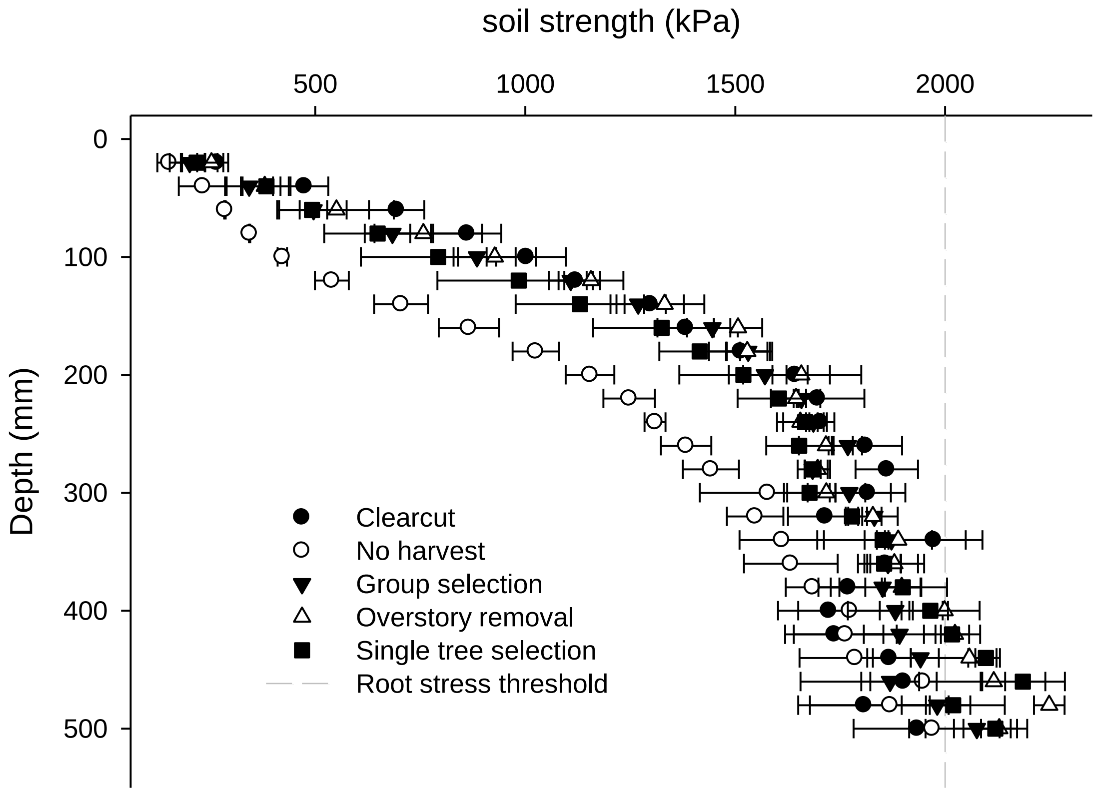
Soil strength profiles followed expected patterns (Fig. 1), where strength gradually increased with depth in the shallow portion of the profile, and increased sharply in lower depths. Across the top 500 mm of soil, there was a detectable difference in soil strength among all treatments (p=0.03). The no-harvest stands clearly had the lowest soil strength (845kpa). The other treatments had similar levels of soil strength (single tree selection = 1146kpa, group selection = 1207kpa, overstory removal = 1232kpa, clearcut = 1276kpa). Between treatment differences indicated that soil strengths in the clearcut and overstory removal stands were greater than in the no-harvest stands. No other between-treatment differences were detected.

These results reflect a coarse-level capacity to detect differences in soil compaction, even where different treatments have been applied for multiple decades. Stands that had a presence of harvesting activity were in one category of treatments that had greater levels of compaction, while the no-harvest treatment was in a separate category of less compaction. The answer to our first question is that only on a coarse scale can we detect differences in soil compaction between treatments. In terms of assessing sustainability, then, our assessment is restricted to comparing harvested versus unharvested stands with respect to soil compaction.

While some investigators have found similar results using measures of soil strength (e.g. Landsberg et al. 2003), there are no long-term assessments of the implications for above-ground productivity. However, we do have information on plant-level responses to different degrees of compaction. Greacen and Sands (1980) reported that increases in soil strength to 3000kpa were necessary for severely restricting root growth. Using a more conservative threshold of 2000kpa, there appears to be very little difference in the depth at which this threshold is crossed between harvested and non-harvested stands from this study (Fig. 1). Hence the below-ground root growth capacity (i.e. root growing space) appears similar between harvested and non-harvested stands, even though harvested stands did tend to have greater levels of compaction. In a nearby stand at BFRS with similar soils to those used in this study, experimental plots were compacted as part of the North American Long-Term Soil Productivity Study (LTSP). 10 years following treatments, above-ground productivity *increased* in plots that were compacted artificially up to 3000kpa (M. Busse, personal communication).

Even though our study site has a relatively long history of management activity, the 30 years that covered this study is much shorter than what will be needed to do a comprehensive empirical evaluation of sustainability. At the least, a rotation age (in this forest 50-100 years) will be necessary to compare regeneration methods. Long-term studies such as the ongoing management experiment at BFRS and the national LTSP study will be essential for evaluating the sustainability of forests with respect to compaction from operations.

Figure 1. Soil strength profiles from stands at Blodgett Forest Research Station, CA. Clearcut stands were regenerated 21 years prior to sampling. Group and single tree selection stands all had 3 entries over the 30 years prior to sampling. Overstory removal stands had 2 entries over the 30 years prior to sampling.



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Estimating the Amount of Available Forest Biomass Using System Dynamics

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Abstract: Japan depends largely on foreign countries for its primary energy resources such as oil, gas and coal while it has an abundance of forest biomass. Many biomass power plants have been constructed in recent years all over Japan as forest biomass has become more and more popular. However, some of them are short of wood chips for power generation and are not able to collect a sufficient amount of construction waste due to a recent economic recession and competition with wood board producers. In this study, we developed a system dynamics model to estimate the future demand and supply of available forest biomass, in which only domestic timber was considered. In the model, wood supply was calculated as a sum of wood volume of not only final cuttings and commercial thinnings but noncommercial thinnings to estimate the potential wood supply including small-sized logs that were usually unutilized and left in the forest. On the other hand, the demand was calculated as a sum of the volume of industrial wood and wood chips. As a result, it was found that the potential wood supply would drop by 4.9 million m^3 from 2006 to 2030 while the wood demand would drop by 4.5 million m^3 during the same period. The amount of available forest biomass calculated as a difference of demand and supply was expected to stay around 12 million m^3 up to 2030.

Introduction

Japan has a high dependence rate of primary energy resources such as oil, natural gas and coal; the rates of imported oil, natural gas and coal are 99.6, 95.7 and 100.0% (Agency for Natural Resources and Energy, 2007). On the other hand, Japan has a forest coverage of 68% and an abundance of forest biomass. The utilization of forest biomass has become more and more popular in Japan as renewable resource since the Kyoto Protocol was adopted at the Third

Conference of the Parties to the United Nations Framework Convention on Climate Change (COP3) in 1997. Forest biomass has an advantage over food-oriented biomass such as corn or sugarcane in that it does not compete with food for humans. In 2002, the Biomass Nippon Strategy was decided upon at the initiative of the Ministry of Agriculture, Forestry and Fisheries. The strategy aimed to utilize biomass as energy and production for the prevention of global warming, creation of a recycling-oriented society, encouragement of biomass industries and activation of agriculture, forestry and fisheries. In Japan, timber consumption for fuel dropped drastically in 1960s, before which a large amount of timber had been used for fuel purposes. Currently, the ratio of fuel wood to the total timber consumption in Japan is 1.0%, which is one of the lowest in the world (Committee on the Promotion of Fuel Wood and Charcoal for Japanese Forests, 2007). In 1960s, domestic timber production also dropped sharply due to the liberalization of imports of timber. The utilization of forest biomass in Japan was greatly disseminated by the Renewables Portfolio Standard that was enforced in 2003. Electric power suppliers were forced to supply more than a certain ratio of electricity generated by using renewable resources. For this purpose, facilities for biomass power generation and thermal recovery were constructed one after another throughout Japan mainly with the fund of the New Energy and Industrial Technology Development Organization (NEDO), and at the time of 2004, approximately 70 such facilities were operating in Japan (Hikosaka, 2006). According to the estimation of the demand and supply of forest biomass for power generation and thermal recovery in nine regions of Japan, demand was more than supply except in three of them (Nose, 2007). After the second half of 2008, the amount of waste wood caused by breaking down wooden houses decreased due to the economic crisis, and therefore there was a tighter balance between demand and supply in forest biomass and new supply sources of forest biomass must be persued. On the other hand, annual harvested volume is much lower than annual growth, and there is plenty of available forest biomass especially in plantation forests. In addition, there is a possibility to utilize logs and slash, which are often left unused when plantation forests are thinned, by developing low-cost harvesting techniques to collect them efficiently.

There are some studies that estimated the supply of forest biomass in Japan. Aruga et al. (2006) predicted future forest production using Richard's growth curves to find the long-term feasibility of timber and forest biomass resources at an intermediate and mountainous area. Tsuchiya et al. (2007) calculated the amount of forest biomass extracted by commercial thinnings based on the price of domestic timber and different types of subsidies. Kayo et al. (2008a) estimated the change of wood resource flows and reduction of CO_2 emissions in the housing, paper and wood energy sectors until 2050. Furthermore, Kayo et al. (2008b) estimated the reduction of CO_2 emissions in consideration of the change of carbon storage in forests and houses until 2050. Tachibana (2006) made an econometrical model to predict the demand and supply of wood until 2020 based on the demand and supply function of imported logs, imported wood products and logs of Japanese cedar, Japanese cypress, other conifers and broad-leaved trees in the domestic market.

We developed a system dynamics model to estimate the future demand and supply of forest biomass in the domestic market from 2006 to 2030. In this model, we did not consider the amount of forest biomass imported from abroad because economic conditions of not only Japan but foreign countries such as USA and China are extremely difficult to forecast. The wood supply was calculated as a sum of wood volume of not only final cuttings and commercial thinnings but uncommercial thinnings to estimate the potential wood supply including small-sized logs that were usually unutilized and left in the forest. On the other hand, the wood demand was calculated as a sum of the volume of industrial wood such as sawnwood or plywood for building houses and wood chips for producing papers. In fact, 96.4% of the demand for domestic timber can be accounted for by such industrial wood (Forestry Agency, 2008). Finally, the amount of available forest biomass was obtained as the above mentioned supply minus demand.

Materials and methods

System dynamics model

We estimated the future demand and supply of forest biomass in the domestic market by using system dynamics, which helps us understand the behavior of complex systems over time, and principles of materials handling. The advantage of using system dynamics is to make a more flexible and customizable model to better fit the actual conditions and predict the future based on different conditions. System dynamics also has the advantages of high compatibility, interchangeability, understandability and simplicity of models. There are some studies that applied system dynamics to forestry research. 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 excavator, bucking and delimbing by chainsaw, log collection by forwarder and log piling. Noda (2006) developed a forestry sector model consisting of four sub-sectors, that is, harvesting, forest resource, silviculture and profit allocation, and predicted the production, productivity and labor force for harvesting and silviculture up to 2030. The system dynamics models developed in this study is rather simple, but focuses on the prediction of demand and supply of domestic timber by carefully choosing comparatively predictable variables following certain trends. To develop these models, we used Stella 9.0 software (ieee systems), which is widely used for system dynamics simulation. Figure 1 shows the four main components used in STELLA, that is, stock, flow, converter and connector. The definitions of these components are explained as follows (MIT

System Dynamics in Education Project, 1996):

(1) 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.
(2) Flow - Movement of a quantity from one level to another.
(3) Converter - A term used in the STELLA software. More generally, known as auxiliary variables. They are usually represented in diagrams by circles. 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.
(4) Connector - The building blocks that carry information from one element in a model to another element. "Information" may be a constant, an algebraic relationship, a graphical relationship (contained by converters or table functions), or a quantity (e.g. how many dollars in your savings account). "Information" flows through connectors to converters (auxiliary variable) or flows (rates), but not to stocks.

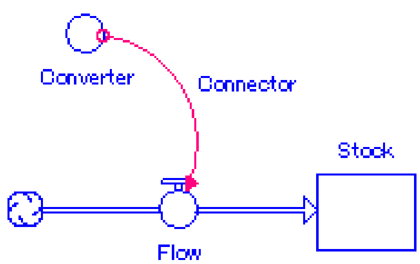

Figure 1. Main components used in Stella.

Supply of forest biomass

The supply model of domestic timber developed with the four main components of Stella software is shown in Figure 2. In this figure, the future final cutting volume was determined by the following regression model:

$$Y=84515000e^{(-0.0302*(X+47))} \quad (R^2=0.958) \qquad (1)$$

where Y is the final cutting volume (m^3); X is the variable indicating the year, which is equal to 0, 2, 3, …, 24 for 2006, 2007, …, 2030. The commercial thinning volume was estimated by the following regression model:

$$Y=119780(X+13)+1575400 \quad (R^2=0.885) \qquad (2)$$

where Y is the commercial thinning volume (m^3); X is the same as the equation (1). The rate of commercial thinning was fixed at 0.514, which was determined as a mean of the actual rate from 1985 to 1997 when the official data of this rate is available. Finally, the supply of domestic timber was obtained as a sum of logs from final and intermediate cutting.

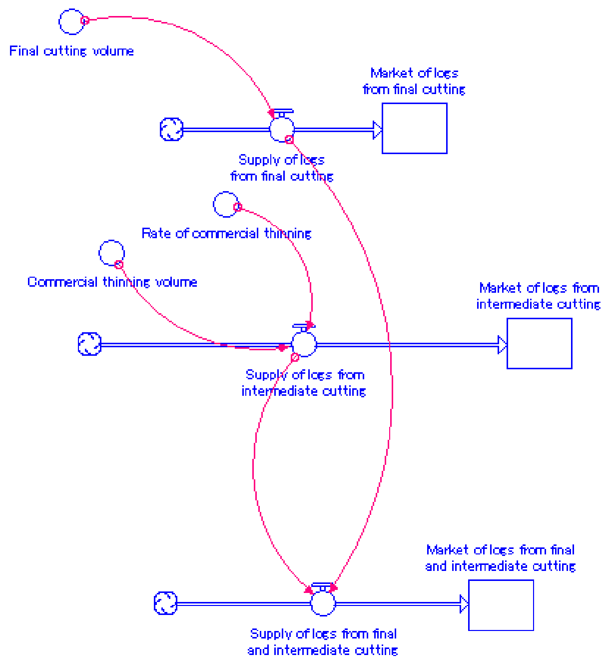

Figure 2. Supply model of domestic timber.

Demand for forest biomass

The demand model of domestic timber developed with the four main components of Stella software is shown in Figure 3. We estimated the future number of constructed wooden houses based on three factors, that is, the number of destroyed wooden houses, currency exchange rate between Japanese yen and US dollar and increase of the productive population with the age of 15 to 64 in Japan by using the following multiple regression model:

$$Y = -481.925A + 0.021B + 1.067C + 416788.868 \quad (R^2 = 0.855) \qquad (3)$$

Where Y indicates the number of constructed wooden houses; A indicates the exchange rate of one US dollar to Japanese yen; B indicates the increase of the productive population; C indicates the number of destroyed wooden houses. The number of destroyed wooden houses was estimated by the following regression model:

$$Y=374801(X+11)^{(-0.4474)} \quad (R^2=0.946) \tag{4}$$

where Y is the number of destroyed wooden houses; X is the same as the equation (1). We used the estimation of the productive population published by the National Institute of Population and Social Security Research (2002). The currency exchange rate between Japanese yen and US dollar is assumed to follow the long-term trend shown as follows:

$$Y=157.17(X+21)^{(-0.1188)} \quad (R^2=0.946) \tag{5}$$

where Y is Japanese yen equivalent to one US dollar; X is the same as the equation (1). We found that there was a strong correlation between the floor area per a constructed house and actual household income:

$$Y= 0.00009X+61.428 \quad (R=0.931) \tag{6}$$

where Y is the floor area per a constructed house (m^2); X is the actual household income (yen). We estimated the floor area per a constructed house by using the following regression model to estimate the future household income:

$$Y=621936(X+12)^{(-0.0816)} \quad (R^2=0.575) \tag{7}$$

where Y is the household income (yen); X is the same as the equation (1). We estimated the increase of the total floor area of constructed houses by the equations (3), (6) and (7). Subsequently, the increase of the total floor area of extended or reconstructed houses was estimated by the rate of the floor area of extended or reconstructed houses to newly constructed houses:

$$Y=0.282(X+24)^{(-0.2705)} \quad (R^2=0.860) \tag{8}$$

where Y is the rate of the floor area of extended or reconstructed houses to newly constructed houses; X is the same as the equation (1). The wood volume per floor area was estimated by the following regression:

$$Y=0.6676(X+42)(-0.3514) \quad (R^2=0.821) \tag{9}$$

where Y is the rate of the floor area of extended or reconstructed houses to newly constructed houses; X is the same as the equation (1). The supply of plywood and sawnwood was calculated as a sum of the increase of the total floor area of constructed houses and extended or reconstructed houses. The supply of pulp and chips was estimated by the following multiple regression model:

$$Y=166.0678A+0.0721B+1335110.475 \quad (R^2=0.934) \qquad (10)$$

where Y indicates the supply of pulp and chips (m^3); A indicates the area of expansive afforestation (ha), which means the tree plantation after the clearcut of the natural forests; B indicates the supply of plywood and sawnwood (m^3). The supply of timber was calculated as a sum of the supply of plywood and sawnwood and pulp and chips (m^3).

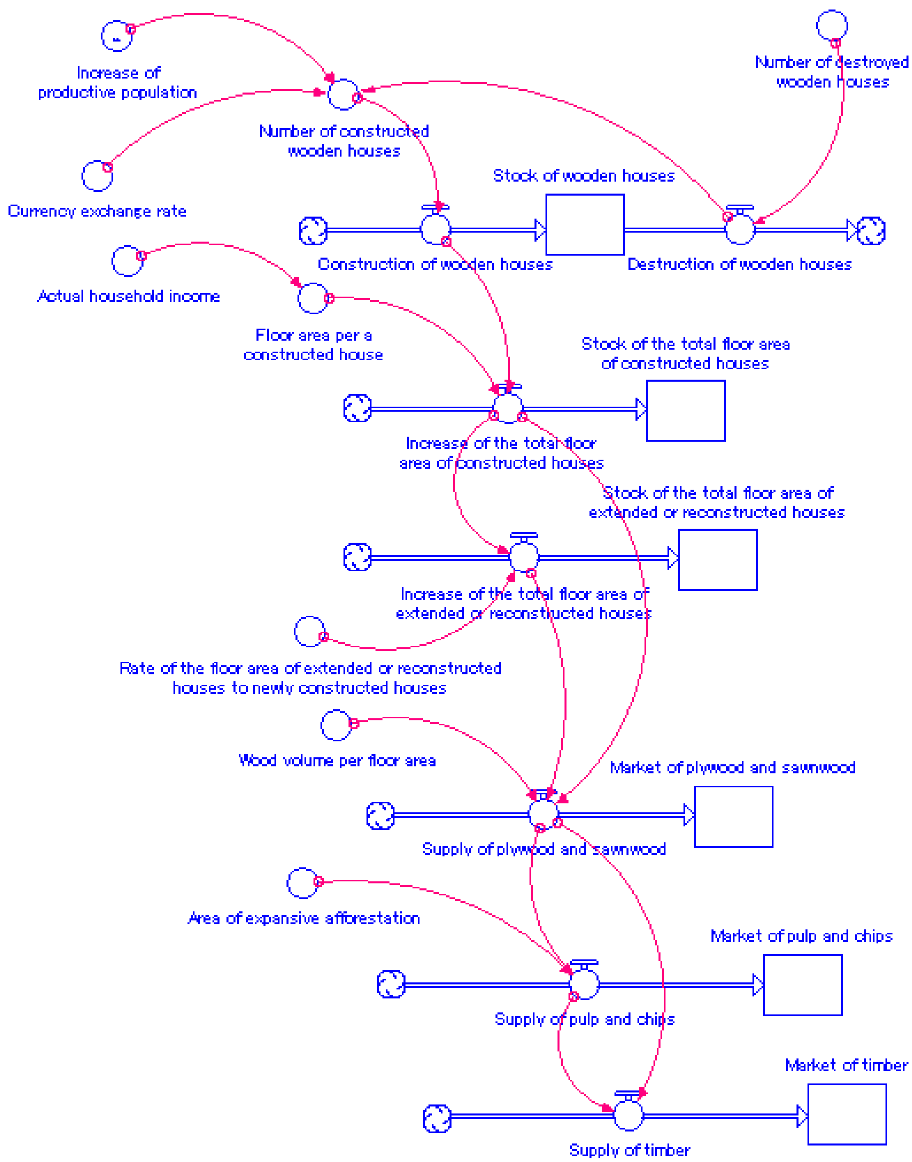

Figure 3. Demand model of domestic timber.

Results and discussion

The future demand and supply of timber in Japan is shown in Figure 4. As shown in this figure, both demand and supply are expected to go down. The supply of timber is 26.5 million m^3 in 2006 and it will be 21.6 million m^3. As a result, the change rate of timber supply is -18.6% although the annual increase of the total stand volume in Japan is approximately 2%. On the other hand, the demand of timber is 14.1 million m^3 in 2006 and it will be 9.6 million m^3. The change rate of timber demand is -31.9%. This estimation was made based on the current trend of timber demand and supply in Japan, which is decreasing for long time. If something that changes the current trend of timber demand and supply, the result will be different. The supply includes the timber amount that is unutilized after thinning, and it is potential timber supply in Japan. That is why there is a large gap between timber demand and supply. It should be noted that potential timber supply is much larger than timber demand in Japan.

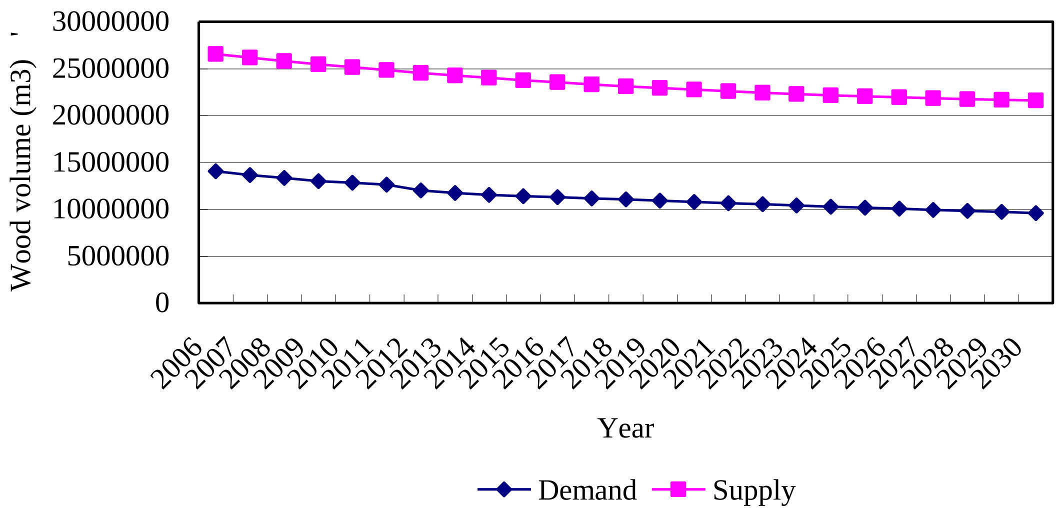

Figure 4. Estimated demand and supply of timber in Japan.

Forestry Agency of Japan has a goal to produce 29 million m^3 of domestic timber in 2025. However, this seems impossible because there will not be such a large demand for domestic timber. There are some scenarios that this goal can be achieved: (1) world timber trade is stopped in terms of environmental conservation; (2) timber prices rise due to the depletion of world forests; (3) Japanese population increases by opening its labor market; (4) Bubble boom comes to Japan again; (5) Japanese yen crashes in the international currency market; (6) timber production cost drastically decreases by advanced mechanization. We estimated that available but unutilized forest biomass in Japan stays around 12 million m^3 up to 2030, and we need advanced mechanization that drastically cut the cost of timber production as stated in the scenario (6).

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