Welcome to the Council on Forest Engineering(COFE)

Publications Website

Engineering New Solutions for Energy Supply and Demand

July 7-10, 2013, Missoula, Montana

Select an individual paper from the list below. Papers are listed in alphabetical order by first author.

Index of Papers

Oregon

- Garland, John. A Look at Logger Training after 35 years
- Greene, Dale; Samantha Marchman; Shawn Baker. Changes in Logging Firm Demographics and Logging Capacity in the US South
- Grushecky, Shawn; Jingxin Wang. The Impact of Natural Gas Development on Forest Operations in West Virginia
- Han, Sang-Kyun; Han-Sup Han; Joel Bisson; Timothy Montgomery. Effects of grate size on grinding productivity, fuel consumption, and particle size distribution
- Harrill, Hunter; Rien Visser. Modelling Dynamic Skyline Tensions in Rigging Configurations: North Bend, South Bend, and Block in the Bight Case Studies
- Hartley, Damon; Jingxin Wang. Modeling and Optimization of Woody Biomass Supply Chains in the Northeastern United States
- Hiesl, Patrick; Jeffrey Benjamin. Assessment Of Feller-Buncher And Harvester Caused Stand Damage In Partial Harvests In Maine
- Hogland, John; Nathaniel Anderson; Greg Jones. Function modeling: improved raster analysis through delayed reading and function raster datasets
- Jang, Woongsoon; Christopher Keyes; Thomas Perry. Long-Term Biomass Harvesting Effects on Forest Productivity under Three Silvicultural Systems in the Northern Rocky Mountains
- Keefe, Robert; Jan Eitel. Application of carriage-mounted agricultural cameras to improve safety in cable logging operations
- Kim, Dong-Wook; Woodam Chung; Russell Parsons; Byungdoo Lee. Impact assessment of tree spacing on crown fire spread distance for Korean pine stands using a fire simulator
- Kizhakkepurakkal, Anil; A. Hohl; Han-Sup Han; Joel Bisson. Geospatial Analysis: Determining transportation cost zones for woody biomass feedstock allocation
- Klepac, John. Performance of a Tracked Feller-Buncher with a Shear Head Operating in Small-Diameter Pine
- Lebel, Luc; Riadh Azouzi. Towards Collaborative Business Models for Wood-Supply Operations in Public Forests
- Lin, Pengpeng; Marco Contreras; Jun Zhang; Woodam Chung. Applying ant colony optimization to solve constrained forest transportation planning problems
- McDonald, Timothy; Frank Corley; Nick Hindman. Performance of a prototype ‘ELoad Sheet’ for monitoring timber hauling operations
- Meek, Josh; Steve Hayes; Beth Dodson. Montana Logging Costs 2013-An Engineering Approach
- Mitchell, Dana; Erin Huffaker. The State of the Logging Workforce in the Southern United States
- Montgomery, Timothy; Han-Sup Han; Anil Kizhakkepurakkal; Joel Bisson. A GIS-based

method for locating and planning centralized biomass grinding operations

- Morris, Brian; Chad Bolding; Mike Aust. Cost and sediment reduction effectiveness of BMPs for a wood panel bridge on a haul road stream crossing in the Virginia Piedmont
- Murphy, Glen; Philippe Passicot; Hamish Marshall; Andy Dick. Shift Length and Time of Day Impacts on Forest Operations Productivity and Value Recovery in Southern Hemisphere Plantations
- Nepal, Sandhya; Marco Contreras. A GIS-based approach to identify suitable locations for bioenergy plantations in northern Kentucky
- Pyles, Marvin; Kevin Boston. Forest Engineering – Professional Practice in Oregon
- Saralecos, Jarred; Robert Keefe. Influence of Moisture Loss, Seasonality, and Species on Weight to Volume Relationships of Commercial Sawlogs in Idaho
- Smidt, Mathew. The effect of weight posted bridges in Alabama on stumpage prices and haul distances for forest products
- Smidt, Mathew; Tom Gallagher. Factors Affecting Fuel Consumption and Harvesting Costs
- Spong, Ben. The West Virginia Logging Operation Notification, Inspection, and Enforcement System
- Thompson, Jason; Wesley Sprinkle. Production, Cost and Chip Characteristics of In-Woods Microchipping
- Visser, Rien; David Hopper; Josiah Simmonds; Matt Wakelin; Hunter Harrill. Efficiency of Log Vessel Loading Operations: A Loader Configuration Case Study
- Vuillermoz, Morgan; Maryse Bigot. Experimental framework to increase wood mobilisation in fragmented private forests in Auvergne (France): lessons learnt after 2 years
- Wells, Lucas; Nathaniel Anderson; Woodam Chung. A Remote Sensing Approach to Estimating Forest Treatment Residue for Alternative Operational Configurations on the Uncompahgre Plateau, Colorado, USA
- Zamora-Cristales, Rene; John Sessions. RENO: A Computerized Solution Procedure and Decision Support System for Forest Biomass Recovery Operations

~ top ~

Return to Publications Homepage

An assessment of fuel, soil and industrial sorbent applications of biochar produced from forest biomass using distributed scale thermochemical conversion

Nathaniel Anderson[1], **Woodam Chung**[2], Wilfredo Perez, Deborah Page-Dumroese and Zhengrong Gu

Abstract

As a component of supply chains in the forest sector, distributed scale thermochemical conversion systems can produce heat, power, biochar, liquid fuels, and other products from woody biomass byproducts including logging residues, sawdust, chips and shavings. In addition to offsetting mill energy and waste disposal costs, biomass conversion has the potential to reduce air pollution from open burning and generate revenue from the sale of value added products. However, many conversion systems have not been deployed in commercial settings and the products they produce from forest biomass have not been adequately described or characterized with regards to chemical properties, possible uses, and markets. Markets for biochar are especially difficult to access because of the lack of standardization and commodification in this nascent industry. This study used a 700 kg hr -1 gasification system and a 225 kg hr-1 pyrolysis system to produce biochar from coniferous forest and mill residues. The biochars produced by the two systems from multiple feedstocks were characterized for three possible end uses: 1) a substitute for coal in utility boilers, 2) a soil amendment intended to improve soil properties and plant growth, and 3) a precursor in the manufacture of activated carbon (AC). The biochars had similar particle size distributions and bulk density, but varied in pH, carbon content, and other properties. With energy content above 30 MJ kg -1, the biochars produced had higher energy content than torrefied wood and slow pyrolysis biochars, but lower energy content than medium and high quality fossil coal. Compared to raw biomass, biochar has improved handling and storage characteristics for co-firing applications. As a soil amendment, biochar can sequester carbon and improve soil properties, but may have a negative liming effect in low pH forest soils. In this case, we believe low application rates of 1 to 2 Mg ha-1 biochar, which mimic the amount of biomass removed during harvest operations, may have little impact on soil pH, but would alter water holding and nutrient cycling conditions enough to improve forest growth. Most commercial ACs have surface area between 400 and 1600 m2g-1. Biochars from both systems were successfully activated to 500 to 1200 m2g-1 using steam activation. Proprietary chemical activation methods yielded AC with surface area as high as 2071 m2g-1. Results are discussed in the context of co-locating these systems with forest industry operations and producing marketable products from logging residues and mill byproducts.

---

[1] Rocky Mountain Research Station
[2] Associate Professor, College of Forestry and Conservation, University of Montana

Planning Systems, Agility and Customisation in Wood Supply Chains – Results from Six International Case Studies

Jean-François Audy[1], Luc LeBel[2], Matheus Pinotti[1], Karin Westlund[3], Sophie D'Amours[1], Mikael Rönnqvist[1]

Abstract

This paper is based on wood supply chain (WSC) data collected in six countries (Canada, Chile, France, Poland, Sweden, and USA) where a total of 94 local actors and experts were consulted. For each WSC studied, the processes for the operational planning and execution of the procurement activities were mapped. Descriptions of the information, material and financial flows were also completed. Three basic designs of planning systems were identified, and for each design, a decision matrix was devised. WSC agility capabilities were assessed according to a four dimensions reference model and compared with those theoretically required by the environment's uncertainties. When comparing location of the decoupling point, agility capabilities, and average order fulfilment cycle time of each WSC, it was possible to reinforce results found in the literature which state that supply chain agility is linked to shorter order fulfilment cycle time. Finally, the personalisation capabilities of each WSC were assessed and two key processes were identified where most of the product differentiation activities along a WSC occur.

Introduction

Agility is increasingly recognised as a key characteristic of high performing supply chain. Yet, for forest operations, it remains unclear how to measure and assess agility. We therefore set to develop a framework for describing different wood supply chains (WSC) in a generic and standardized way with the objective of assessing their agility and personalisation capabilities. This work was conducted within the Flexible Wood Supply Chain research project (www.flexwood-eu.org). The framework was applied in six international case studies (Canada, Chile, France, Poland, Sweden and USA). Field visits and interviews allowed us to collect information from 94 local actors and experts. Complete results and methodology are provided by Audy et al. (2012). This paper highlights selected results collected from six different supply chains located in as many countries. More specifically, in next section we introduce key elements of the framework and discuss findings on the WSC planning systems. Then, the following sections discuss the agility and personalisation capabilities of the cases, respectively. Concluding remarks are then provided.

Planning systems

The processes for the operational planning and execution of the procurement activities were mapped for each WSC studied. This included all activities from selling agreements to delivery at mill yard. Process mapping also included the identification

[1] FORAC Research Consortium, CIRRELT, Université Laval, QC G1V 0A6, Canada

[2] Faculté de foresterie, géographie et géomatique, Université Laval, QC G1V 0A6, Canada

[3] The Forestry Research Institute of Sweeden (Skogforsk), Swwden

of the actors involved, the location of the decoupling points (i.e. the boundary between forecast driven and order driven planning), and the information, material and financial flows.

Table 1: Planning and execution processes.

Process group (Meta-process)	Planning (P) and execution (E) processes
Procurement	- Select block (P) - Buy block (P)
Harvesting	- Schedule harvesting (P) - Pre-harvesting preparation (E) - Harvesting in the full tree (FT) or cut-to-length (CTL) method (E) - Primary transport in the FT or CTL method (E) - Merchandising at roadside landing (E) - Measuring at roadside (E)
Secondary transportation	- Schedule secondary transportation (P) - Secondary transport (E) - Measuring at the mill (E) - Reception (E)
Sales	- Value commitment (E)

Table 2: Decision matrix for the three identified designs of planning systems.

<table>
<tr><th colspan="2"></th><th colspan="3">Design of the planning systems</th></tr>
<tr><th>Planning process</th><th>Planning decisions (operational level)</th><th>1</th><th>2</th><th>3</th></tr>
<tr><td>Select or buy block</td><td>Harvest units sourcing</td><td rowspan="8">The decision ‘Harvest units sourcing’ is, at least, jointly planned with one of the decisions in the ‘Schedule harvesting’ process.</td><td>This decision is planned individually.</td><td>This decision is planned individually.</td></tr>
<tr><td rowspan="7">Schedule harvesting</td><td>Harvest units scheduling</td><td rowspan="12">At least, one decision in the ‘Schedule harvesting’ process is jointly planned with a decision in the ‘Schedule secondary transportation’ process.</td><td rowspan="7">No decision in the ‘Schedule harvesting’ process can be jointly planned with a decision in another process.</td></tr>
<tr><td>Assortments to produce by harvest unit and allocation to demand</td></tr>
<tr><td>Harvest equipment selection by harvest unit</td></tr>
<tr><td>Harvest unit assignment to contractors/teams</td></tr>
<tr><td>Harvest unit layout</td></tr>
<tr><td>Bucking/merchandising instructions and sorting rules by harvest unit</td></tr>
<tr><td>Harvest crew scheduling</td></tr>
<tr><td rowspan="5">Schedule secondary transportation</td><td>Assortments (re)allocation to demand</td><td rowspan="5">No decision in the ‘Schedule secondary transportation’ process can be jointly planned with a decision in another process.</td><td rowspan="5">No decision in the ‘Schedule secondary transportation’ process can be jointly planned with a decision in another process.</td></tr>
<tr><td>Balance transportation with harvesting, inventory and reception</td></tr>
<tr><td>Transportation quotas assignment to contractors</td></tr>
<tr><td>Transportation equipment routing and scheduling</td></tr>
<tr><td>Transportation crew scheduling</td></tr>
</table>

Table 1 depicts a standard of 17 generic processes based on an adaptation of the Supply Chain Operations Reference (SCOR) model (Supply Chain Council, 2008). It accounts for the main planning and execution processes at the operational level in a WSC. These processes are grouped within meta-processes: “procurement” of standing/harvested timber, “harvesting”, “secondary transportation” and “sales” of harvested timber.

When applied to each of the six cases studies, the description of the plan obtained from each aforementioned planning process allows proposing 13 generic planning decisions at the operational level in a WSC (

Table 2). The “Select or buy block”, “Schedule harvesting” and “Schedule secondary transportation” processes were associated to one, seven and six decisions, respectively. Then, by identifying the main actor(s) taking the decision(s) in each process, three basic WSC planning systems designs were identified: (1) integrated sourcing and harvesting planning (observed in: Canada, Poland, and Sweden), (2) integrated harvesting and transportation planning (observed in: USA), and (3) decoupled sourcing, harvesting and transportation planning (observed in: Chili, and France).

In a supply chain, the decoupling point corresponds to the point where production shifts from being forecast-driven to become customer order-driven. It also corresponds to a point where decisions are made with much less uncertainty. Seven decoupling points locations were identified in the cases: Buy block-to-order, Select block-to-order, Bucking-to-order (only for CTL method), Primary transport-to-order, Merchandising-to-order (only for FT method), Measuring-to-order and Secondary transport-to-order. The location of these decoupling points along the material flow of the WSC is illustrated in the upper part of **Error! Reference source not found.**. Each case uses more than one decoupling point located within at least two of the three main sections of a WSC (i.e. procurement, harvesting, secondary transportation). The proportion of the total demand satisfied per decoupling point is uneven, and roughly half of all the demands are satisfied using more than one decoupling points, which means that inventories located at different steps along the WSC are used to plan demand fulfilment.

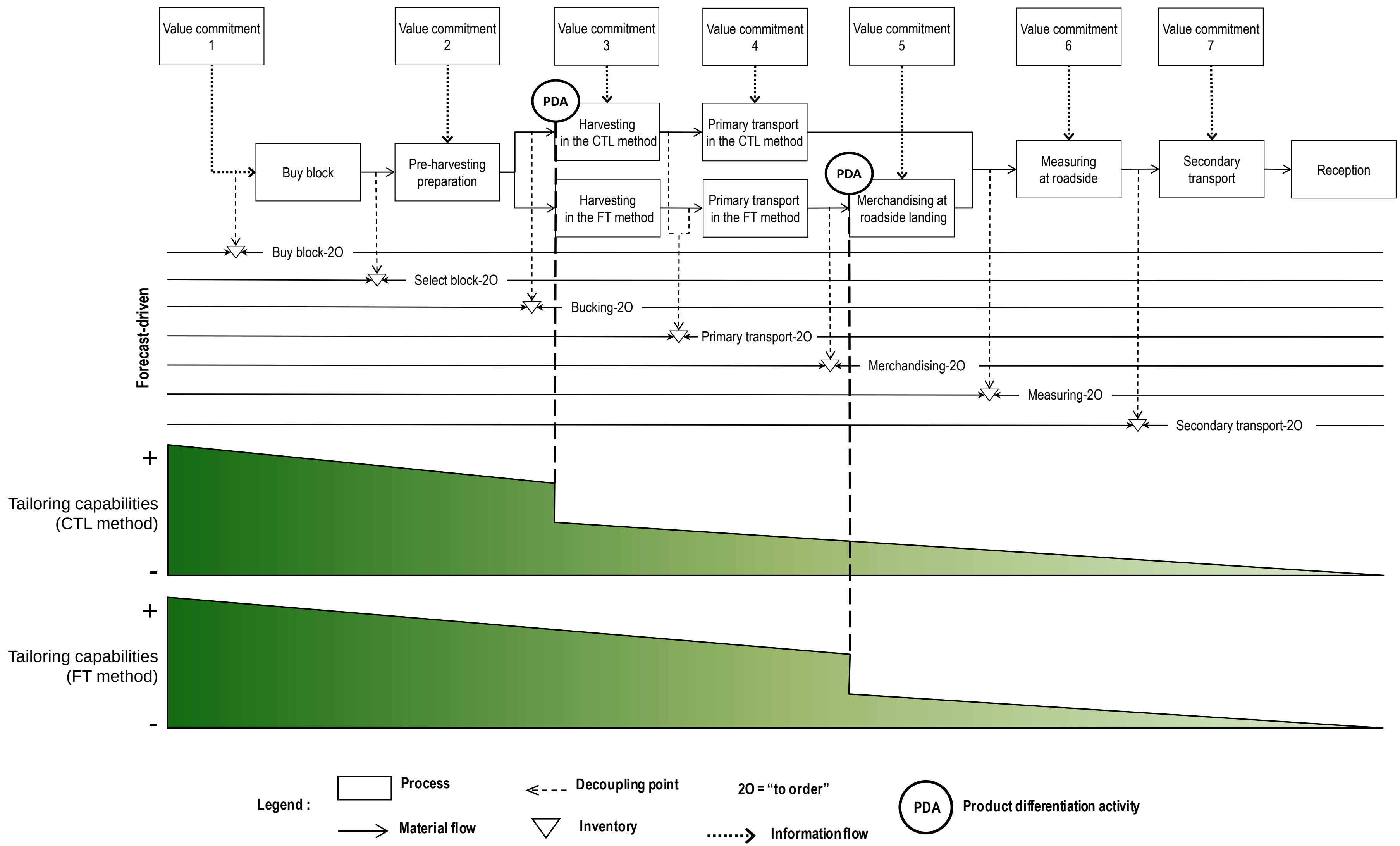


Figure 1: Location of the seven decoupling points and the two main product differentiation activities.

Agility capabilities

The agility capabilities of each WSC were assessed according to the four dimensions of supply chain agility proposed by Christopher (2000): customer sensitivity, process integration, information drivers and network integration. On a 0-4 scale, the developed methodology rates how well different enablers and practices, identified in each of the four aforementioned WSC meta-process, contributed to each of these four dimensions. For instance, Figure presents the evaluation of agility capabilities per meta-process (left side), and the average results per dimension (right side) for the USA case. The agility dimension of information drivers obtained a slightly lower evaluation compared to the three other dimensions but overall the agility capabilities of the USA case were assessed “high”.

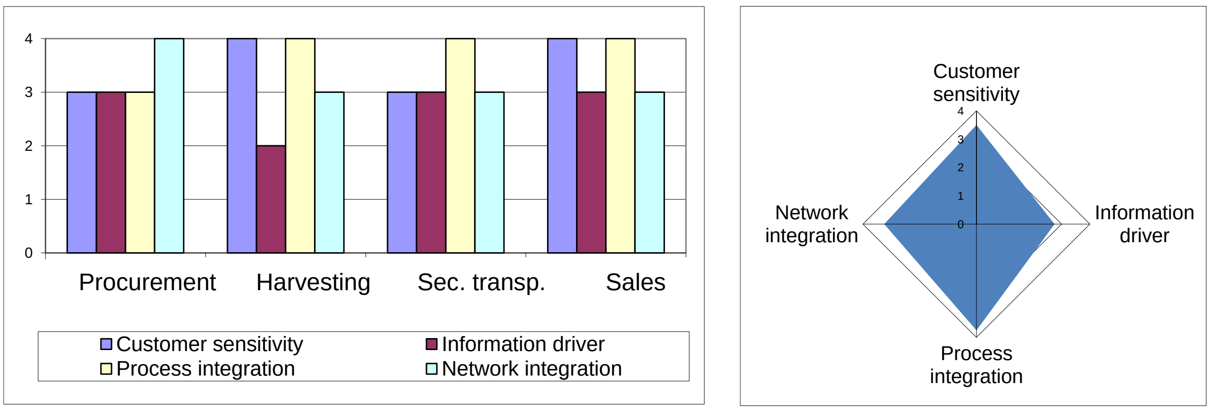


Figure 2: USA case agility capabilities by meta-process (left) and in average (right).

A WSC should strive towards proper agility capabilities in response to uncertainty in their environment. Based on an appraisal of the level of supply and demand uncertainty in each case, three clusters of cases can be made according to their levels of supply (Figure -left) and demand (Figure -right) uncertainty.

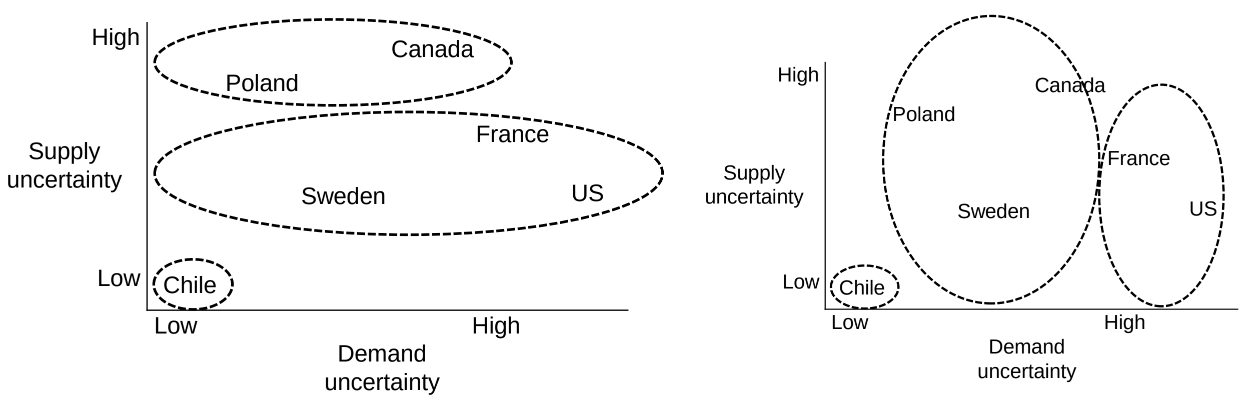


Figure 3: Clusters of cases with similar levels of supply (left) or demand (right) uncertainty.

For each case, to improve their agility capabilities, it appears important to first close the most significant gaps and/or the ones judged priority. The enablers and practices of the cases that stand above average can serve as benchmark. Attention should be paid, however, to the level of uncertainty in the environment of the cases to be used as a reference for others. If their supply and/or demand uncertainty differs considerably, then extra care should be used to adapt and adjust enablers and practices to different conditions. Thus, a case aiming to improve its agility capabilities in respect to one or several of the meta-process associated to the supply side of a WSC (i.e. “procurement”, “harvesting” and “secondary transportation”), should first review the enablers and practices of a case with high agility capabilities and located within the same cluster of supply uncertainty (Figure -left). The same comment applies for a case aiming to improve its agility capabilities on the demand side of a WSC (meta-process “sales”) by searching for the same cluster of demand uncertainty (Figure -right).

According to the generally accepted idea found in the literature on supply chain agility, an environment with high uncertainty calls for a supply chain with high agility capabilities. Thus, if we compare agility capabilities evaluated in the cases and those theoretically required according to the level of uncertainty (in demand and supply), our analysis shows a case (Chile) with high agility capabilities not required by the level of uncertainty. We also observe cases where the uncertainty level calls for higher agility capabilities (France, Canada and Poland for the supply level) and, finally, cases with agility capabilities relatively well balanced with their level of uncertainty (Sweden and USA).

In the literature (e.g. Agarwal et al. (2007); Carvalho et al. (2011)), supply chain agility is also linked to shorter order fulfilment cycle time (i.e. the time from the placement of an order by a customer to the fulfilment of the order by the supplier). The SCOR model splits Order fulfilment cycle time into two parts: order fulfilment process time (OFPT) and order fulfilment dwell time (OFDT). OFPT is defined as the time from the first process to fulfil the demand to the fulfilment of the demand by the supplier. This time includes possible ‘idle time’ and ‘non-value-added lead time’ caused by inefficiencies in the organisation. OFDT is defined as ‘any lead time during the order fulfilment process where no activity takes place, which is imposed by customer requirements’ (Supply Chain Council, 2008). Self-reported and deducted data on order fulfilment cycle time were obtained for each case. Table 3 presents the OFPT and OFDT by case (ranked from the highest to the lowest agility capabilities).

The three cases with the highest agility capabilities did not present a decoupling point located at the end (downstream) of the WSC (secondary transportation section), while the two cases with the lowest agility capabilities did not present a decoupling point located at the beginning of the WSC (procurement section). For the decoupling points located in the procurement and harvesting sections, in general, the higher the agility capabilities, the shorter the average fulfilment cycle time in the section. This is due basically to shorter times in the OFPT, while higher agility capabilities do not impact the OFPT for the decoupling points located in the transportation section. In summary, when comparing location of the decoupling point, agility capabilities and average order fulfilment cycle time of each WSC, it confirms results found in the literature stating that greater supply chain agility is linked to shorter order fulfilment cycle time.

Table 3: Order fulfillment cycle time in the cases.

Supply Chain agility		Procurement		Harvesting		Secondary Transportation	
		OFPT	**OFDT**	**OFPT**	**OFDT**	**OFPT**	**OFDT**
+	**USA**	0.5-1.5 days	A few weeks to months	0.5-1.5 days	≥1 day(s) to a few weeks	*Not used*	*Not used*
	Chile	10 days	A few months	10 days	A few weeks to months	*Not used*	*Not used*
	Swe-den	≤1 month	A few weeks to months	<1 month	A few weeks	≤1 day	A few weeks
	Canada	3-4 weeks	Many weeks to a few months	3-4 weeks	A few weeks	≤1 day	A few weeks
	France	*Not used*	*Not used*	3.5-7 days	2-3 days to a few months	≤1 day	1-3 day(s)
-	**Poland**	*Not used*	*Not used*	3-9 days	A few weeks to two months	≤1 day	≥1 day(s) to a few weeks

Personalisation capabilities

Personalisation refers to a supplier's design of its value proposition (i.e. the product and logistics services specifications) to meet specific needs of customer segments. Personalisation capabilities of each WSC were assessed based on the location of the decoupling points and their respective order fulfilment cycle time. It is assumed that the closer the decoupling point is to the sourcing of standing timber, the easier the specifications of the value proposition can be personalised to a customer.

For the product specifications personalisation, two key processes were identified where most of the product differentiation activities along a WSC occur: merchandising at roadside landing for the FT method or harvesting in the CTL method. Indeed, the process represents the main activity along the WSC where a felled tree is processed in one (FT method) or a set (CTL method) of specific products to be delivered to the mills. Specialising the work-in-progress inventory into specific end products is a process designated as product differentiation activities (PDAs) in the concept of form postponement (Forza et al. 2008). Thus, form postponement consists in delaying one or more PDAs along the manufacturing and distribution process. As illustrated in the lower part of Figure 1, the potential capabilities to tailor product specifications before a PDA are superior to the tailoring capabilities after a PDA. The localisation of the two main PDAs along the WSC is illustrated in Figure 1.

Conclusion

A qualitative framework was developed and applied to rate agility of forest WSC. It was tested on WSC observed in six forest regions of different countries. By providing a description of their WSC and an assessment of its agility and personalisation capabilities, the proposed framework can support an organisation in an exercise of self-diagnosis to identify improvement opportunities and to anticipate the impact of a change in its WSC (e.g. the introduction of a new technology, a new value proposition for a customer). The framework introduced a common vocabulary to be used by researchers and practitioners in different disciplines. It represents an original attempt to develop a reference model for future research addressing WSCs. Our results indicate that WSC in Sweden, USA and Chile benefit from high agility capabilities. WSC observed in Canada, France, and Poland would probably benefit from realigning their agility capabilities to what is required from their environment.

Acknowledgements

The authors acknowledge the contribution of the local host partners in each case study (Dr. Dale Greene and Mr. Shawn Baker, University of Georgia; Drs. William B. Stuart and Laurie Grace, Mississippi State University; Ms. Morgan Vuillermoz and Mr. Adrien Arraiolos, Institut technologique FCBA; Mr. Fabián Cid Yáñez, Universidad Austral de Chile; and Dr. Krzysztof Jodłowski, Instytut Badawczy Leśnictwa) and all the participants from the private and public sectors involved in the case studies, as well as all the experts from local hosts' institutions met during the fieldwork. For their contribution to different topics, the authors also acknowledge Mrs. Anna Furness-Lindén (former researcher at Skogforsk), Dr. Dag Fjeld (Swedish University of Agricultural Sciences), Mr. Martin Opferkuch (University of Freiburg) and Mrs. Élaine Mosconi and Dr. Riadh Azouzi (Université Laval). Finally, the authors also acknowledge the financial support of the European Union, the Quebec Ministry of Economic Development, Innovation and Export Trade and the partners of Skogforsk and the FORAC Research Consortium. Jean-François Audy acknowledges a scholarship by the FQRNT International Internship Program.

References

Agarwal, A., Shankar, R. and Tiwari, M.K. (2007). Modeling agility of supply chain. Industrial Marketing Management, 36(4): 443-457.

Audy, J.-F., Pinotti, M., Westlund, K., D'Amours, S., LeBel, L. and Rönnqvist, M. (2012). Alternative logistic concepts fitting different wood supply situations and markets. Research paper CIRRELT-2012-24, CIRRELT, Canada.

Carvalho, H., Duarte, S. and Cruz Machado, V. (2011). Lean, agile, resilient and green: divergencies and synergies. International Journal of Lean Six Sigma, 2(2): 151-179.

Christopher, M. (2000). The agile supply chain: competing in volatile markets. Industrial Marketing Management, 29(1): 37-44.

Forza, C., Salvador, F. and Trentin, A. (2008). Form postponement effects on operational performance: a typological theory. International Journal of Operations & Production Management, 28(11): 1067-1094.

Supply Chain Council (2008). Supply Chain Operations Reference Model. Version 9.0, 651 pp.

Logging Cost Components of US Timber Producing Regions and Their Use in a Regional Logging Cost Index

Shawn A. Baker[1], W. Dale Greene[2]

Abstract

Data on logging cost components were reported with some frequency through the mid-1980's, but the expansion of contract logging and elimination of company logging crews reduced the ease with which large datasets on logging costs could be readily collected. A timely, accurate indicator of changes in logging costs would establish a baseline against which logging contractors could compare their own costs and would offer buyers and sellers of timber a reference for shifts in cut and haul rates.

To determine the variation in logging costs across the country, we interviewed contractors in each of the four major timber producing regions. We conducted 48 face-to-face interviews across eleven states, and 27 of the interviewed contractors shared information related to their 2011 operating costs. Using the cost information provided by the 19 participants in the South, we developed percentage breakdowns of the key factors driving logging costs.

We developed a logging cost index for the South, where we had the most data on the percentage breakdown of logging costs. Publicly available data on costs of diesel, equipment, maintenance, labor, interest, and other factors were used to drive the changes in the cost index over time. The methodology used to develop the southern logging cost index could be extended to other regions if more region-specific cost data were available.

Introduction

The Bureau of Labor Statistics listed 8,300 logging businesses employing 46,300 people across the U.S. as of the 2nd quarter of 2012 (Bureau of Labor Statistics 2012). In employee wages alone, the logging industry generates $430 million. It is also a vital component of the U.S. forest products supply chain. Despite the importance of the logging industry, information on the condition of the logging workforce has historically been limited. The business is dominated by small independent contractors, and

[1] Research Professional, Center for Forest Business, Warnell School of Forestry & Natural Resources, University of Georgia, Athens, GA 30602-2152
[2] Professor, Center for Forest Business, Warnell School of Forestry & Natural Resources, University of Georgia, Athens, GA 30602-2152

substantial effort is required to gather sufficient information to make generalizations about the industry as a whole.

Many approaches have been designed to estimate the cost of logging operations. Some of these were based on specific detailed historic cost records, while others used simplifying assumptions and reasonable estimates of cost components. All cost estimates need to be based on real data as much as possible to improve their validity. While sources of data on cost components were reported with some frequency through the mid-1980's, the elimination of company logging crews reduced the ease with which large datasets on logging costs could be readily collected.

One previous effort to index logging costs used accounting records collected annually from a group of contractors (Stuart and Grace 1999). The information in reports generated by Stuart *et al.* (2008) has been one of the most widely available indicators of logging cost changes over the past 20 years. One disadvantage of Stuart's reporting was the 1-2 year delay between the recording of the cost information by a contractor and the availability of reports to potential users.

Our objective was to generate a timely, accurate indicator of changes in logging costs to provide value to everyone in the industry. It would establish a baseline against which logging contractors could compare their own costs and would offer buyers and sellers of timber a reference for shifts in cut and haul rates.

Methods

We contacted 95 logging contractors around the country to gauge their interest in participating in the study. Potential participants were selected based on their reputation as reliable record-keepers and above average performers. The goal of the study was not to estimate an average cost for the industry, but to collect accurate cost data from a collection of efficient operators. Contractors who agreed to participate were visited for a face-to-face interview during which data on the structure of their business were collected. In addition, detailed breakdowns on the distribution of costs incurred in 2011 were requested. Follow-up phone calls were made in an attempt to collect data not shared during the interviews.

We used the accounting records of participants as the starting point to calculate a logging cost index by separating the costs into major cost categories: labor, petroleum-based consumables, depreciation, repair & maintenance, interest, insurance, and administrative. We found publicly available cost data tied to most of the major logging cost components. Average wages paid to logging employees, costs for heavy equipment and equipment repairs are all reported by the Bureau of Labor Statistics, retail diesel prices are reported by the Energy Information Administration, and the

Federal Reserve reports interest rates. Combined, these data represented over 90% of the cut and load cost of southern logging operations. Indicators in changes of administrative and insurance costs were not readily apparent. As a result, the core Consumer Price Index (CPI) minus food and fuel was used to modify these portions of the cut and load cost.

Weekly wage data are reported quarterly by the Bureau of Labor Statistics. We weighted the average weekly wage reported in each of the states in a region by the total number of logging employees in each state. This weighted average wage was then used to modify the labor portion of the cut and load rate.

Using the percentage breakdown reported by participants, we weighted each of the public data sources to adjust the cost per ton of that component of the cut and load cost. The initial value of the index was set at $12.50 per ton in the fourth quarter of 2011 to coincide with the data shared by participants.

Haul costs were not included in the index due to the separate and unique distribution of costs associated with operating heavy trucks. Many of the participants in the study did not maintain separate cost records for hauling, making calculation of a detailed cost breakdown problematic.

Results

Of the 95 contractors contacted, 47 agreed to interviews, and 28 ultimately shared cost data (Table 1). Nineteen of the 28 contractors who shared cost data were located in the southern US. As a result, our sample size of contributors was only large enough to allow for development of a cost index for the South.

Table 1. Breakdown of participating contractors by region of the country, including those who provided cost data.

	South	West	Lake States	Northeast
Contractors Contacted	40	19	20	16
Participants	23	8	9	7
No. Providing Cost Data	19	5	2	2
Total Participating Logging Crews	63	34	35	22
Average Contractor Weekly Production (Tons)	4200	4050	1800	3650
Weeks Worked per Year	50	48	49	40

The distribution of cut and load costs from southern logging contractors was similar to previously reported cost distributions (Figure 1). A major difference between the index developed here and the previous logging cost index reported by Stuart *et al.* (2008) is the exclusion of haul costs in the index methodology we use. While contractor records usually included detailed information on the cost associated with contract hauling, contract hauling only comprised roughly 45% of the total loads delivered for participating contractors. Detailed breakdowns of the cost to operate their own heavy trucks were not available from the majority of respondents, hindering our ability to accurately link the major cost components to cost indicators. Our index therefore only reports cut and load costs.

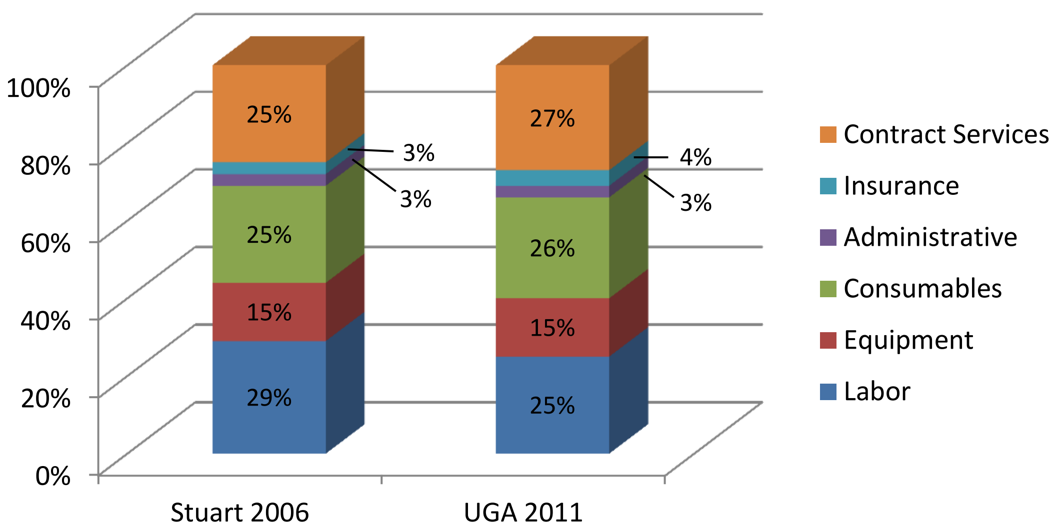


Figure 1. Percent breakdown of major cut and haul cost categories reported by Stuart, *et al.* (2008) for 2006 and for Southern contractors from this study.

Excluding the haul costs (the majority of the "contracted services" referenced by Stuart and Grace (1999)), labor was the largest cost component, followed by fuel, depreciation and repair and maintenance (Figure 2). The initial index value was set to $12.50 per ton, which was the average cut and load cost for participating contractors in 2011, rounded to the nearest $0.50. The proportion of the cost in each of the major cost categories was linked to the fourth quarter 2011 value of the public data source tied to that category. For example, depreciation represented 19% of the cut and load cost ($2.375 per ton). The value of the PPI for heavy equipment (NAICS 333120) over the last three months of 2011 was 231.6. The contribution of equipment depreciation to the index in any quarter is the initial depreciation cost ($2.375) multiplied times the PPI for heavy equipment in that quarter divided by the initial PPI for heavy equipment (231.6).

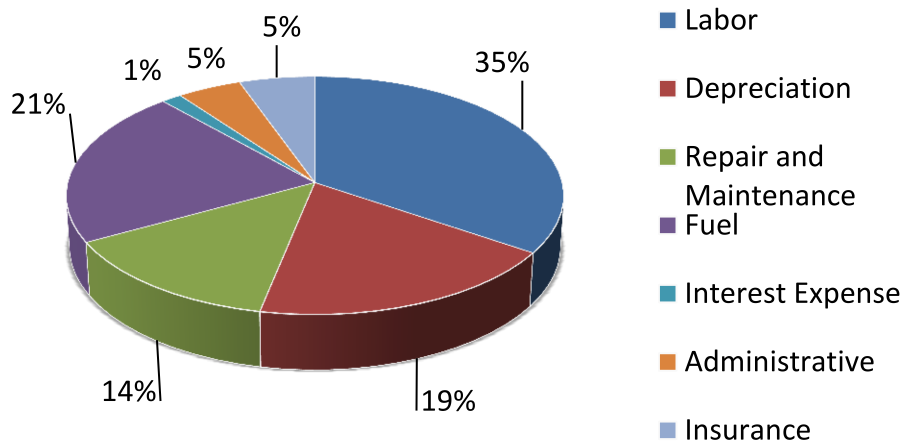


Figure 2. Percent breakdown of cut and load costs for Southern contractors by major cost category, 2011.

Using this methodology, we were able to track the logging cost index moving forward past 2011 as well as compare the index value backward to the values reported by Stuart *et al.* (2008). To compare index values back to 1995, we had to replace the PPI for heavy machinery repairs (NAICS 811310), which was created in 2007, with the CPI as no comparable data were available. The trend of the quarterly index we generated compared favorably with the annual trend of Stuart *et al*. (Figure 3).

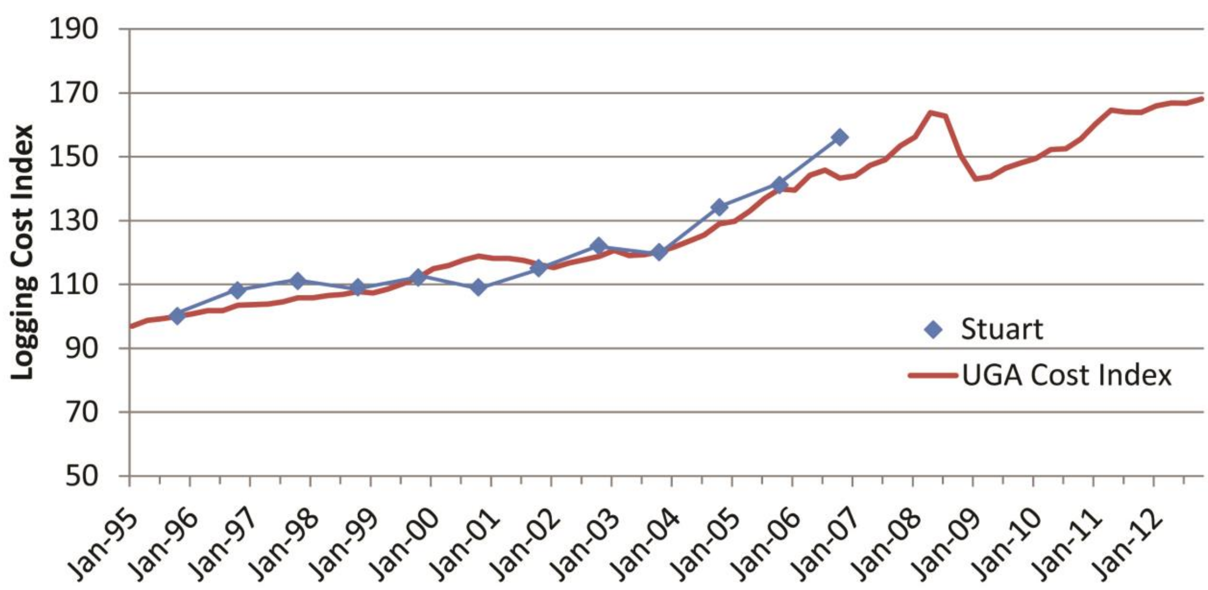


Figure 3. The UGA Logging Cost Index shown quarterly and Stuart's Logging Cost Index reported annually, from 1995-2006.

Historic performance of the index methodology is not a guarantee of future accuracy. We intend to evaluate the trends in logging cost reported by the index in the future using data provided by logging contractors. The approach appears to provide a simple, rapid measure of changes in logging costs which can aid the industry in identifying large shifts in logging cost. The structure of the index should also indicate the scale of changes in volatile cost components, such as diesel fuel.

References

Bureau of Labor Statistics. 2012. *Quarterly Census of Employment and Wages*. Available online at http://www.bls.gov/cew/home.htm; last accessed November 15, 2012.

Stuart, W.B., and L.A. Grace. 1999. Wood supplier productivity and cost survey. American Pulpwood Association Technical Paper. 46 p.

Stuart, W.B., L.A. Grace, C.B. Altizer, and J.J. Smith. 2008. 2006 Preliminary Logging Cost Indices. Wood Supply Research Institute. 14 p.

Preparing for expansion in the logging workforce: Results from a survey of logging contractors in a region expecting rapid growth in woody biomass utilization

Scott M. Barrett[1]
[1]Extension Associate and Coordinator, Virginia SHARP Logger Program
Virginia Tech Department of Forest Resources and Environmental Conservation
228 Cheatham Hall (0324)
Blacksburg, VA 24061
540-231-6494 sbarrett@vt.edu

Abstract

Following a dramatic downturn, the forest industry in southeastern Virginia and adjacent North Carolina is experiencing rapid expansion. This expansion is led by the wood energy sector with plans to produce electricity and pellets. Additionally, a previously closed paper mill in Franklin, VA was recently repurposed and reopened. Combined, these facilities are expected to have the capacity to utilize over 3 million additional tons of wood compared to 2012 consumption levels in this region. Increased demand is expected to exceed the capacity of the existing logging workforce. The southeast Virginia forestry community, along with a local community college came together to develop a task force focused on addressing a potential shortage of logging capacity. A mail survey of existing logging business owners in southeastern Virginia was conducted to determine needs and focus task force efforts. Eighty-six percent of respondents indicated the expected change in wood markets would benefit their business. Sixty-one percent of operations were evaluating whether or not to expand roundwood harvesting capacity. Nineteen percent of operations currently harvested fuel chips. Fifty percent of operations not currently harvesting fuel chips believed they could feasibly add a chipper to utilize logging residues for energy. Primary barriers related to expanding capacity included uncertainty about new markets, concern that demand will go down after investing in additional equipment, and concerns related to trucking.

INTRODUCTION

Southeastern Virginia and Northeastern North Carolina are poised for rapid growth in wood utilization. This growth is a result of the re-opening of the paper mill in Franklin (International Paper 2011), a new pellet mill under construction in Southampton County, VA and construction of two new pellet mills in northeastern North Carolina (Enviva 2013). In addition, two power plants are under renovation and will soon be utilizing wood fuel for producing electricity in Hopewell, VA and Southampton County, VA (Dominion 2013). Based on announced wood consuming facility start-ups, by the end of 2013 wood consumption in this region could exceed 3 million additional tons compared to 2012 wood consumption levels.

In response to this anticipated rapid increase in wood utilization, the Paul D. Camp Community College Division of Workforce Development took steps to develop a resource center to help existing logging businesses that are interested in expanding operations and to help new owners considering entering the logging business. A task force was developed to provide recommendations and assist with developing a resource center at Paul D. Camp Community College. This task force was named the Southeast Virginia Logging Capacity Task Force and adopted the following mission statement: “To facilitate an increase in logging capacity by providing training and additional resources”. The task force consisted of representatives from the paper industry, pellet industry, the VA Loggers Association, the VA Forestry Association, Paul D. Camp Community College, consulting firms and Virginia Tech Forestry Extension.

METHODS

A mail survey was utilized to assess needs within the logging community and to help prioritize efforts of the committee. A questionnaire was developed with assistance from the Logging Capacity Task Force. The survey was developed and administered based on the Dillman (2000) method and included questions to gather basic demographic and operational characteristics from logging business owners as well as measures of their interest in services the logging business resource center could offer. The survey also included questions to identify barriers in relation to expanding operations to meet the new demand for wood.

The questionnaire was distributed to southeastern Virginia logging business owners using a mailing list of VA SHARP Logger program participants. The mailing list included logging businesses located in Southeastern Virginia in the counties of Southampton, Suffolk, Isle of Wight, Surry, Prince George, Dinwiddie, Sussex, Greensville, Brunswick, and Mecklenburg. Questionnaires were mailed in November and December 2012.

RESULTS AND DISCUSSION

Thirty-six out of 75 eligible business owners completed the questionnaire, resulting in an adjusted response rate of 48%. On average, respondents were 49 years old and had operated their own logging business for 15 years. Thirty-six percent of respondents were college graduates, 11% had attended some college, 47% were high school graduates and 6% had attended some high school. On average, owners reported that 74% of their total production was pine. Firms had an average of 1.7 crews (Figure 1) with an average total weekly production from all crews of 69 loads per week (Figure 2).

Figure 1. Number of crews operated by logging business owners.

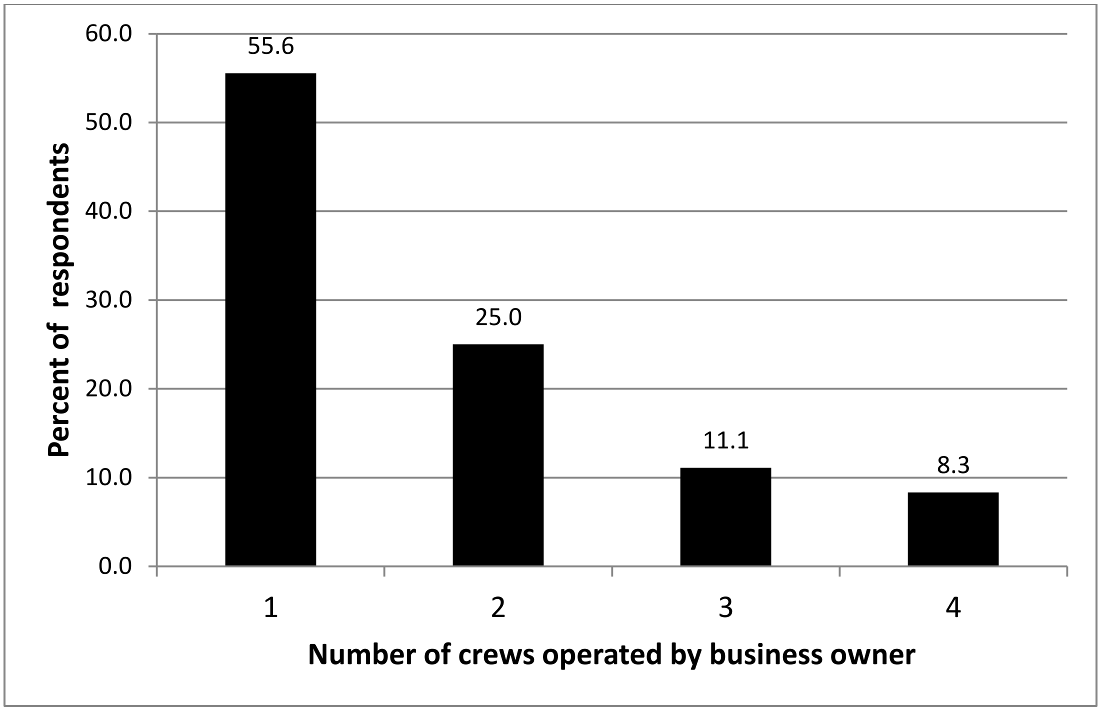
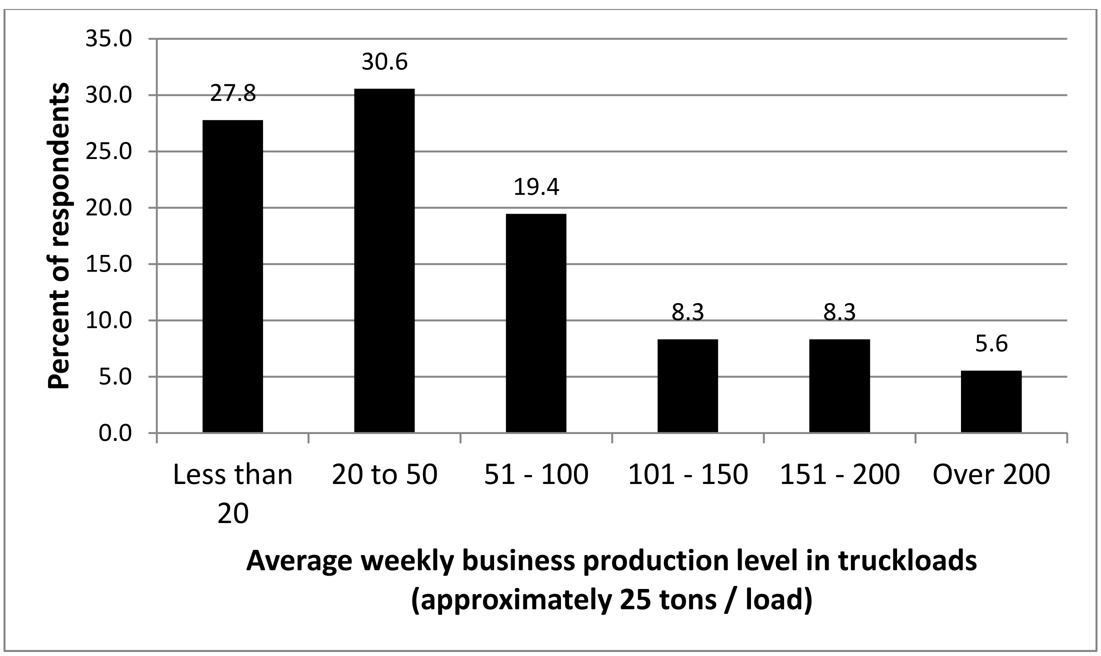


Figure 2. Average current production level for logging businesses (truckloads per week).

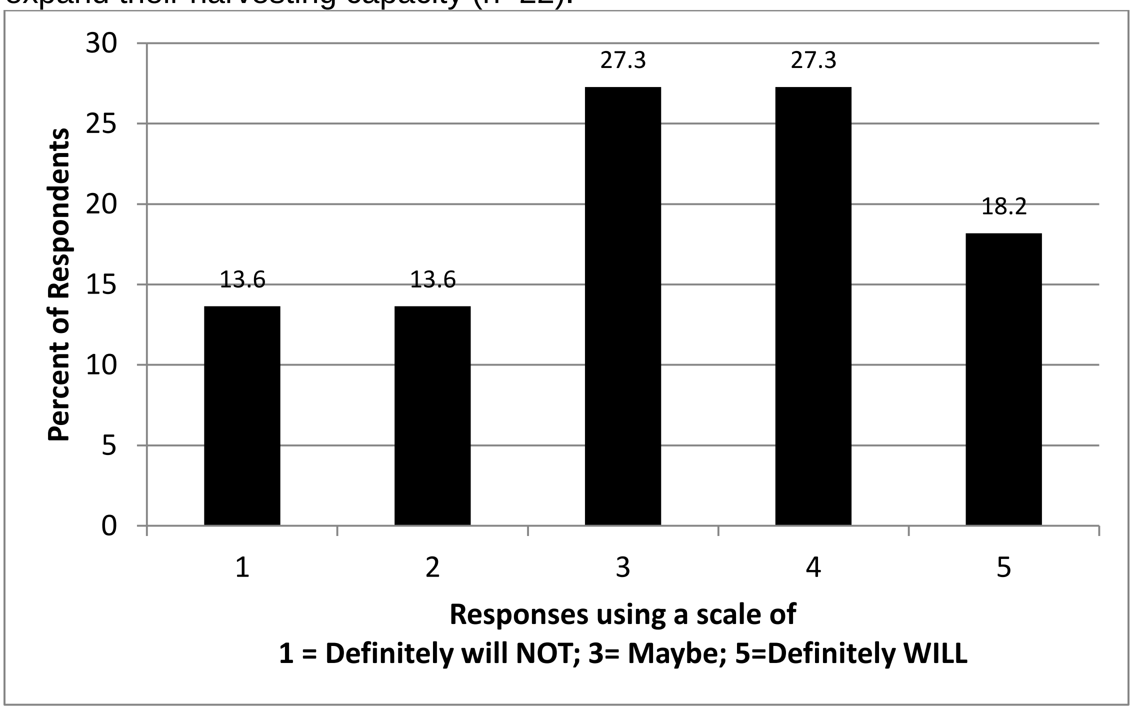


Production levels were similar to those reported by Bolding et al. (2010) for logging operations in the Coastal Plain of Virginia based on a larger statewide survey of logging businesses.

Business owner expectations for expansion

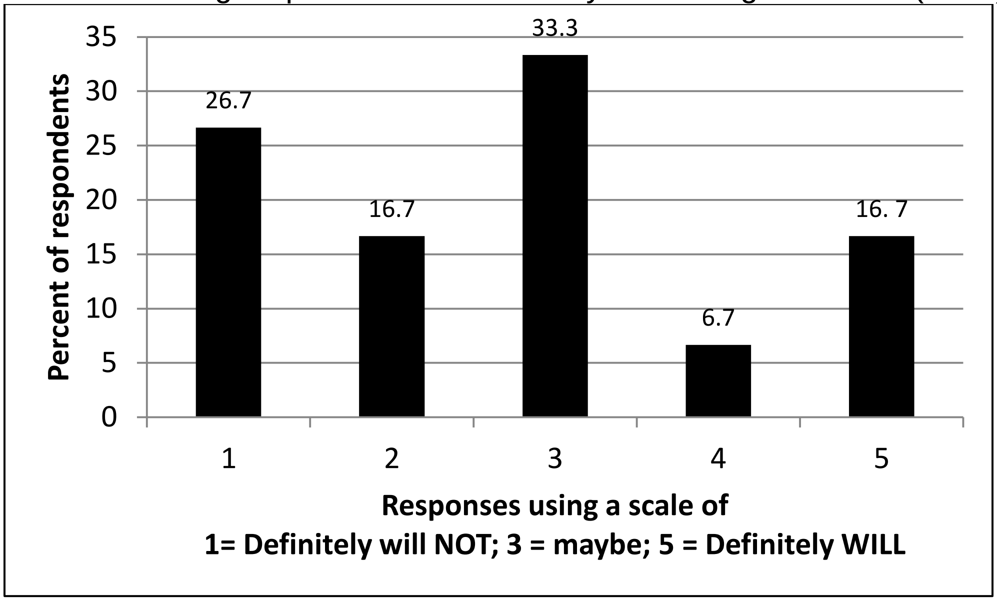
Eighty-six percent of respondents expected increases in markets for pulpwood and biomass would bring substantial changes to wood markets that would improve their business. When asked if they were considering expanding their roundwood harvesting capacity by adding additional equipment or crew(s) in the next 1-2 years 22 of 36 respondents (61%) indicated they were currently evaluating whether or not to expand. Most of the 22 respondents (73%) indicated "maybe" they would expand or that they were likely to expand their operations (Figure 3). When asked if they would be more likely to expand roundwood harvesting operations if there were additional sawtimber markets, 76% responded "Yes".

Figure 3. Likelihood of expanding roundwood harvesting capacity by adding additional equipment or crews for respondents that are currently evaluating whether or not to expand their harvesting capacity (n=22).



Additional markets will utilize both roundwood and wood fuel chips, so an increase will be needed in production capacity for both. Only 19% of respondents indicated they currently harvested logging residues for wood fuel. Of those that did not, 50% indicated they could effectively add a chipper and efficiently harvest biomass fuel chips from logging residues such as limbs, tops, and non-merchantable trees. When asked how likely they were to add a chipper or grinder to utilize wood fuel from logging residues, most indicated "maybe" or that they were not likely to (Figure 4).

Figure 4. Likelihood of adding a chipper or grinder to harvest wood fuel from logging residues among respondents not currently harvesting wood fuel (n=30).



Barriers to increasing production

The questionnaire provided a list of 10 issues that could be a barrier for logging businesses considering an expansion of their harvesting capacity (Table 1). Respondents were asked to rank each of the issues using a scale of 1 to 5 where 1 = not a concern at all; 2= slight concern; 3=moderate concern; 4=very concerned; 5 = extreme concern.

Table 1. Business owner response related to barriers associated with expanding logging production capacity. Responses use the following scale where: 1 = not a concern at all; 2= slight concern; 3=moderate concern; 4=very concerned; 5 = extreme concern.

Barriers related to expanding capacity	**Response Mean**
Trucking and DOT regulations	**4.22**
Concern that demand will go down after investing in additional equipment	**3.83**
Uncertainty about the long term stability of new markets	**3.75**
Concern that you won’t get a solid purchasing commitment from wood consuming mills	**3.72**
Finding qualified truck drivers to deliver additional production	**3.64**
Finding enough suitable timber to harvest	**3.61**
Lack of markets for sawtimber	**3.61**
Environmental concerns and regulations	**3.5**
Finding suitable logging equipment operators	**3.44**
Obtaining financing to purchase additional equipment	**2.92**

The top three most concerning issues were: trucking and DOT regulations, concern that demand will go down after investing in additional equipment, and uncertainty about the long term stability of new markets. Concerns related to trucking and trucking efficiency have also been noted by previous studies (Lang and Mendell 2012, Baker and Greene 2008).

Business owner's interest in using a logging resource center

Respondents were provided with a list of 10 possible services which Paul D. Camp Community College Division of Workforce Development could offer to help existing logging businesses that are interested in expanding operations and to help new businesses considering entering into the logging business (Table 2).

Table 2. Responses from logging business owners related to the usefulness of potential services offered by a logging business resource center at Paul D. Camp Community College Workforce Development Center. Responses use the following scale where: 1 = not useful; 2= slightly useful; 3=moderately useful; 4=very useful; 5 = extremely useful.

Potential Services a Resource Center Could Offer	Response Mean
Establishing a co-op that provides savings on tools, supplies, and fuel	**4.39**
Providing assistance to help comply with laws and regulations	**3.72**
Providing a truck driver training program	**3.44**
Developing a business plan to understand cost and potential return	**3.42**
Providing a logging equipment operator training program	**3.42**
Providing assistance to evaluate operations using a logging cost calculator	**3.36**
Providing assistance to help owners access various equipment financing options	**3.33**
Providing business counseling services	**3.14**
Providing assistance locating timber hauling service providers	**3.14**
Providing assistance in evaluating equipment selection	**2.5**

Eighty-two percent of respondents indicated it would be helpful for the Paul D. Camp Community College Division of Workforce Development to offer a logging business resource center. Respondents were asked how likely they would be to use a logging business resource center using a scale of 1 to 5 where 1 = definitely would not use; 3 = may use; 5= definitely would use. Less than 17% responded with a 1 or 2 indicating they would not likely use the services of a logging business resource center. The remainder, over 83% indicated they may use, or would use the resource center.

CONCLUSIONS

With recently reopened mills and multiple new wood using facilities currently under construction, southeast Virginia will likely see dramatic increases in wood utilization in the near future. Most loggers believed that that predicted demand will be beneficial for their operations. While not all businesses were interested in expanding roundwood harvesting capacity, many were considering the option of expanding harvesting capacity for both roundwood and wood fuel. Even with almost certain expansion in markets, and willingness among business owners, there can still be considerable barriers to expanding logging operations. Logging businesses believed it would be useful to develop a logging resource center at the community college and most indicated they would use the services of the center. The mail survey was a useful tool for identifying needs and helping the task force prioritize potential services they may offer. Rankings of potential services will be helpful to the task force as they move forward to facilitate logging capacity expansion by addressing issues such as transportation, business planning, and assistance in complying with regulations.

REFERENCES

Baker, S. A. and D.W. Greene. 2008. Changes in Georgia's Logging Workforce, 1987-2007. Southern Journal of Applied Forestry, 32(2), 60-68.

Bolding, M.C., S.M. Barrett, J.F. Munsell, and M.C. Groover. 2010. Characteristics of Virginia's logging businesses in a changing timber market. Forest Products Journal 60(1):86-93.

Dillman, D.A. 2000. Mail and Internet Surveys: The Tailored Design Method. John Wiley and Sons, NewYork. 480pp.

Dominion Virginia Power. 2013. Biomass Conversions. Available online at https://www.dom.com/about/stations/renewable/biomass-conversion.jsp last accessed on May 7, 2013.

Enviva. 2013. Manufacturing Operations. Available online at http://www.envivabiomass.com/manufacturing-operations/ last accessed on May 7, 2013.

International Paper. 2011. International Paper Announces Repurposing of its Franklin, VA Mill. Available online at http://investor.internationalpaper.com/phoenix.zhtml?c=73062&p=irol-newsArticle_Print&ID=1564671&highlight= last accessed on May 7, 2013.

Lang, A. H. and B.C. Mendell. (2012). Sustainable Wood Procurement: What the Literature Tells Us. Journal of Forestry, 110(3): 157-163.

Production Tracking System for Swing-to-Tree Feller Bunchers

Jeffrey G. Benjamin[1] and Donald Burr[2]

[1] Associate Professor of Forest Operations, University of Maine, Orono ME
[2] Equipment Operator, Madden Timberlands, Passadumkeag ME

Abstract (Oral Presentation):

Successful logging contractors continuously seek ways to improve their operations. The key to process improvement is accurate measurement of critical metrics to obtain baseline data that can be monitored over time. There are many tools, techniques, and technologies commercially available to monitor production in forest operations, but they are almost exclusively for cut-to-length operations. For example, computer technology is readily available in cut-to-length harvesters to measure and record volume production, piece count, productive time, and fuel consumption. Unfortunately, there are few options available for production tracking with whole-tree systems. This is especially critical in Maine where over 80% of the volume harvested annually is with swing-to-tree feller bunchers. It may take several weeks from the time the machine begins a new harvest to when production can be estimated at roadside. An innovative logging contractor in Maine has collaborated with the University of Maine to develop a prototype system for a swing-to-tree feller buncher that automatically estimates, records, and geo-references twitch sizes during active logging operations. We have developed a relationship between hydraulic pressure readings in the harvesting head to the weight of trees per accumulation. Pressure readings are recorded in real time using a laptop computer in the cab and then converted to twitch weights using a predetermined function. Preliminary results indicate that production estimates are within 10% of the actual weight of logs on a loaded logging truck.

Introduction

The logging industry in the Northeast United States has faced significant challenges in recent years including a fragmented supply chain, rising fuel prices, high equipment replacement costs and variable markets. Logging contractors must continuously seek innovative ways to improve their operations to overcome these challenges. As outlined by Coup et al. (2011) it is possible to apply principles of statistical process control to forest operations, but the key to process improvement is accurate measurement of critical metrics to obtain baseline data that can be monitored over time.

There are many tools, techniques, and technologies commercially available to monitor production in forest operations, but they are almost exclusively for cut-to-length operations. For example, computer technology is readily available in cut-to-length harvesters to measure and record volume production, piece count, productive time, and fuel consumption. Unfortunately, there are few options available for production tracking with whole-tree systems. This is especially critical in Maine where over 80% of the volume harvested annually is with swing-to-tree feller bunchers (Leon and Benjamin 2013) and where it may take several weeks from the time the machine begins a new harvest to when production can be estimated at roadside. <u>The objective of this paper is to present a production tracking system for swing-to-tree feller bunchers.</u>

Approach

During the winter of 2012, researchers at the University of Maine collaborated with a local logging contractor to determine a relationship between hydraulic pressure at the harvesting head and the weight of trees accumulated in the head. A pressure transducer (PX409 by Omegadyne Inc.) was inserted into the pressure line on the lift-side of the main boom cylinder (Figure 1) on a 1996 Timberjack 608 with a Koehring 4542 harvesting head. The transducer output (psi) links to a tablet computer at 1-second intervals through a USB connection.

Figure 1. Location of splice into hydraulic line for lift pressure readings. Transducer and tablet computer are installed in the machine cab.

In April 2012, a partial load of 20 tree length logs was weighed at a sort yard in Passadumkeag, Maine using industry standard truck scales. An additional 12 tree length logs were numbered with spray paint, separately loaded onto the same log truck and re-scaled. Weights of each numbered log were then calculated by subtracting the previous scale reading. All logs were unloaded at a separate yard in the facility (Figure 2). The 12 numbered test logs were picked up separately (and in bunches) multiple times each with the boom extended 10 ft. and 16ft. from the cab. The harvesting head (with logs) was lifted up from ground position to simulate the movement of an actual tree harvest. The time for each sequence of lifting was recorded to coincide with the 1-second readings from the pressure transducer system.

Figure 2. Feller buncher boom extended to 10 ft. during preparations for testing in log sort yard. Twelve numbered test logs in foreground.

The maximum transducer reading for each lifting sequence, as shown in a sample on Figure 3, was compared to the known test log weights using simple linear regression techniques in R (R Core Team 2012). Linear models were developed for data collected with the boom extended 10 ft., 16 ft. and also for all data combined. Transducer readings for lift sequences using the 20 unnumbered logs from the partial load described above were used to calibrate the linear models.

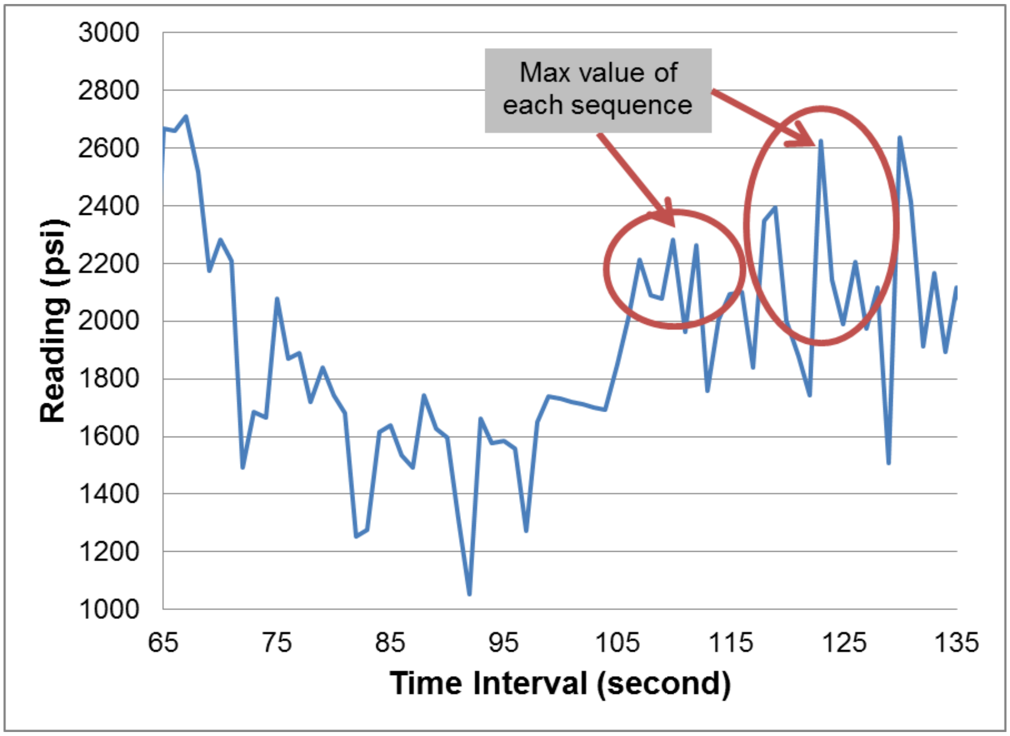


Figure 3. Sample output from transducer system. Peak values within each lifting sequence were used to compare with log weights and to develop linear models.

Results

Total log weight in this study was approximately 18 tons (35,880 lbs). The 12 test logs weighed 14,540 lbs. and the 20 calibration logs weighed 21,340 lbs. Peak readings from the lift sequences for each log showed considerable variation which is not surprising given the nature of the boom movements associated with swing-to-tree feller bunchers. As expected, both the pressure reading (PSI) and the distance of the boom from the cab (DIST) were significant in the prediction of stem weight in Model 1 (Table 1, Figure 4), but in Model 2 pressure reading alone still explained 24 percent of the variation in the data.

Table 1. Regression coefficients and summary statistics for linear model to predict stem weight (lbs).

Model	Adj. R^2	Coefficients	Estimate	Std. Error	t value	p value
1	0.42	Intercept	-143.354	181.196	-0.791	0.430
		PSI (psi)	1.043	0.097	10.780	<0.001
		DIST (ft)	-90.284	12.970	-6.961	<0.001
2	0.24	Intercept	-281.336	204.797	-1.374	0.171
		PSI (psi)	-0.608	0.084	7.239	<0.001

Figure 4. Model 1 prediction of stem weight (lbs) based on boom extension of 10 ft. (solid circles and thick line) and 16 ft. (open circles and thin line).

Discussion / Conclusion

Although the above models are not ideal to predict individual stem weight, the important consideration is how well they predict the weight of a load of logs. When each model was used to predict the weight of the 20 unnumbered logs the results were much more meaningful and encouraging to the logging contractor (Table 2). In fact, Model 1 only underestimated a 10 ton partial load by 9 to 10 percent. Clearly the effect of boom distance significantly limits predictions for Model 2, but on average this model would only under predict by 13 percent. More testing of the models during active logging conditions is required as there are likely to be additional spikes in pressure during harvesting that were not simulated in this study. Since whole-tree harvesting operations currently have no mechanism to estimate production of feller-bunchers, this system is still a significant step forward. This system is expected to aid in the production and planning of biomass harvests specifically.

Table 2. Comparison of predicted weight to actual weight for the 20 calibration logs.

Model	Prediction (lbs)	Actual (lbs)	Difference (%)
1 (Based on data at 10ft.)	19,253	21,340	-9.8
1 (Based on data at 16ft.)	19,359	21,340	-9.3
2 (Based on data at 10ft.)	16,153	21,340	-24.3
2 (Based on data at 16ft.)	18,632	21,340	-1.1

It is important to note that although prediction of stem weight is clearly improved by the addition of boom distance from the cab (Model 1), this measurement is neither constant during active operations nor easy to obtain. Until an automated system is developed to measure boom extension, accuracy in the predictions will have to be sacrificed by using Model 2 or using an average distance in Model 1. This project is ongoing with recent addition of an electronic “trigger” in the data recording system to indicate that a merchantable stem has been cut and that the subsequent spike in pressure is the one to use in the model. Future plans will incorporate an automated boom distance measurement using laser technology and geo-referencing bunches by weight in the on-board GIS system. A full-scale calibration of system performance on a biomass harvest operation is planned for 2013.

Literature Cited

Coup, C.E., J.G. Benjamin, and R.W. Rice. 2011. Applying Statistical Process Control to Feller Bunchers in Maine. Paper presented at the 34th Council on Forest Engineering. June 12-15. Quebec City, Canada.

Leon, B. and J.G. Benjamin. 2013. A Survey of Business Attributes, Harvest Capacity, and Equipment Infrastructure of Logging Businesses in the Northern Forest. The Northern Forest Logging Industry Assessment. University of Maine. Orono, ME. 29p.

R Core Team. 2012. R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing. V 2.15.

Evaluating the system logistics of a biomass recovery operation in northern California

Joel A. Bisson[1], Sang-Kyun Han[2], Han-Sup Han[3]

1. Research Associate, Department of Forestry and Wildland Resources, Humboldt State University, Arcata, California, U.S.A (Presenting Author)
2. Assistant Professor, Department of Forestry and Landscape Architecture, Korea National College of Agriculture and Fisheries, Hwaseong-si, Gyeonggi-do, South Korea
3. Professor, Department of Forestry and Wildland Resources, Humboldt State University, Arcata, California, U.S.A

In the north coast of California some of the benefits of utilizing forest residues resulting from harvesting operations include expanding current bioenergy generation, reducing site preparation costs, and reducing hazardous fuels. Despite its abundance, uses, and advantages, forest residues remain underutilized due to economic and operational barriers related to the cost of collecting, processing, and transporting a product with low market value. In this study, we evaluated the productivity and cost of every function in a unique biomass recovery operation to determine cost effective system logistics. Costs analysis determined a stump-to-power plant cost at $36.70 per bone dry ton (BDT) with a one-way hauling distance of 15.5 miles. The system was divided into three segments: collection, comminution, and transportation. Average costs per segment were, $8.63, $17.11, and $10.97/BDT respectively. To control overall cost it is imparative to maintain maximum productivity of the most expensive function (i.e. grinding in this study). Therefore, upstream and downstream functions were examined to determine how they influence the system. Regression analysis on the loader operation show a 33% increase in cycle time when handling hardwood whole trees piled at a landing compared to conifer slash piled within the unit. Analysis on a modified dump truck used in the pre-haul, confirm that distance has a significant impact on overall centralized biomass grinding operation: a 20% reduction in its productivity due to increase travel time resulted in a 25% increase in grinding cost. A decoupled transport system used all wheel drive tractors to haul hog fuel from the grinder to a trailer landing and regular highway tractors to complete the trip to the power plant. This system was found to reduce delays in loading and improved access to the grinding location. Through an understanding of the complete system we could identify cost saving elements, adjust up stream productivity to meet demand, and reduce the overall cost of a biomass recovery operation.

Keywords: biomass energy, forest biomass, primary transport, system balance, logging slash

Introduction

The utilization of forest residues has great potential for expanding electrical power generation from alternative fuel sources on the north coast of California. Currently, our processed sub-merchantable or small diameter trees, limbs, tops, logging slash, and mill waste, power a third or 60 MW of Humboldt County's electical demand (Center 2012). County wide, its availability has been estimated to provide enough to support up to 220 MW capacity (Williams 2007 - Report).

In addition to increasing power generation, the recovery of forest residues on commercial timberlands has its benefits by significantly reducing site preperation costs. According to Alcorn (2012), direct cost to remove piled residues is about the same as burning it without the risk of fire and air quality issues. The total cost savings to reforestation activities can range from $350/acre to $800/acre or more, when consequent reductions in carbon emissions, fire risks and herbicide application are considered (Alcorn 2012).

Benefits from biomass recovery can also be realized in the mechanical removal of slash piles created from fuel management practices. This method has been used on National Forests in northern California as an alternative to open pile burning as a way to avoid negative effects such as smoke production, residual tree mortality, and the risk of fire escape (Han et al. 2010).

Despite its abundance, use as an alternative fuel, and advantages in timber harvesting, forest residues remain to be underutilized due to economical and operational barriers related to the cost of collecting, processing, and transporting a product with low market value. Pan et al. (2007) reported that average stump to energy plant production cost of harvesting, processing, and transporting small diameter trees (< 10 inch) was $55.27/bone dry ton (BDT), of which 47% and 23% of the cost are from transportation and processing, respectively. They also suggested that improved system balance reducing operational delays and utilizing residues already piled at the landing were identified as ways to improve productivity and reduce cost.

Methods to improve transportation of residues from the stump to a centralized processing area were also examined (Harrill et al. 2009). In this study, bundles were loaded into hook-lift trucks and hauled to a centralized grinding area. The total production cost to bundle, load, haul, and grind was $60.98/BDT. High system cost resulted from poor system balance suggesting an improvement in pairing of machine's capacity and operational productivity could result in a lower biomass operations cost.

In a similar study, hook-lift trucks were used to haul slash piled at landings and along road sides to a centralized location for processing. The total production cost of $48.08/BDT was possible due to careful planning and strategic logistical arrangements (Han et al. 2010).

Productivity and cost of hook-lift trucks used to remove slash piles from shaded fuelbreak treatments not accessable by typical highway chip trucks were also examined. Collection and pre-hauling (landing to a central grinding site) costs were observed at $30.68/ BDT with a note that cost could significantly increase with an increase in hauling distance (Han, et al. 2010).

In a more recent study, Anderson et al. (2012) reported a comparison between the transport of slash to a concentration yard using 5th wheel end-dump trucks and transport of ground material in high-sided dump trucks to the concentration yard. System costs were comparable at $23.62 and $24.52 respectively. In both cases, the system was dependent on appropriately balancing productivity rates of individual machines.

In all these studies, an understanding of individual machine productivity and cost was essentail in determining an efficient system balance. To improve our knowledge of cost reduction methods and system balance techniques, this study investigated the production cost of collecting, processing, and transporting forest residues from mixed conifer clear cut harvests on the north coast of California. The emphasis of this study was to identify key variables that influence the productivity of individual functions in an attempt to create system balance and control cost.

Study Methods

Study site and biomass recovery system description

The study was conducted on a private industrial timberland in northern California that typically utilizes clearcut harvesting methods. Forest residues in the form of limbs, tops, small diameter trees, and sub-merchantable trees of mixed conifer and whole-tree hardwood were piled along the roadside, at landings, or scattered throughout the harvested units. We selected six separate units for this study ranging from 7 to 33 acres in size. The vegetation was second growth mixed conifer consisting of redwood (*Sequoia sempervirens*), Douglas-fir (*Pseudotsuga menziesii*) and tanoak (*Lithocarpus densiflorus*). The units were previously harvested using either a shovel logging or cable yarding system, depending on ground slope. The amount of biomass removed ranged from 12 to 55 BDT/acre and was dependent of harvest unit size, harvesting method, and access (Alcorn 2012).

The study observed the collection, comminution, and transportation of forest residues (Fig. 1). The collection segment of the operation started in the harvested unit with a loader (Linkbelt 3400) using a rotating 10 tine grapple. The loader collected from piles at roadside landings, piles within the unit, or from compiling scattered residues. Its primary function was to load an all-wheel drive articulated dump truck (Volvo A35C or Caterpillar D300D) modified with additional side walls and a rear gate extension to increase the normal carrying volume to 50 cubic yards or more when whole trees or long limbs/tops are loaded beyond the extended tail end. In addition the truck used skidder tires for increased traction as it hauled material over native surface spur and single lane roads with an average grade of ± 4% to a centralized processing area.

The comminution segment was the central part of the biomass recovery operation logistics. It incorporated a majority of the machines beginning with the dump truck delivering material to the loader. The loader (Linkbelt 3400) using a rotating 7 tine grapple, swung dumped material 90 -180 degrees onto the grinder's (Perterson Pacific 5710C) infeed conveyer. After processing the hogfuel was fed via conveyor into a positioned chip trailer. This segment of the operation required adequate space to accommodate every machine.

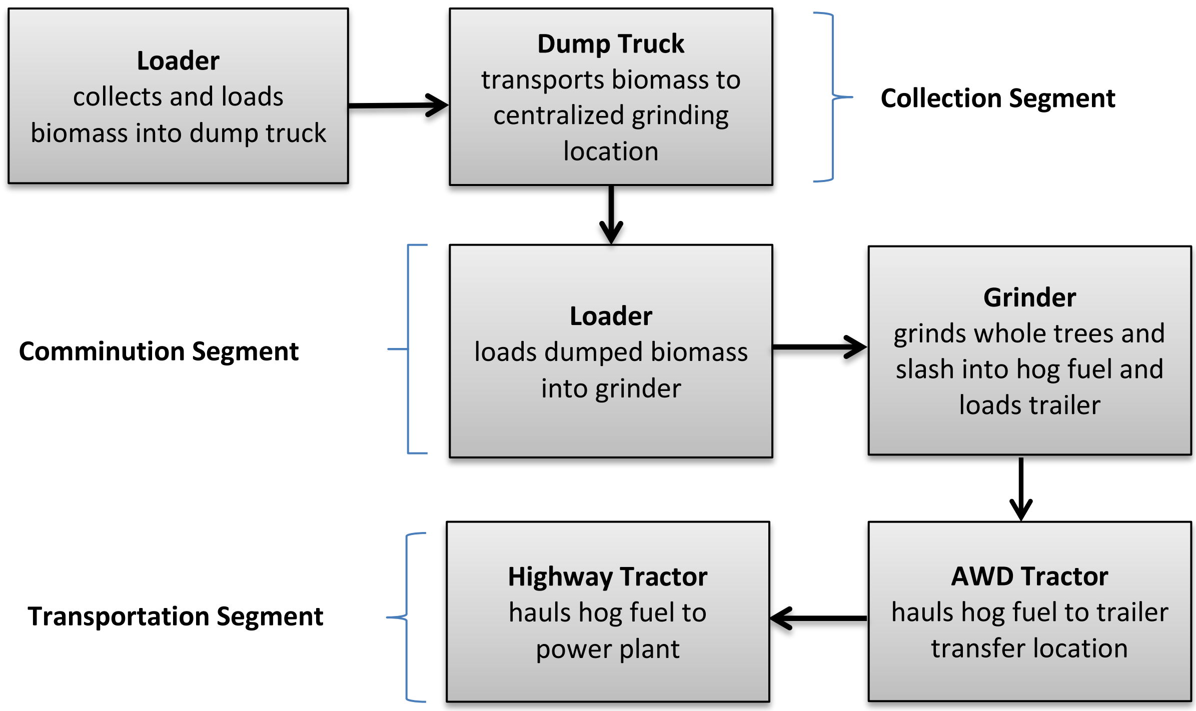


Figure 1. Description of the biomass recovery system logistics and its three major components observed in this study.

The transportation segment was de-coupled using two to three trucks to haul from the grinding area to a staging area and two to four truck to haul from the staging area to the power plant. All wheel drive (AWD) truck tractors, modified from cement trucks, were used to haul loaded chip trailers an average of two miles, one–way distance, to the staging area. The truck would leave the loaded trailer and pick up an empty one and return to the grinder. An additional truck and empty trailer was positioned close to the grinding area to quickly move in and replace the loaded chip truck. The staging areas were located either in existing parking areas adjacent to the highway or roadside on well traveled, wide, two-lane, rocked roads. Returning highway chip vans would leave an empty trailer and pick up a loaded one to deliver to the power plant. The observed round trip travel was 30 miles for both AWD trucks and highway chip trucks.

Data collection and analysis

Hourly cost for each machine was calculated using standard methods (Miyata 1980; Brinker et al. 2002). Cost factors including modifications were collected from the contractor. Detailed time study data was collected to estimate machine productivity and production cost using standard work study techniques (Olsen et al. 1998). Time duration of cycle elements and delays for each machine were recorded using centi-minute stop watches. Independent variables hypothesized to have an influence on machine productivity were also recorded for each cycle. Calculations were performed using R 2.15.1 statistical software program (R, 2012). Moisture content of samples collected from chip trailers were used to calculate BDT weights used in determining production rate (BDT/productive machine hour (PMH). Distance, speed, and road grade for transportation of slash and ground materials were collected using a hand-held Garmin Csx60 GPS unit placed in the machine and analyzed using ArcMap 10.0.

Cycle elements for the loader filling the dump trucks included swing empty, grappling, and swing loaded. Pile type (whole tree, slash, or mixed), pile location (pile in unit, at landing, or scattered), pile species (hardwood or conifer), and arm swing degree, were estimated visually as predictors for regression analysis. Time associated with movement to new pile and compiling material was recorded to evaluate its contribution to productivity.

Dump truck cycles included travel empty, positioning empty, loading, travel loaded, positioning loaded, and dumping. Slope and distance were recorded when traveling and positioning. Material type (whole tree or slash) placed in the truck was also recorded.

Productivity of the loader and grinder was evaluated on total time to fill a chip trailer. Productivity of the two machines was assumed to be the same because any delay in the loader could also be considered a delay in the grinder. Samples of ground wood materials were taken every other load and moisture content was measured. The number of dump truck loads per trailer was also observed to calculate the average dump truck load weight.

The all-wheel-drive tractor and highway tractor and trailer had similar cycle elements including traveling loaded, positioning loaded, unhooking, travel to empty trailer, positioning to hook up trailer, hooking up trailer, travel empty, positioning empty, and loading. Instead of loading the highway tractor was unloading. Other variables such as distance of each travel segment, average road slope, weights from scale tickets, and road type, were recorded.

Results and Discussion

Loading activity analysis

The average cycle time for the loader in the unit was one minute. The largest time component (48%) was spent compiling. (21%) was in grappling material. Swinging loaded represented (18%) which was greater than swinging empty at (13%). It took 4.27 min. or 9.97 cycles on average to load a dump truck. Productivity and production costs are summarized for all machines in (Table 1.) below.

Regression analysis indicated an increased in cycle time when handling material from whole tree piles compared to slash piles. This could be explained by the difference in size and length of the material making it more difficult for the loader to handle. Pile location also influenced cycle time. Scattered material increased cycle time more than piles at landings, while piles within the unit reduced cycle time. Hardwood species material increased loading time over conifer.

Table 1. Productivity and Cost of a biomass recovery system including centralized grinding operation in northern California.

Machine	Productivity	Cost	Ave. Distance[1]
	(BDT/PMH)	($/BDT)	(miles)
Loader in Unit	46.57	4.36	-
Dump Truck	26.16	4.27	0.96
Loader	38.04	5.33	-
Grinder	38.04	11.78	-
AWD Chip Van	26.47	4.59	4.25
Highway Chip Van	14.08	6.38	26.00
Total Stump to Truck		25.74	0.96
Total Transportation		10.97	30.25
Total		36.70	31.21

[1]Round-trip distance.

Dump truck pre-hauling operations

The dump truck round-trip cycle time averaged 13 min. traveling an average distance of 0.9 mi. on a grade of ± 4%. On average it traveled 9.3 miles per hour (mph) carrying 5.63 BDT per trip. Total cycle time was divided by loading (34%), traveling loaded (23%), traveling empty (20%), postioning empty (13%), positioned loaded (4%), and unloading (5%). The difference in loaded and empty travel could be explained by load weight and slower travel speeds to avoid material from falling off the back, especially on steeper road grades. Positioning empty distances were variable and typically longer compared to loaded positioning time. This could account for the greater empty positioning time.

Regression analysis did not show any significant variable (p-value < 0.05) influencing cycle time when examining travel time, slope, and material type. However, a reduced model regressing delay-free time by total distance traveled was highly significant. Coefficients were used in a sensitivity analysis to shows production cost starting at $2.25/BDT at a quarter mile round-trip distance and increasing $0.40/BDT for every quarter mile.

Centralized grinding productivity and cost

The productivity of both the loader and the grinder in the centralized grinding operation were assumed to be the same. The grinder processed an average of 17.15 BDT in 26 min. for an average production rate of 38.04 BDT/PMH. The grinder had the highest machine cost ($448.02/BDT) compared to any other machine in the study. Production cost was $11.78/BDT for the grinder and $5.33/BDT for the loader for a total of $17.11/BDT.

Transportation of ground materials to a power plant

The AWD tractor and trailer averaged 48 min. per cycle on a round-trip distance of 4.25 mi. The greatest percentage of time (53%) was spent during “hot” loading.

Traveling empty and positioning for loading (15%) was greater than traveling loaded and positioning for unloading (12%). Empty travel time may have been greater as a result of radio communication between grinder-loader and driver, reducing the urgency to rush back to get into position. In addition, positioning empty distances were greater and done at the congested grinding site. The transfer of trailers by unhooking loaded trailer and hooking up empty trailer represented (10%) while (9%) was waiting in position to be loaded. It should be noted that production cost could significantly increase with an increase in hauling distance. Sensitivity analysis shows that production cost increases $0.22/BDT every additional quarter mile round-trip distance. More data was needed to develop a regression to model this function and develop further analysis.

The standard highway tractor and chip trailer traveled an average of 26 miles round-trip with a cycle time of 73 min. Travel empty time (29 min.) was nearly the same as loaded travel time (31 min.). Average speed on two-lane rock road was 27mph for a round-trip distance of 19 mi. Average speed on two-lane paved roads was 31mph at a distance of 6.8 mi. A single observation of highway transport provided a speed of 55 mph for a distance of 78 mi. This observation was not used in calculating productivity and cost. A sensitivity analysis was done to estimate the difference in production cost based on road type. Two-lane rock and paved road speeds were averaged together and compared to the highway speed. Production cost was 2.3 times greater for two-lane rock and paved roads compared to highway travel. This is due to slower travel speeds resulting in an increase in cycle time.

System balance directly affecting productivity and cost

This operation involves a combination of machines to collect, process, and transport material. The balance of production within the system is important as it has a direct effect on an overall production cost. Unused capacity resulting from an imbalanced system will reduce units of output increasing fixed costs of under-utilized functions and drive up per unit production cost (Rummer, 2008).

The highest per unit production cost observed was the grinding operation ($17.11/BDT). To minimize total production cost, the operation would first need to maximize processing productivity by reducing any delay created between loader and grinder. Four percent of the total time observed was in operational delay. Of the four percent, 71% represented waiting on the dump truck to deliver material. Upstream delay could have come from either the loader or the dump truck. Observations of the loader revealed less than one percent delay. The dump truck experienced a 17% delay while waiting for a dump truck to pass and allow access. This suggests that road network and turnouts can have a downstream effect on productivity.

Balancing the collection segment to match grinding production can be challenging when considering the spatial diversity of the material. To assist in balancing upstream functions a sensitivity analysis was conducted to calculate the productivity at different travel distances. A dump truck could travel 0.75 miles round-trip and meet the 38 BDT/PMH grinder demand. At 2.5 mi. productivity drops to 19 BDT/PMH or 50% of the demand, requiring an additional truck to keep the system in balance and the overall operational cost at a minimum. The effects of decreased dump truck productivity on loader and grinder cost were also analyzed. It was found that a 20% drop in production would result in a 25 % increase in grinding cost or $3.86/BDT (Fig. 2).

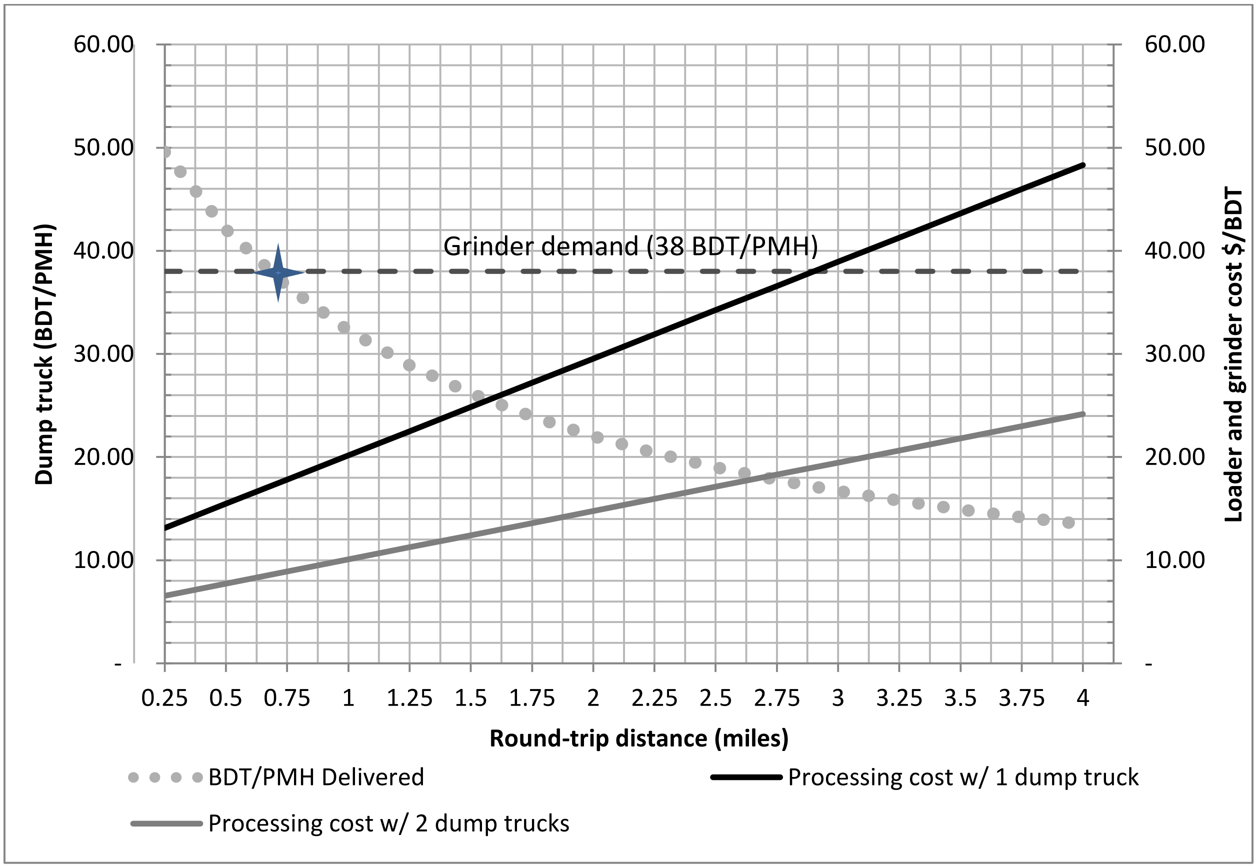


Figure 2. Loader and grinder cost as a function of dump truck productivity.

A de-coupled transportation system was used to control delays created from downstream production. This divided the transportation distance allowing AWD trucks to return quickly with an empty trailer. During the operation only a two percent operational delay was observed. Time spent positioned waiting to be loaded (4 min.), was not considered delay time. This buffer ensured that a truck was always available to load, reducing any delay to the grinder. In this operation, if an additional mile was added to the transfer location, the added travel time would have required an additional truck or delay could have been created. The loaded trailer pick up at the transfer location required that an empty trailer be available every 26 min. Eight empty trailers were used to ensure availability. The loaded trailers were taken to one of three local power plants located 13, 31, or 57 mi. away. The observed delays while waiting to be unloaded (12%) had no effect on the operation.

The total system cost for this operation using one to two loaders in different units, two to three dump trucks traveling an average of one mile, a loader and grinder, two to three AWD tractors traveling an average of 4.25 miles, three highway tractors traveling an average of 26 miles, and eight trailers was $36.70/BDT. This must be read with the understanding that the calculated cost is pure production cost not including overhead, profit allowance, or supporting equipment needed in the operation. These cost figures can also increase with an increase in transportation distance.

Conclusion

This study evaluated the productivity and cost of a biomass recovery operation logistics to identify key variables that influence the productivity of individual functions in an attempt to create system balance and reduce production cost. Total production of 38 BDT/PMH was observed at a total stump-to-truck cost of $36.70/BDT with a range of 14 to 38% moisture content.

The cost to load material into the dump trucks was $4.36/BDT. Productivity increased when handling loose slash material over whole tree material. Loading piles from within the unit were found to be more productive than piles at landings. Modified dump trucks used in the pre-haul were effective in transporting material over single lane forest roads to a centralized grinding location. Productivity was 26.16 BDT/PMH at a cost of $4.27/BDT on an average round-trip distance of 0.9 mi. Sensitivity analysis on distance shows an increase of $1.60/BDT for every additional mile. The loader and grinder together processed 38.17BDT/PMH at the highest production cost of $17.11/BDT. AWD tractors pulling chip vans moved 26.47 BDT/PMH over an average of 4.25 miles at a cost of $4.59/BDT. Sensitivity analysis shows a $0.63/BDT increase for every additional mile. Transportation of 14.08 BDT/PMH to the power plant, averaged 26 miles round-trip at a cost of $6.38/BDT. Sensitivity anlysis shows that rock road travel cost $0.12/BDT/mile and $0.06/BDT/mile for highway travel.

Analysis on upstream productivity predicts a 25% increase ($3.83/BDT) in grinding production cost when there is a 20% decrease (7.6 BDT/PMH) in dump truck production. Utilizing a de-coupled transportation system with with an adequate number of trailers successfully eliminated any delays on grinder productivity.

This study provides a stump–to-power plant productivity and cost for every machine in the biomass recovery system. In addition sensitivity analysis on travel distances for transport machines provides additional information to better understand total production cost. The cost estimates are limited to pure production cost and does not include any other cost information.

Literature Cited

Alcorn, Mike. *Chief Forester, Green Diamond Resource Company* (8, 2012).

Anderson, Nathaniel, Woodam Chung, Dan Loeffler, and John G. Jones. "A Productivity and Cost Comparison of Two Systems for Producing Biomass Fuel fro Roadside Forest Treatment Residues." *Forest Products Society* 62, no. 3 (2012): 222-233.

Brinker, R, J Kinard, B Rummer, and B Lanford. *Machine rates for selected forest harvesting machines. Circular 296 (revised).* Auburn: Alabama Agriculture Experiment Station, Auburn University, 2002.

Center, Schatz Energy Research. *RePower Humboldt A Strategic Plan for Renewable Energy (DRAFT).* Arcata: Schatz Energy Research Center, 2012.

Han, Han-Sup, Jeff Halbrook, Fei Pan, and Lucy Salazar. "Economic evaluation of a roll-off trucking system removing forest biomass resulting from shaded fuelbreak treatments." *Biomass And Bioenergy* 34 (2010): 1006-1016.

Harrill, Hunter et al. "Application of Hook-lift Trucks in Centralized Slash Grinding Operations." *Biofuels* 1, no. 3 (2010): 399-408.

Harrill, Hunter, and Han-Sup Han. "Productivity and Cost of Integrated Harvesting of Wood Chip and Sawlogs in Stand Conversion Operations." *International Journal of Forestry Research* 2012 (2012): 10.

Harrill, Hunter, Han-Sup Han, and Fei Pan. "Combining Slash Bundling with in-woods Grinding Operations." Lake Tahoe: Council on Forest Engineering, 2009.

Miyata, E.S. *Determining fixed and operating costs of logging equipment. General Technical Report NC-55.* St. Paul, Minnesota: USDA Forest Service, North Central Forest Experiment Station, 1980.

Olsen, E.D, M. N Hossain, and M.E Miller. *Statistical comparison of methods used in harvesting work studies.* Forest Research Laboratory, Oregon State University, Research contribution., 1998.

Pan, Fei, Han-Sup, Johnson, Leonard R Han, and William J Elliot. "Production and cost of harvesting, processing, and transporting small-diameter (<5 inches) trees for energy." *Forest Products Journal* 58, no. 5 (2007): 47-53.

Rummer, Bob. "Assessing the cost of fuel reduction treatments: A critical review." *Forest Policy and Economics* 10 (2008): 355-362.

Williams, Robert. *An Assessment of Biomass Resources in California.* California Energy Commission. Contract Number 500-01-016, 2007 - Report.

Comparing whole tree to tree-length fuel reduction thinning operations: cost and actual amounts of biomass removal

Joel A. Bisson[1], Sang-Kyun Han[2], Han-Sup Han[3], Jianwei Zhang[4], and Timothy D. Montgomery[5]

Abstract

Biomass equations, vegetation models, and remote-sensing techniques are often used to estimate potential amounts of biomass supply for bioenergy. However, due to different harvesting and handling methods actual amounts of biomass removed are usually less than estimated. Quantifying lost biomass when applying different biomass removal methods in mechanical fuel reduction thinning has not been clearly studied. Accurate estimates of actual amounts of biomass removal and supply are critical to economic analysis of biomass utilization. A replicated, field-based study to determine the efficiency and the cost of biomass removal using two mechanical fuel reduction treatment methods (whole tree and tree-length thinning) has been conducted in two units of the Salmon-Scott RangerDistrict, Klamath National Forest. Pre- and post-treatment timber cruises and downed woody debris surveys have been collected to determine the amount of standing and forest floor biomass before and after treatment for each replicate. Detailed time studies of operations were conducted to estimate biomass removal cost. Felling, skidding, processing, and loading operations were observed. Log truck scale data, as well as sample log volumes were collected to determine sawlog removal and to estimate volume per machine cycle. We hypothesized that there would be a greater biomass removal from the whole tree thinning compared to tree-length. That is, we expect to see more biomass left on site in the tree-length units, directly affecting the amounts of biomass removed and delivered to an energy plant. Mechanized felling and whole tree skidding in whole tree thinning would increase productivity resulting in lower costs, compared to tree-length thinning.

[1] Research Associate, Department of Forestry and Wildland Resources, Humboldt State University, Arcata, California, U.S.A
[2] Assistant Professor, Department of Forestry and Landscape Architecture, Korea National College of Agriculture and Fisheries, Hwaseong-si, Gyeonggi-do, South Korea
[3] Professor, Department of Forestry and Wildland Resources, Humboldt State University, Arcata, California, U.S.A
[4] Research Scientist, USDA Forest Service, Pacific Southwest Research Station, Redding, California, U.S.A
[5] Graduate Research Assistant, Department of Forestry and Wildland Resources, Humboldt State University, Arcata, California, U.S.A

SNAP for ArcGIS: A Planning and Educational Tool for Forest Engineers

Woodam Chung[1], Fred Bower[2], Obie O'Brien[3], John Sessions[4]

[1]Department of Forest Management, The University of Montana, Missoula, MT 59812
[2]U.S. Department of Agriculture, Forest Service, Northern Region, Missoula, MT 59807
[3]Forest Operations Engineering LLC, Helena, MT 59602
[4]Department of Forest Engineering, Resources, and Management, Oregon State University, Corvallis, OR 97331

Abstract

SNAP for ArcGIS is a computer software developed to streamline harvest area analysis for spatially-explicit timber harvest scheduling and transportation planning at a project level. This planning tool uses modern scheduling and network algorithms to develop harvest schedules up to three time periods with consideration of harvesting options and costs, multiple timber products, alternative mill destinations, and road systems. SNAP for ArcGIS attempts either to maximize net present value (NPV) or minimize discounted costs of harvesting and transportation over the planning horizon, while meeting given harvest volume and acreage constraints per planning period. With SNAP for ArcGIS, the user can generate vegetation management solutions that are cost-effective and operationally feasible under given management goals and strategies.

The potential users of the tool are project planners and logging engineers who have basic knowledge of timber harvest and transportation planning, silvicultural prescriptions, and geographic information systems. SNAP for ArcGIS can be also used as an educational tool in classroom, workshop, and professional training that provides students with insight into the dynamics and complexity of tactical and operational planning for timber management.

Introduction

Forest managers have to make decisions on forest management activities and access roads when managing forest resources. Most forest management is engaged with access roads, but simultaneous planning of the resource management and transportation constantly becomes a challenge due to the increase of problem size and complexity of such planning problems. Early efforts to integrate the two problems include mixed integer programming approaches, but those approaches are significantly constrained by the problem size. To overcome the limitation of the MIP solution techniques, heuristic optimization approaches have been introduced to forest planning, aiming to quickly produce good and feasible solutions, without necessarily providing a guarantee of solution optimality (Bettinger and Chung 2004, Bettinger and Zhu 2006). Scheduling and Network Analysis Program (SNAP; Sessions and Sessions 1993) was an example of a decision support system that solved integrated tactical planning problems using a series of heuristic optimization approaches. However, the old SNAP program developed for the MS-DOS environment, does not work in modern computer operating systems.

SNAP for ArcGIS, a new version of SNAP, has been developed to provide an easy-to-use spatially-explicit forest planning tool that simultaneously optimizes resource scheduling and transportation problems, while taking advantage of modern computer operating and geographic information systems (Chung et al. 2012). Combining a simulated annealing optimization technique (Kirkpatrick et al. 1983) with a network algorithm (Chung and Sessions 2003), this new tool is able to solve a forest-level harvest scheduling problem and build efficient road networks that make selected management activities possible. In this paper, we introduce the tool in the context of presenting its potential as a spatially-explicit forest planning tool as well as an educational tool for forestry students, engineers and managers.

Overview of SNAP for ArcGIS

SNAP for ArcGIS (hereinafter referred to as SNAP) is a computer software developed to streamline harvest area analysis for spatially-explicit timber harvest scheduling and transportation planning at a project level. SNAP attempts either to maximize net revenue of timber harvest or minimize costs of harvesting and transportation, while meeting given harvest volume and acreage constraints. SNAP can be used to generate a straight automated harvest solution, or to simulate management alternates with user directed manual control to help decision makers identify economic and operationally feasible tactical area plans.

Potential users of SNAP are project planners, logging engineers and land managers who have basic knowledge of timber harvest and transportation planning, silviculture, and geographic information systems. Developed using Microsoft Visual Studio 2010, the tool was developed as an ArcMap toolbar working in the Windows 7 operating system.

As input data, SNAP requires two shapefiles: harvest unit polygons and road network (Figure 1). Required attributes for individual harvest unit polygons include acres, current merchantable timber volume per acre by product, harvest unit status (i.e., eligibility or restriction of harvest), dominant seral stage, silvicultural treatments, and stump-to-landing harvesting system options with estimated costs and log landing locations. For individual road segments, the user needs to provide distance, estimated construction cost, maintenance cost, average travel speed for the design vehicle (e.g., log truck, chip van, log forwarder), and types of transportation (e.g., ground, aerial or water). Additional information required for the analysis includes alternative mill locations and delivered prices of timber products at each mill.

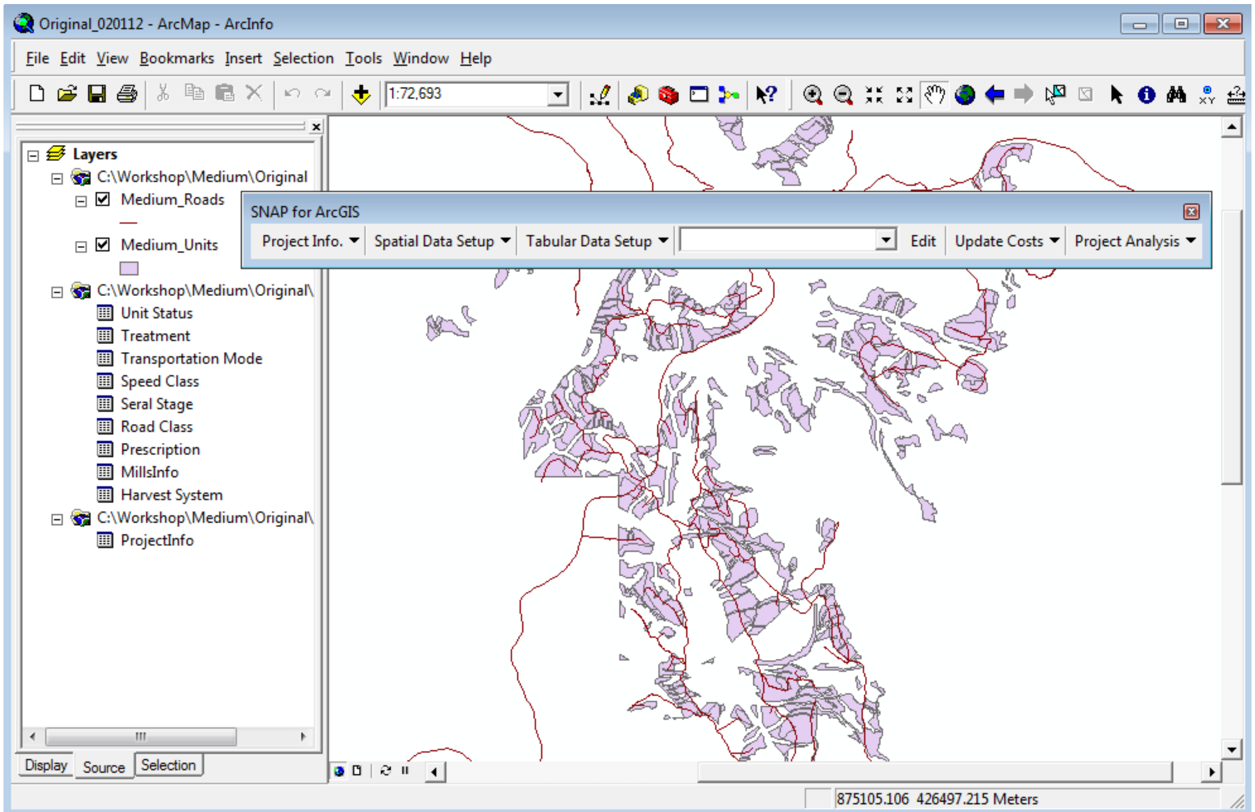


Figure 1. SNAP for ArcGIS toolbar shown in ArcMap, and examples of datasets required by SNAP for ArcGIS.

Solutions generated by SNAP include recommended actions about where to harvest, when to harvest, and how to harvest selected treatment units (Figures 2 and 3). Through solution interpretation, the user can also identify locations of necessary and unnecessary road segments for the project area, timber volume flows over the road system during the planning horizon, and the selection of mill destinations for given timber products. These transportation analysis results may be useful for future forest road management decisions, such as road construction, upgrade, maintenance, or decommissioning.

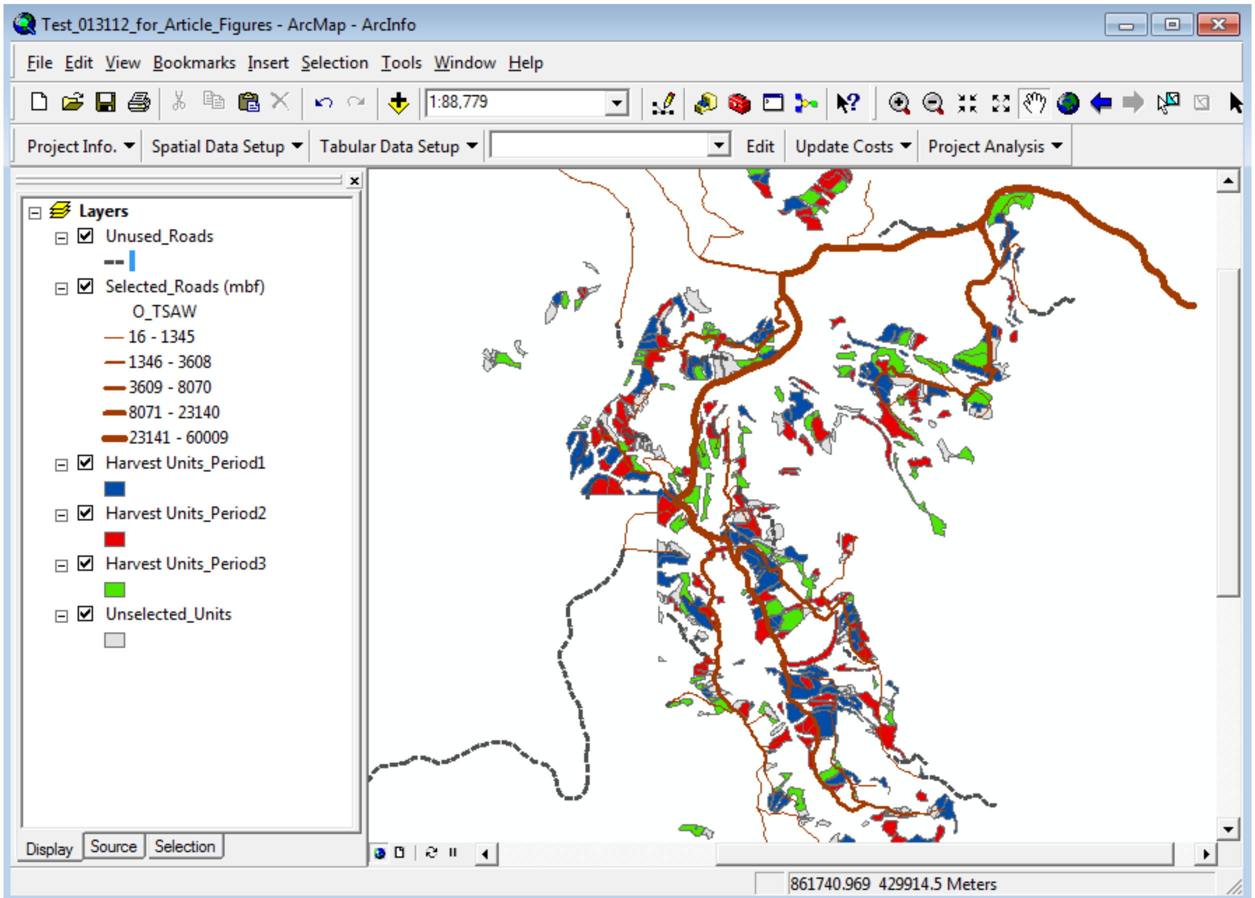


Figure 2. An example of a solution generated by SNAP for ArcGIS. Colors of treatment polygons represent different harvest periods. Thickness of the brown solid lines represents amount of timber volume flows along the forest roads, while black dashed lines represent unnecessary road sections for the selected treatment polygons.

Attributes of Medium_MultiPeriods_Summary

OID	ITEM	VALUE	UNITS
0	Sawlog Volume in Period 1	20000.835988	MBF
1	Sawlog Volume in Period 2	20000.670957	MBF
2	Sawlog Volume in Period 3	20007.75047	MBF
3	Total Sawlog Volume	60009.257416	MBF
4	Total Pulplog Volume	0	Tons
5	Total Acres To be Treated	2732.194068	Acres
6	Total Discounted Harvest Cost	7889706.30326	$
7	Total Discounted Road Cost	2970265.55157	$
8	Total Discounted Haul Cost	725758.810961	$
9	Total Discounted Costs	11585730.6658	$
10	Total Discounted Revenue	12620778.2566	$
11	Total Discounted Residual Value	1035047.59084	$
12	Total Miles of Road Built	26.260623	Miles
13	Road Cost per Mile	113107.202631	$/mile
14	Solution Feasibility	1	Feasible(1),Infeasible(0)

Record: 1 Show: All Selected Records (0 out of 15 Selected)

Figure 3. A summary output table generated by SNAP for ArcGIS, presenting the solution in terms of harvest volume in each time period and estimated costs and revenue.

The powerful analytical feature of SNAP is the ability to simultaneously solve timber harvest scheduling problems with transportation network access and product routing problems. The user can easily estimate net revenue of timber harvest in each harvest unit, and identify "easy" or "challenging" units across the project area from the financial standpoint (Figure 4).

Another powerful feature of SNAP is that, once the database is built for the project area, the user can run the model multiple times to test various management scenarios and the sensitivity of assumptions. These analyses enable the user to better understand forest capacity, illustrate present product availability, develop a suitable management strategy, and address the effects of proposed actions on changes in forest products, structure and conditions of interest over time. For example, by maximizing net revenue of timber harvest without any volume or treatment acreage constraints, SNAP can select and display the treatment units that yield positive net revenue ("easy" units) for timber harvest. If the user requires a higher timber volume than what the "easy" units can produce, SNAP will start including negative net revenue-yielding units into the solution to meet the higher volume requirement. Through these iterations, the user can identify the appropriate harvest level for the project area to best meet the given management goal and strategy.

In addition, the user can easily override the SNAP solution and re-run the model to examine manually developed harvest plans or analyze trade-offs among different harvest and road options. This is particularly useful when projects move into environmental analysis phase and the effects of alternatives are being compared. Because SNAP is an ArcGIS-embedded program, the user has all the functionality of ArcGIS, making it an easy task to handle large amounts of spatial data as well as display SNAP solutions and outcomes of interest at the user's preference (Figure 5).

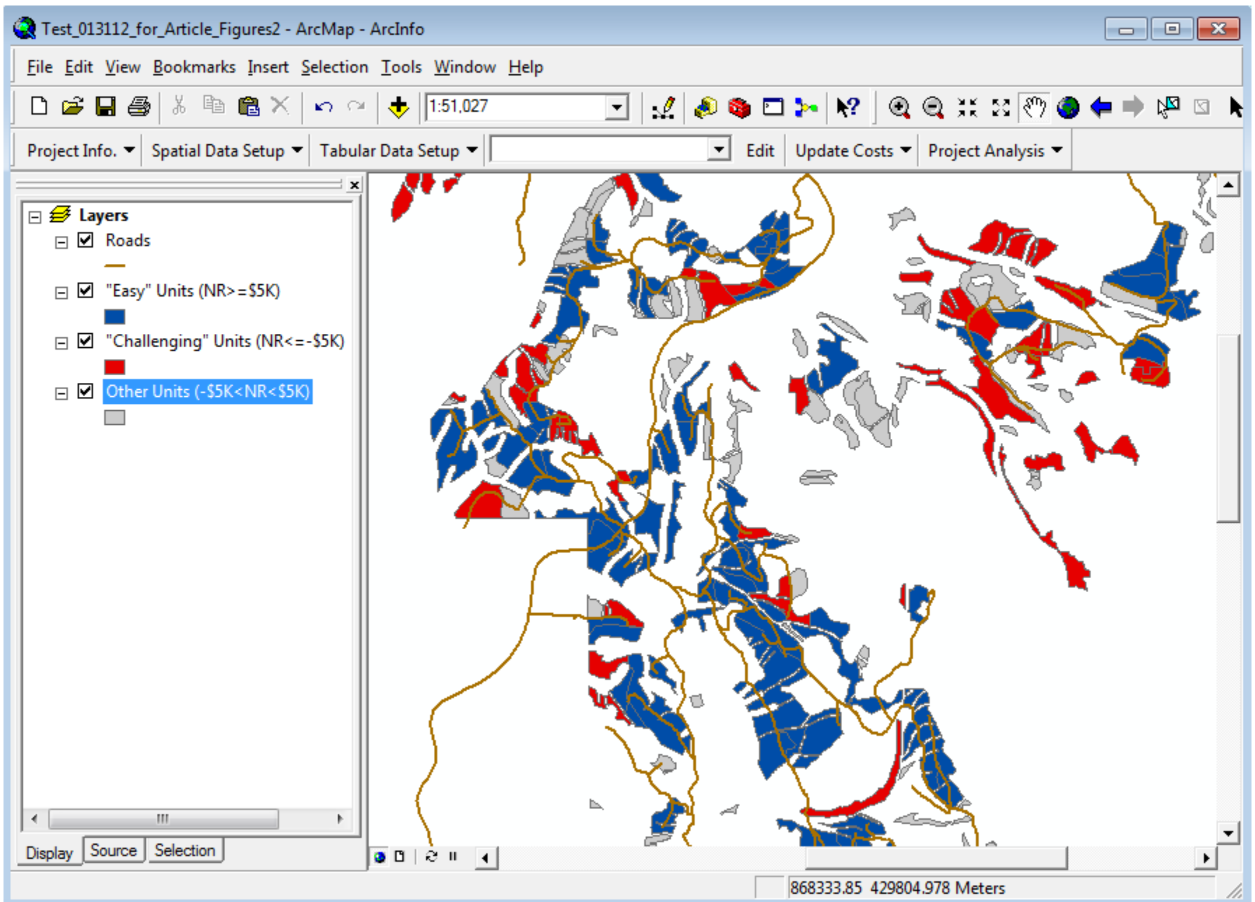


Figure 4. A map presenting the financial feasibility of each treatment unit. Blue polygons indicate treatment units that can generate large positive net revenue, whereas red polygons are the treatment units where harvest costs largely exceed timber revenue, thus yielding large negative net revenue. Grey polygons represent the treatment units that are in between those two ends of the net revenue spectrum.

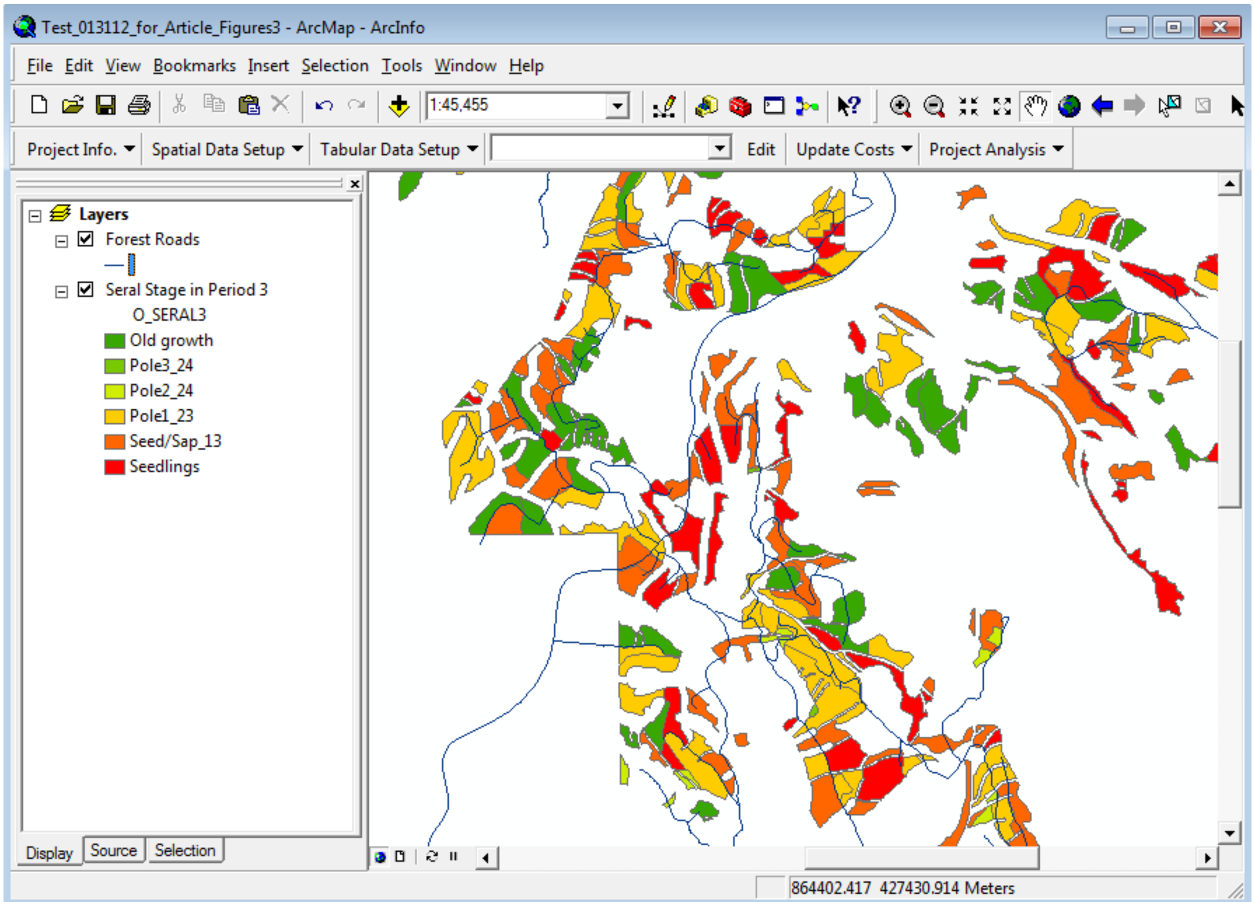


Figure 5. An example of an output map presenting distribution of resulting seral stages after harvest in time period 3.

Concluding Remarks

Consisting of an ArcGIS user interface and a heuristic optimizer, SNAP for ArcGIS is an easy-to-use forest planning tool that spatially optimizes timber harvest and transportation system. In addition, SNAP for ArcGIS can be used as an educational tool in classroom, workshop, and professional training. Students can easily learn and understand dynamics and complexity of tactical-level forest planning through the processes of 1) data gathering and development, 2) testing of various management strategies, and 3) solution acquisition and interpretation.

References

Bettinger P., and W. Chung. 2004. The key literature of, and trends in, forest-level management planning in North America, 1950-2001. International Forestry Review 6: 40-50.

Bettinger P., and J. Zhu. 2006. A new heuristic method for solving spatially constrained forest planning problems based on mitigation of infeasibilities radiating outward from a forced choice. Silva Fennica 40: 315-333.

Chung, W. and J. Sessions, 2003. NETWORK 2000: A Program for Optimizing Large Fixed and Variable Cost Transportation Problems. In: G.J. Arthaud and T.M. Barrett (eds.) Systems Analysis in Forest Resources, Kluwer Academic Publishers. pp. 109-120.

Chung, W., D.P. Dykstra, F. Bower, S.A. O'Brien, R.M. Abt, and J. Sessions. 2012. User's Guide to SNAP for ArcGIS®: ArcGIS Interface for Scheduling and Network Analysis Program. USDA Forest Service PNW-GTR-847. 34p.

Kirkpatrick, S., C.D. Gelatt, and M.P. Vecchi. 1983. Optimization by simulated annealing. Science 220: 671-680.

Sessions, J. and J.B. Sessions. 1993. SNAP II+ version 2.07 user's guide. USDA Forest Service, Washington Office, Ft. Collins, CO.

Projecting the Future of Idaho's Contract Logging Sector

Keith Coulter[1], Steven R. Shook[2]

Abstract
Logging firms supply raw materials in the form of sawlogs, pulp chips, and biomass to the wood consuming primary forest products industry's (PFPI) milling sector of Idaho. Idaho's PFPI has experienced tremendous raw material supply disruptions (e.g., large withdrawals of federal timber) and industry restructuring in the last twenty years. Today, there are fewer and more geographically distanced mills/commercial forest landowners for logging firms to engage in contract for services. Idaho's logging firm sector is adapting to these changes and would benefit from the ability to anticipate future impacts to the operating interface between logging firms and forest landowning mills/commercial forest landowners. Through the use of in-depth interviews of PFPI stakeholders, results were used to assist in an industry level strategic planning assessment of Idaho's logging firms. Among other PFPI sector participants, the study surveyed the Associated Logging Contractors of Idaho membership. A total of 171 logging companies were contacted and 61 firms agreed to be interviewed for this study, resulting in a 35% effective response rate. The study's participants state they frequently cannot expect to procure a satisfactory level of annual work volumes necessary to optimize their company's assets, leading to chronic layoffs, labor challenges, poor financial returns, and sector-wide reluctance to invest in further modernization. Grappling with periodic inadequate raw material supply for the number of currently participating logging firms, an improved future would focus on reducing logging firm numbers and elevating minimum standards of efficiency. Bidding against competing logging firms may become the industry norm according to study participants.

Introduction
The forest products industry is an important economic and cultural contributor in Idaho, employing over 15,000 workers and ranked eighth in the nation for overall wood production (Cook and O'Laughlin 2006). The primary forest products industry (PFPI) of Idaho consists of logging contractors and the firms (mills) that use the raw materials logging contractors produce (e.g., saw logs, pulp, wood fiber) for manufacture into lumber, paper, and wood panels (Brandt et al. 2012). Idaho's PFPI has experienced tremendous raw material supply chain disruptions in the last twenty years, in part due to a severe decline in stumpage availability from federal lands in Idaho (Morgan et al. 2004). Mills/mill ownerships in Idaho's PFPI have been merged to fewer, geographically dispersed facilities that are located near reliable supplies of reasonably priced private and state raw material sources. The greatest decline in terms of employment and number of production facilities, has been in the sawmilling sector, though the total annual sawmill production volume has not declined (Morgan et al., 2004). Among other factors, structural change in the sector may conflict with many logging contractors' business models.

[1] afognakkfp@gmail.com, Koncor Forest Products, PO Box 1159, Kodiak, AK 99615
[2] shook@uidaho.edu, Professor of Marketing, Univ. of Idaho, PO Box 443161 Moscow, ID 83844

Many contractors’ business models rely on the contracting relationship with forest land owning mills. By massing more logging contractors on fewer mills, a structurally asymmetric industry is created (Mei and Sun 2007). In the past, numerous mills in Idaho were vertically integrated forest products companies, with a primary goal of long-term forest management. In recent years, many forest product firms' business structures have reorganized to reduce operating costs into real estate investment trusts (REITs) and timberland investment management organizations (TIMOs). The long-term management of these organizations does not necessarily focus on forest management solely, perhaps suggesting a less symbiotic logging contractor and mill relationship than in the past. An alternative business structure for these companies incorporates the real estate potential of land assets on the open market to generate revenue (Brandt et al. 2012).

Idaho's logging contractors are adapting to these sector changes. The PFPI employs independent logging contractors as a strategy for managing risks, uncertainties, and rigidities in production (Prudham 2002). In doing so, the firms (mills/commercial forest landowners) can transfer the costs incurred in natural resource-based production onto independent logging contractors. Thus, the firm is no longer encumbered with the liability of wages, benefits, labor issues, safety, costs of equipment ownership, and some production issues directly related to market volatility.

Given the changes in the industry sector, what does the future hold for Idaho’s contract loggers? This paper examines the logging contracting interface with large, commercial forest land owning mills (fee lands)/commercial forest landowners and what influences may affect the future viability of logging contracting in the state. The motivation for this research stems from concern surrounding work force sustainability issues in Idaho's logging contractor sector (other efforts include http://www.idahoforests.org/img/pdf/WorkforceSurveyFINAL.pdf). There is evidence that the logging contractor workforce in Idaho is demographically shifting, with older workers and fewer new entrants poised to take the place of exiting firms (Allen et al. 2008). There is also considerable speculation surrounding the reasons why labor is becoming more difficult to attract to this segment of the PFPI, as well as concern about the long-term financial viability of the logging contracting sector in Idaho in general.

Without a robust logging contracting sector, the competitive advantage of Idaho's milling infrastructure could suffer from chronic supply chain disruptions, increased raw material costs, and disruptive business uncertainty. Periodically, academic and trade association groups have attempted to capture the profile (e.g., demographics, harvesting methods, operational characteristics) of Idaho's logging contractors (e.g., Allen et al. 2008). In general, that information only provides "point in time data" of the sector and does not reveal potential future trends useful for strategic planning purposes. Also, similar survey endeavors from other geographic regions of the United States, such as the South, have vastly different industry structures (for both the mill/landowner sector and logging contractor sector) and cannot be reliably used as a barometer for Idaho's future operating environment (e.g., Green et al. 2001, Luppold et al. 1998, Munn et al. 1998). Reports concerning Idaho and the inland west areas (e.g., Brandt et al. 2012, Keegan et al. 2005 and 2006) are published on an annual basis; these reports monitor primary processing of logs into lumber/value added. However, these efforts do not include an assessment of logging contractors, which can significantly influence PFPI performance. The ability to anticipate future impacts and drivers of Idaho's PFPI would be valued information for Idaho's logging contractors and milling sectors. The overall goal of this paper is to outline the future operating environment of the PFPI in Idaho by gathering information that is based on the professional judgment of logging contracting business owners and senior management of the large industrial mills and commercial forest land-owners throughout the state. This knowledge can assist in the strategic planning for logging contractors within Idaho's PFPI.

Methodology

Access to proprietary information that could provide insight and fuel a quantitative analysis of the interface between Idaho's logging sector and PFPI is not readily available. As an alternative, this study used an inductive and qualitative approach to determine sector stakeholder issues through a literature search for current industry challenges and forming these challenges into open-ended survey questions. In-depth interviews were performed to assess the challenges facing those portions of the primary forest products sector(s). The target populations included (1) logging contractors, (2) policy-setting managers from fee land owning mills, (3) commercial forest landowners, (4) non-land owning mills, and (5) the State of Idaho. The sampling frame for the contract loggers of Idaho was the 2009 membership list of the Idaho's Associated Logging Contractors (http://www.idahologgers.com).

All interviews were digitally recorded and then transcribed. Once completed, the transcriptions were read independently by two researchers to develop an understanding of the overall content and to highlight specific characteristics of the data (Amberg 2008). Coding of responses was used to discover reoccurring patterns and themes that emerged from the content of the interviews. These observations were then noted and organized into general categories relating to broad or specific perceptions that logging contractor business owners and managers maintain about the future of that sector of Idaho's PFPI.

Results

A total of 171 logging contractors were contacted for participation in this study; 110 contractors did not respond. Thus, a total of 61 contractors agreed to be interviewed for the study, resulting in a 35% effective response rate. Both mills and commercial forest land owning organizations were identified during interviews of logging contractors who were asked to name the firm(s) in which they contracted their own firm's business. In addition to this, the Idaho Forest Products Commission website (http://www.idahoforests.org) was used to identify mills that were not specifically identified by the logging contractors. Mills that own fee land and large commercial forest land owning firms were the main focus of this study. As a consequence of the consolidated structure of that portion of the PFPI in Idaho, one mill ownership group may own multiple mills, so the sampling population size (5), while seemingly small, actually captured much of the targeted population's total annual production. Eleven mills were interviewed that did not own any substantial forest land acreage and, consequently, required no contract loggers because they purchased their raw materials on the open market. The State of Idaho's Department of Lands (IDL) was also included in the forest land owning firm category, and a short survey instrument was directed at upper level management personnel within that government organization. IDL offers, through auction on the open market, several hundred million board feet of timber on an annual basis to fulfill constitutional obligations of the State. IDL interview questions focused on the effects that state timber sales have on the private forest products industry market.

The following excerpts outline a portion of the most salient topics revealed by survey participants:

Continued loss of markets/mills or milling consolidation:

(Logger) *"Just less mills and the same amount of loggers."*

(Mill) *"But the company can't handle the potential inherent inefficiency. And so, again, we used to keep a lot of contractors around that we exited in the last several years. And the good contractors came back and said, 'Gosh I'm glad you finally did that. Here this guy was taking volume away from me, and I know his quality ... they were nowhere near what I've been doing for you.' … but in our old mindset, you know, we were helping everybody along, and so forth, and probably costing everybody a lot."*

Loss of federal lands as a source for raw material:

(Logger) *"Well, there's a lot of wood out there. Like on the Targhee National Forest where I logged for years, they just quit putting wood up and shut it down."*

Chronic layoffs:

(Logger) "*We went from working year round to working six months a year. And we would be thankful for six months. So that makes it tough for our people that … you know, everybody's starting to lose people, because … guys can't hang around and work six months out of the year."*

Mill Supply Chain Management and Logging Contractor Firm Size

Putting logging contractors at a disadvantage, mills maintaining many logging contractors during peaks in production when additional supply is required, continues to be the model for supply chain management at many Idaho mills. This surplus logging capacity is maintained by contractors, whether used or not, to account for spikes in production demands. During periods when less raw material is necessary, logging contractors are essentially shut off, essentially sub-optimizing the operating season, and/or placed on quotas to manage raw material inventories required by Idaho's mills.

Many Idaho forest products companies have been replaced by firms with advanced communication systems and information technologies that have the ability to capture the supply chain operation over disparate production networks (Prudham 2002). While there are several variations in logging contractor sizes and abilities, successful future logging contracting firms will likely become larger, automated, flexible, versatile, and more able to quickly adapt to the parent firm's (mills) changing domestic and international marketing demands and "just in time" saw log inventory management.

Improving Harvesting Efficiency and Reducing Harvesting Costs through Bidding/Contractor Timber Sale Purchases

An improved logging sector in the future may be accomplished by maintaining fewer logging contractors and focusing more on the remaining contractors' efficiency standards. Placing all timber harvesting jobs out to bid would likely result in incentivizing logging contractors to make every effort to increase automation and efficiencies to be cost competitive and profitable. At the same time, it would also reduce the number of logging contractor operations, thereby decreasing competition and increasing sustainable business over the long term. Increasing the number of predictable harvest volumes per logging company may also urge logging contracting businesses to increase hourly shift levels for machines and employees. This could be accomplished by spreading the capital intensive costs of harvesting machinery over more scheduled machine hours per year, while also matching equipment technology to specific harvesting applications, allowing operation of more days per year. Logging contracting firms can take a cue from their counterparts in the PFPI (mills) and increase their sizes through mergers and acquisitions. By expanding harvesting firm size and increasing economies of scale and scope, the remaining logging firms can more readily compete against a smaller pool of rival firms for relatively scarce harvest volume.

During the interviews, it was discovered that one particular non-land owning commodity producing lumber mill that relies heavily on Idaho State timber sales to supply its sawlogs has shifted its use of logging contractors. Instead of soliciting bids from logging contractors and then hiring them to harvest sales the mill purchased from the State, the mill has opted for an “all gatewood” supply approach. This strategy involves the logging contractors purchasing the timber sales themselves instead of being hired by the mill, thus reducing the logging contractor's harvesting costs, which the mills suggested were higher than average in the interviews. Having the logging contractors take over the timber sales relieved the mill of oversight of these contractors. The logging contractors were also perceived to be more efficient since they had to be price competitive in order to achieve the highest return for *themselves* when they sold the gatewood to the mill. Additionally, logging firms that were able to purchase land and harvest timber from it and re-sell the parcel appeared to have more autonomy, better access to diversification opportunities, and a more promising future outlook than those firms conditioned only to working for the remaining mill(s) in their area.

Discussion

While part of a broader study of Idaho's PFPI, this paper explores the specific challenges facing logging contracting firms in Idaho by using in-depth interviews of logging contracting firm owners and senior management of Idaho mills who contract with logging firms for their raw material needs. Perhaps the most influential future sector driver is the number of housing starts nationally. Mediocre housing starts and a stagnant economy will stifle Idaho’s PFPI regardless of steps taken to prepare for opportunities or threats. Interview results exposed a less paternalistic contracting relationship between logging firms and mills than was experienced in the past. In the future, individual logging firms cannot expect mills to provide one harvest unit after another throughout the operating season. Instead, open bidding used as a price control mechanism by mills may become standard operating procedure. Logging firm owners will have to determine the level of investment that they are willing to risk in order to stay automated, versatile, and cost effective among a future of ever increasing uncertainty, or exit the industry. Logging firms able to purchase timber sales or timberland appear to have greater control of their operating futures as compared to those logging firms solely attached to one or two large mills/commercial forest landowners.

While not all of Idaho's milling and commercial forest landownership's corporate structures are changing, many are, and that will affect the long-term outlook that logging contractors can expect in terms of the availability and predictability of volume in which to harvest. Given the interview results, there frequently appears to be too many logging contractors attempting to optimize their businesses over inadequate harvest volumes in a given year in Idaho. While there are many efficient and automated logging firms in the state, there are many firms that are not; these less efficient firms are removing volume from the progressive firms creating an unstable future for the logging sector, leading to chronic layoffs and a sub-optimized rate of return for many of the logging contracting firms. Future start-up logging firms are discouraged from entering this industry sector due to the uncertainty. Logging firm owners refrain from making investments in capital intensive modern logging machinery because many sector participants cannot fully optimize the dated machinery they currently own, creating a drag on the entire sector. The future of Idaho's logging sector will depend on emphasizing efficiencies so that remaining firms are stronger and can attract qualified labor with sufficient operating season lengths, wages and benefit packages.

Many contractors who were interviewed in this study were reluctant to enter into emerging markets for biomass as that segment of the industry requires substantial financial risk without the "guarantee" of mills to supply and/or purchase raw materials. The biomass market is also considered quite volatile. Mill representatives expressed concern that threats to Idaho's forestry sector future may manifest themselves in the form of forest land tract fragmentation due to conversion to housing or other non-forestry activities. Increased environmental regulatory pressure was also perceived to reduce the overall competitiveness of Idaho's PFPI. Additionally, a lack of reasonably priced and/or distanced raw material sourced from federal lands was expected to continue to constrain the entire Idaho PFPI into the future and may curtail potential industry expansion into emerging markets. Further periodic analysis of Idaho's PFPI by academic, agency and industry groups can capture developing patterns that would assist in increasing the competitive advantage of this industry sector into the future.

References

Allen, T. T., H. Han, and S. Shook. 2008. A structural assessment of the logging contractor sector in the Inland Northwest. *Forest Prod. J.* 58(5): 27-33.Amberg, S. M. 2008. *Public Perceptions of Aquaculture: Exploring the Influence of Mass Media and Decision Heuristics in Shaping Risk Perceptions*. PhD Dissertation, Univer. of Idaho, Moscow, Idaho, USA. 140 p.

Brandt, J. P. , T. A. Morgan, C. E. Keegan, J. M. Songster, T. P. Spoelma, and L.T. DeBlander. 2012. Idaho's forest products industry and timber harvest, 2006. Gen Tech. Rep. RMRS-RB-12. Fort Collins, CO; USDA, Forest Service Rocky Mountain Research Station. 45 p.

Cook, P., and J. O'laughlin. 2006. *Idaho's Forest Products Business Sector: Contributions, Challenges, and Opportunities*. Report No. 26, College of Natural Resources Policy Analysis Group, Univer. of Idaho, Moscow. 48 p.

Green, W. D., B. D. Jackson, and J. D. Culpepper. 2001. Georgia's logging businesses, 1987 to 1997. *Forest Prod. J.* 51(1), 25-28.

The Idaho's Associated Logging Contractors membership list; personal communication Shawn Keough, April 2009 (see also http://www.idahologgers.com; last accessed on Oct. 5, 2012).

Idaho Forest Products Commission available online at http://www.idahoforests.org/img/pdf/WorkforceSurveyFINAL.pdf; last accessed on Sept. 7, 2012.

Keegan,C. E., III, T. A. Morgan, J. B. Brandt, F. G. Wagner, and K. A. Blatner. 2005. Montana's forest products industry: Current conditions and 2005 forecast. Montana Business Quarterly 43(1):31-32.

Keegan, C.E., III, T. M. Morgan, K. M. Gebert, J. P. Brandt, K. A. Blatner, and T. P. Spoelma. 2006. Timber-processing capacity and capabilities in the Western United States. *Journal of Forestry*. 104(5):262-268.

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

Mei, B. and C. Sun. 2007. Measuring Oligopsony and Oligopoly Power in the U.S. Paper Industry. 2007 Southern Forest Economics Workshop (SOFEW), San Antonio, Texas. 11 p.

Morgan, T. A., C. E. Keegan III, T. P. Spoelma, T. Dillon, A. L. Hearst, F. G. Wagner, and L. T. DeBlander. 2004. Idaho's Forest Products Industry: A Descriptive Analysis, USDA Forest Service-Rocky Mountain Research Station, Resource Bulletin RMRS-RB-4: 1-31.

Munn, I. A., J. B. Cutshall, and D. G. Hodges. 1998. 1993 Pulpwood logging contractor survey. *Forest Prod. J.* 48(7/8), 47-53.

Prudham, S. W. 2002. Downsizing Nature: Managing Risk and Knowledge Economies Through Production Subcontracting in the Oregon Logging Sector. *Environment and Planning*, A34, 145-166.

Cruising Methods, Volume Estimation, and Chipping Productivity for Western Juniper Biomass Market Development

Elizabeth Dodson[1], Stephen Fitzgerald[2], Tim Deboodt[2]

Abstract

In support of efforts to utilize western juniper for biomass markets, a study was undertaken to: 1) assess cruising methods appropriate for western juniper; 2) develop a form classification for western juniper that combines the potential uses of the tree with likely processing effort required; and 3) estimate chipping cost and production of western juniper. An method for estimating allometric variables used in volume calculation was developed and tested. This estimation method was less expensive to implement and provided no poorer results than measured allometric variables when compared to chipped volumes. The form classification developed segregated processing effort and tree form. Estimates of chipping production were found. Volume equations for total aboveground biomass for juniper remain poor predictors of actual volume.

Introduction

Western juniper (*Juniperus occidentalis*) has expanded ten-fold in central and eastern Oregon in the last century. There are undersiable effects from juniper exapansion, including loss of plant diversity, wildlife habitat and loss of watershed function. Currently, western juniper has marginal economic value. Therefore, for most watershed and rangeland restoration projects, junipers are cut down and left on site. Western juniper represents a potential biomass source and there are efforts underway to construct biomass plants in central Oregon. Federal land management agencies and private landowners are interested in utilizing and selling juniper biomass, but they need a straight-forward method of determining the amount of juniper biomass (tons) they have available to potentially sell. One set of equations for total above-chipped biomass does exist for western juniper (Ratchford et al. unpublished); however it requires field measurements that are expensive and, thus, may not be economical over large land areas. Therefore estimations of allometric variables used in the equations need to be explored and cruising best practices developed.

This project had three main objectives:

1. Assess cruising methods appropriate for western juniper
2. Develop a form classification for western juniper that combines the potential uses of the tree with likely processing effort required
3. Estimate chipping cost and production of western juniper for potential biomass markets

[1] Associate Professor, College of Forestry and Conservation, University of Montana
[2] Oregon State University Extension Service

Methods

Above-chipped biomass equations for western juniper depend on crown area or crown volume (Table 1). The measurement of both crown area and volume require the measurement of crown diameter using a tape measure in the widest direction and a second measure of crown diameter perpendicular to the first. Consider the nature of most western juniper trees with limbs that typically cover the entire bole, measurement of crown diameter is not a realistic prospect if a large number of trees are to be measured. A surrogate measure of crown diameter is proposed and involves measuring the "radius" of the crown from the widest point in the crown to the bole of the tree using a 10-foot PVC pipe with 1-foot markings. Test measurements were taken to determine if the second estimate of crown radius should be taken at a point perpendicular to the widest crown span or at the narrowest distance between the tree dripline and the bole. Estimates of crown area were compared with crown area measured using the taped crown diameter method and it was determined the widest radius and a radius perpendicular (in a clockwise direction) to the widest distance between the bole and dripline of the tree provided the best estimate (Figure 1).

Table 1: Volume equations for western juniper, where y is the natural log of the total biomass and x is the natural log of the respective variable (Rachford et al. unpublished)

Variable	Equation	R2
Height	y = 0.057 + 2.68x	0.79
Age	y = -3.369 + 2.03x	0.38
Basal Diameter	y = -1.96 + 2.03x	0.83
Canopy Volume	y = 1.60 + 0.85x	0.87
Canopy Area	y = 2.07 + 1.09x	0.83

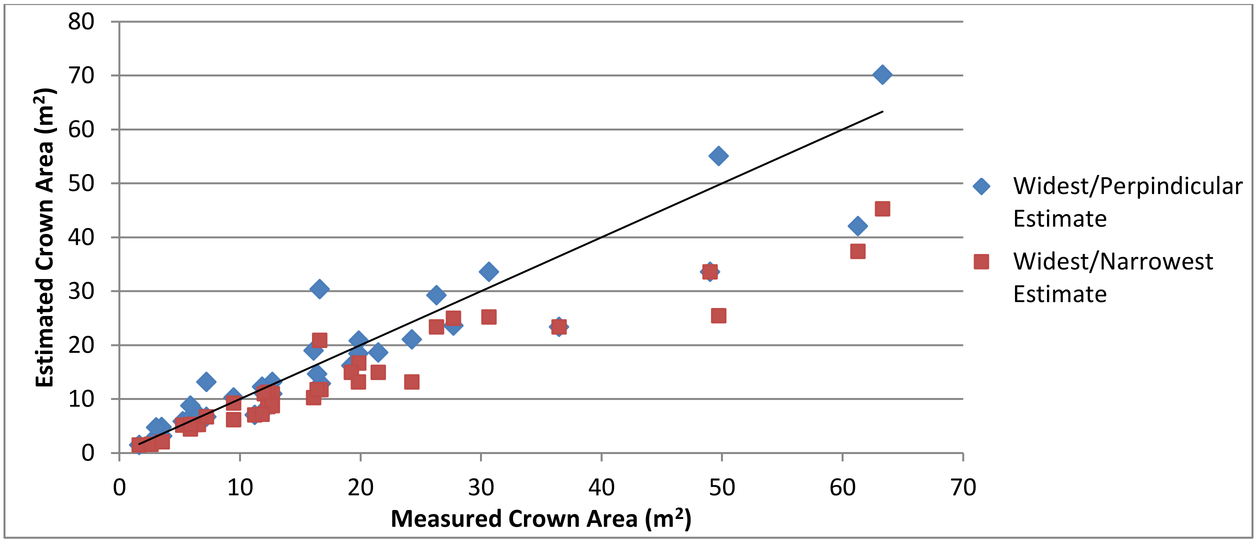


Figure 1: Crown area estimation

Heights were estimated and measured using the 10-foot PVC pipe as an ocular guide and using clinometer, respectively. Ocular height estimates were generally within one foot of heights measured using a clinometer for tree heights up to 40 feet. This encompasses most western juniper stems encountered.

Existing phase descriptions for western juniper consist of ecological categorizations of woodland development and do not take potential utilization of wood fiber into consideration. Additionally, existing juniper volume equations do not consider form, in part because no form classification has been available. Therefore, five form classes were developed for western juniper considering a combination of growth form, required processing effort, and potential end product. The form classes are as follows:

Class 1: Tree-like, small limbs
Class 2: Tree-like, heavy limbs
Class 3: Tree-like, multi-stemmed
Class 4: Shrub-like, single-stemmed
Class 5: Shrub-like, multi-stemmed

Two sites in central Oregon approximately 20 miles northeast of Brothers were selected on private land. Each site was 10 acres in size and consisted of pure stands of western juniper. Site 1 consisted of a better-stocked stand of more tree-like stems while Site 2 was along a ridge line, sparsely stocked in placed with more shrub-like stems. Ten plot centers were located within each site on a systematic grid. Two fixed-area circular plots were installed at each plot center; one one-tenth acre and the other one-twentieth acre in size. At each plot center a coin was flipped to determine the plot size to be installed first and a second coin flip was used to determine if the first plot installed would be a measured plot (cloth tape used to measure the widest crown diameter and perpendicular crown diameter, laser used to measure total crown height) or an estimated plot (10-foot PVC pipe used to estimate widest crown "radius" and perpendicular crown radius, ocular estimate of crown height using the PVC pipe as a guide). The first plot installed at each plot center was timed. The second plot size was then installed using the other method of gathering allometric information not used in the first plot. In this way all trees within the smaller plot were both measured and estimated for crown area and volume. All trees were tagged with metal tags for future identification and form class was recorded for each.

A forwarder-mounted chipper was used to chip and weigh all trees within measured plots. The initial intention was to use the on-board scales to weigh individual trees however the scales were not sensitive enough. Therefore weights were recorded for all trees combined within each one-tenth acre plot. Time to chip individual tagged trees was recorded. Time to maneuver the machine within plots was not recorded as this was an artifact of asking the machine to work in an unnaturally small area. Additional time-and-motion data was taken during production chipping outside the measured plots.

Results

Table 2 presents average stems per acre found in each of the two sites as well as estimates of the costs of the two methods of gathering allometric variables. The estimation method assumes one person at $25/hour; the measurement method requires a crew of two.

Table 2: Stand summary and plot cost

	Site 1	Site 2
Average TPA	152	75
Plot Establishment (min.)	3.8	1.7
Estimate (min/plot)	23.0	11.4
Measure (min/plot)	26.7	13.2
$/plot – Estimate	$11.18	$5.42
$/plot – Measure	$25.47	$12.38

Predictable differences were seen when crown area was compared to height for the five form classes (Figure 2). Shrubbier-formed trees generally had larger crown areas for a given height as opposed to tree-like forms which were taller relative to crown area.

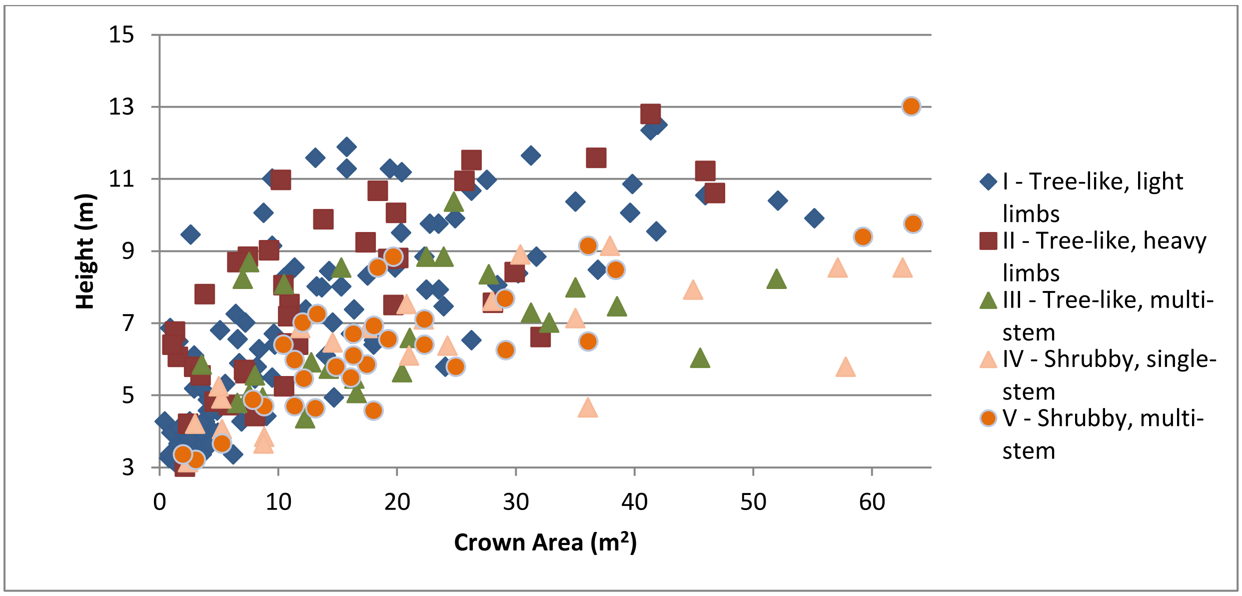


Figure 2: Crown area vs. crown height by form class

On a per-tree basis, many tree volumes per the equations for the measured versus estimated crown area and volume were very different (Figure 3).

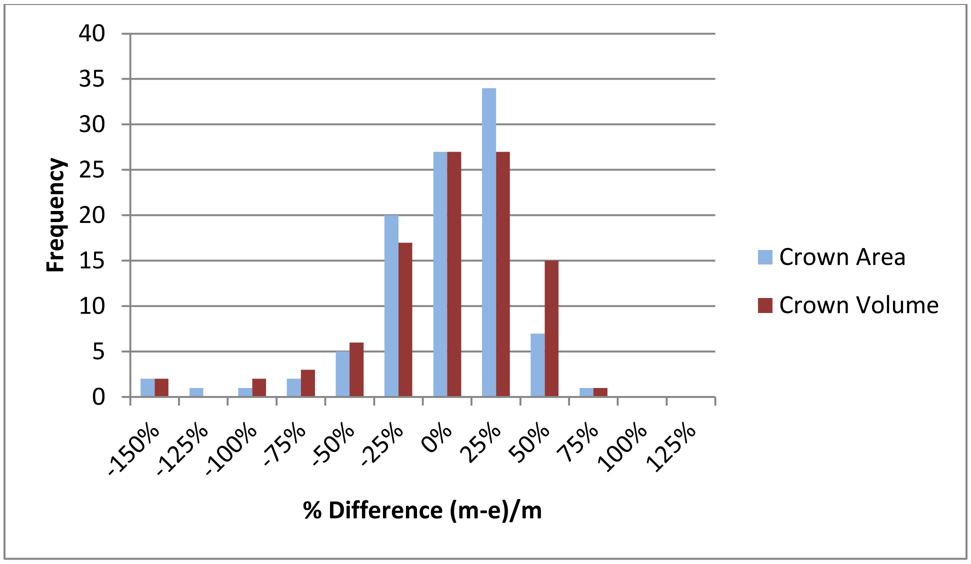


Figure 3: Percent difference between total tree volume calculations using measured and estimated allometric variables

In aggregate, this also translated into different estimates of tons per acre per plot (Figure 4) and for the stand (Table 3). For nine out of the 17 plots chipped, the total weight of chipped material adjusted to a tons per acre basis assuming 45% moisture content was between the estimates of per acre tonnage provided by the estimation and measurement methods. For the same number of plots (9), the estimation method provided a higher tons per acre estimate than did the measurement method. In only two cases did the chipped weight of trees within a plot exceed the estimated biomass from both measured and estimated allometric variable methods.

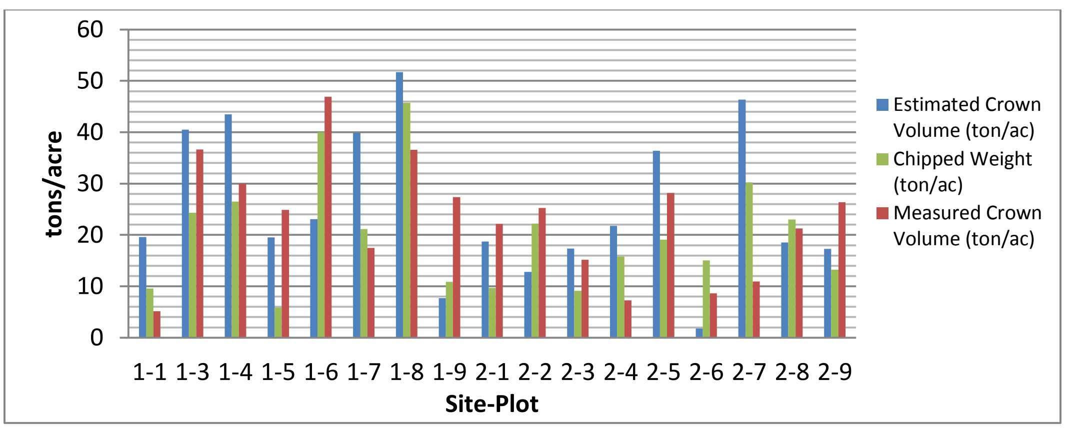


Figure 4: Comparison of tons/acre estimates based on estimated crown radii and height, measured crown diameter and height, and chipped plot weights

Table 3: Estimates of total ton/acre for each site using the three methods

Site	Estimate (ton/acre)	Measure (ton/acre)	Chipped (ton/acre)
1	32.0	29.4	23.0
2	19.5	17.1	17.5

Total volume on the plot appears to have little to no impact on the quality of volume estimate (Figure 5) nor does estimated versus measured allometric variables.

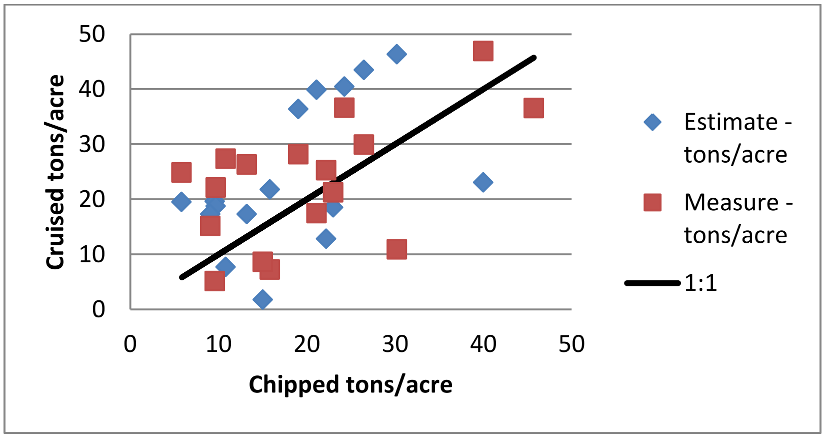


Figure 5: Cruised versus chipped ton per acre estimates

Plots where chipped weights were higher than either volume estimation method had more shrub-like stems than those plots where chipped weights were either less than or mid-way between volume estimation methods (Figure 6). Little difference existed between the form class distribution of plots where chipped weights were either below both or mid-way between volume estimation methods.

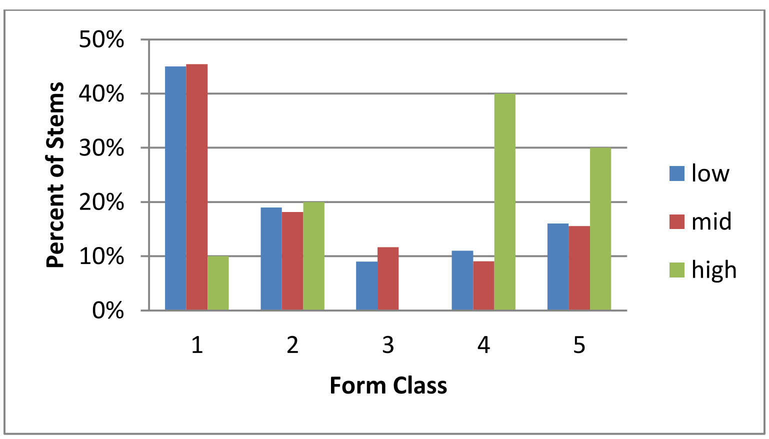


Figure 6: Percent of stems per plot in each form class for plots where whole-plot chipped weight was less than both volume estimation methods ("low"), between volume estimation methods ("mid"), and greater than both volume estimation methods ("high")

Individual stems within plots where whole-plot chipped weights were less than both volume estimation methods tended to be smaller trees with lower than average crown radii and heights, and therefore lower crown area, crown volume, and total estimated above-ground chipped biomass (Figure 7).

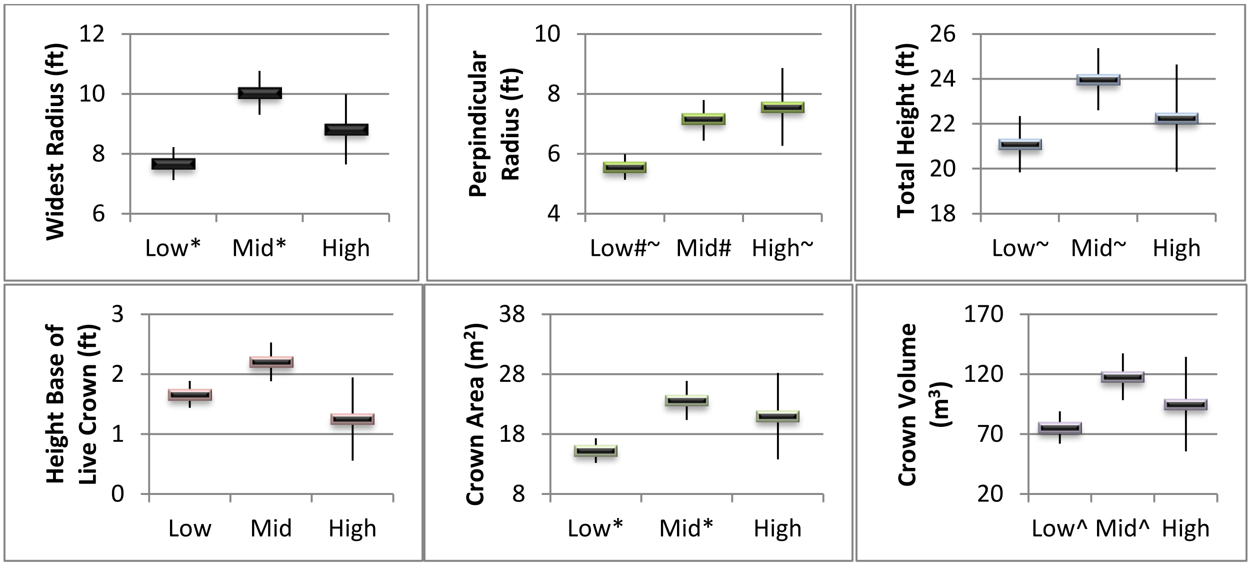


*Figure 7: Comparison of individual tree characteristics within plots where whole-plot chipped weights were less than both volume estimation methods ("Low"), between volume estimation methods ("Mid"), and greater than both volume estimation methods ("High") at an 80% confidence level. Statistically significant difference are indicated as *a=0.05; #a=0.10; ^a=0.15; ~a=0.20*

Chipping times were collected for individual stems. Additionally, production chipping activities were also recorded and separated into moving, chipping, grabbing/positioning trees, dumping, and delay categories (Figure 8). Due to logistical delays, production chipping was limited to two complete bin cycles (51.16 minutes). The chip and grab cycle elements were included in the timing of individual stems.

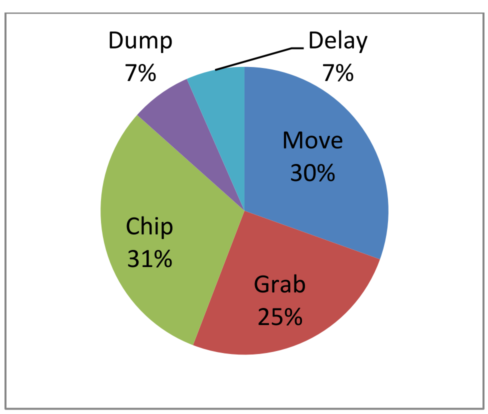


Figure 8: Chipper time allocation

The chip and grab cycle elements were included in the timing of individual stems. Figure 9 presents resulting $/ton (bone dry) estimates for chipping assuming three different chipper hourly rates.

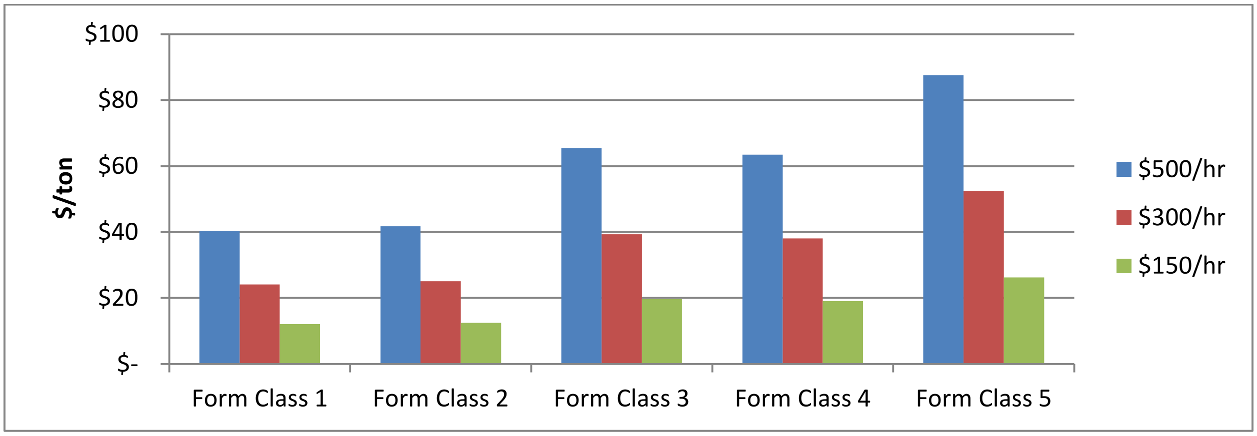


Figure 9: Stump to truck chipping cost estimates, by form class, for western juniper

Conclusions

The less-expensive estimation of allometric variables using a PVC pole, while frequently providing different per-tree estimates of volume as compared to measured allometric variables, does not appear to be a factor in how well volume of western juniper can be estimated as compared to actual chipped volumes. In other words, current equations do a poor job estimating biomass and the method of gathering crown area and volume data do not significantly impact the performance of these equations. Form class is a significant variable in describing differences in chipping effort and therefore cost and in describing plots where chipped volume exceeded estimated volume per either estimated or measured allometric variables.

References

Ratchford, J, R. Miller, P. Doescher, B. Sabin, A. Tierney. Estimating aboveground biomass and nutrient pools in semi-arid conifer woodlands. Unpublished manuscript.

First Entry Commercial Thinning: A comparison of Traditional and Contemporary Harvesting Methods on Steep Slopes in the Coast Range of Oregon

Benjamin Flint[1], Loren D. Kellogg[2]

ABSTRACT

The practice of first-entry commercial thinning, without prior pre-commercial thinning, has recently emerged as a beneficial method to thin young stands in the coast range of Oregon. However, little is known about the economic feasibility of the techniques being utilized to thin harvest units with steeper terrain (>35%). This exploratory study utilized a shift-level assessment to compare six different harvesting systems to determine the economic feasibility of each harvesting method when applied on steep terrain (>35%). The six different harvesting systems were a Koller K301 yarder with manual felling on steep terrain (> 35%), a Koller K301 yarder with a Ponsse Ergo harvester cutting and pre-bunching whole trees with no processing on steep terrain (>35%), a Koller K301 yarder with a Ponsse Ergo harvester cutting with full processing and pre-bunching on steep terrain (>35%), a Ponsse Ergo harvester cutting and processing for a Ponsse Buffalo King forwarder on steep terrain (>35%) with an adverse haul to the landing, a Ponsse Ergo harvester cutting and processing for a Ponsse Buffalo King forwarder on steep terrain (>35%) with a favorable haul to the landing, and a Ponsse Ergo harvester cutting and processing for a Ponsse Buffalo King forwarder on flat terrain (<35%). Economic feasibility was determined by evaluating and comparing the productivity and cost of each harvesting system. The results of the comparison of the six harvesting systems showed that on steeper terrain (>35%) the harvester/forwarder treatments had the lowest overall harvesting costs. However, this study also found that processing and pre-bunching using the Ponsse Ergo harvester caused an increase in productivity of 79% and a reduction in cost of 58% for the Koller K301 yarder. Through the results of this study, land managers will be better prepared to make decisions regarding the adaptation of first-entry commercial thinning onto their land base.

INTRODUCTION

Timber land managers face many decisions regarding the health and growth of their respective stands. Traditionally, once a stand had been planted, the next progression of management would be to pre-commercially thin in an attempt to add significant amounts of growth in the early stages of stand development. However, pre-commercial thinning can be an expensive endeavor which provides only the promise of improved net volume return and the potential for increased future profits. Given the current timber market, land managers are making strides to both reduce overall harvesting costs and increase the net volume return from their respective land bases. One of the ways in which land managers can achieve these goals is to forego pre-commercial thinning and instead conduct a first-entry commercial thinning of small, low-value timber.

[1]Presenting Author, Graduate Research Assistant, Department of Forest Engineering, Resources and Management, Oregon State University, Corvallis, OR, 97331.
[2]Lematta Professor of Forest Engineering, Department of Forest Engineering, Resources and Management, Oregon State University, Corvallis, OR, 97331.

By transitioning their management in this fashion, land managers are able to eliminate the cost of pre-commercial thinning while at the same time retain the growth potential of their stands. This approach works very well with mechanized harvesting systems, because of their higher production rates and relative low cost. But this approach has found considerable obstacles in the coast range of Oregon where land managers are faced with terrain that has traditionally been reserved for high cost cable thinning systems. Thus, there was a strong desire from local land managers to conduct an exploratory research study into the economic feasibility of harvesting small, low-value timber from units with steeper (>35%) slopes.

STUDY AREA & TREATMENT UNITS

The study area was located on Starker Forest Inc. timberland in Benton County, Oregon. The total harvest area was a combination of two thinning units totaling 170 acres. From the 170 acre harvest area, six study units were selected based on: topographic conditions, applicability to proposed harvesting techniques, and operational constraints. The six study units totaled 22.18 acres. The terrain throughout the unit was broken or uneven in slope with portions being either flat (0-35%) or steep (50-70%) with multiple benches and drainages throughout. The timber was primarily 28 year old Douglas-fir (*Pseudotsuga menziesii)* with a low proportion of red alder *(Alnus rubra)* and true fir *(Abies spp.).* The six different treatments conducted by Miller Timber, Inc. (Philomath, OR) were unique to each unit, and were compared based on similar factors such as: yarding methods, felling method or slope conditions. Each treatment consisted of one of two yarding methods involving either a Koller K301 yarder or a Ponsse Buffalo King (double bogie) forwarder. The yarding method was then combined with either a Ponsse Ergo (double bogie) Harvester (with or without ghost roads) or manual felling. Three of the six treatments were conducted using the yarder and the other three treatments utilized the forwarder for yarding. The three yarder treatments were on steep (>35%) slopes and were differentiated either by: processing method (whole-tree, tree-length or cut-to-length), felling method (manual or harvester) and/or number of ghost roads (single or double). The three forwarder treatments were differentiated either by the slope of the treatment area or the type of loaded return trail travel (haul) to the landing (adverse or favorable) whereby all felling operations were cut-to-length via the harvester without ghost roads. See Table 1 for a summary of the harvesting techniques used in each treatment unit.

Ghost roads were corridors that the harvester traveled on to cut stems but where yarding operations were not conducted. Ghost roads were used to increase the spacing between cable yarding corridors. The use of a single ghost road provided a corridor spacing of 100 feet; which, was the corridor spacing utilized by the contractor under standard operating procedures; additional ghost roads provided extra spacing between cable yarding corridors that was above the standard operating procedure. The standard operating procedures utilized by the contractor were used in the determination of the harvesting system in the two control treatment units. Under standard operating procedures, cable yarding on steep (>35%) slopes would consist of tree-length manual felling and yarding with a corridor spacing of 100'. Conversely, ground-based harvesting on flat (<35%) slopes would consist of cut-to-length falling via the harvester followed by forwarding to a roadside landing. Thus, a control unit was set up both for cable yarding and forwarding based on the standard operating procedure of the contractor utilized in this study.

Table 1. A summary of the: yarding mechanism, felling mechanism, felling type (PB = Pre-bunching, CTL=Cut-to-Length, GR= ghost roads and number of ghost roads) and slope for the five treatment configurations.

Treatment Units							
Treatment	**Size (ac)**	**Road Spacing (ft.)**	**Yarding**	**Felling**	**Processing**	**GR**	**Slope (%)**
1	2.75	100	Koller 301	Manual	tree-length	None	50-65
2	1.80	100	Koller 301	Harvester	Whole-tree, PB	Yes, 1	50-65
3	3.63	150	Koller 301	Harvester	CTL, PB	Yes, 2	50-65
4	2.87	50	Forwarder (adv. haul)	Harvester	CTL	None	50-75
5	4.08	50	Forwarder (fav. haul)	Harvester	CTL	None	45-65
6	7.05	60	Forwarder (flat)	Harvester	CTL	None	< 35

METHODS

The research methodology used to develop the harvesting productivity assessment for each of the six treatment units was adopted from the procedures outlined by Kellogg et. al (1999). A shift level assessment was conducted within each of the six treatment units to generate a productivity and cost analysis. The shift level assessment was conducted by noting and recording the various productivity factors that occur on a given day and within a given treatment unit. The productivity factors were assessed individually by harvest system component (felling or yarding). Thus, there were four different sets of productivity factors analyzed representing the two felling methods (manual, harvester) and the two yarding methods (forwarder, yarder). The general productivity factors that were assessed are listed below:

Manual felling: Start and stop time; Number of timber fallers; Number of stems cut; Delays (>10 minutes): Operational (walk in/out of unit, hang-ups), Mechanical (chain saw repair/ maintenance, fuel & lube), Other (personal, etc.)

Harvester: Start and stop time, Treatment unit; On board computer production report (stems cut); Fuel consumption (to the nearest gallon); Delays (>10 minutes): Operational (wait time or travel between units), Mechanical (repair or maintenance, including scheduled daily maintenance, fuel & lube), Other (personal, etc.)

Forwarder: Start and stop time; Treatment unit; Number of Bunks forwarded; Number of trucks loaded and the duration of loading; Delays (>10 minutes): Operational (wait time or travel between unit, etc.), Mechanical (maintenance/repair including scheduled daily maintenance), Other (personal, etc.)

Yarder: Start and stop time; Number of crew members; Treatment unit; Number of turns and number of pieces yarded; Number of trucks loaded; Processing time (if needed); Yarder fuel consumption; Loader and/or processor fuel consumption; Road and/or landing change time; Delays (>10 minutes): Operational (rig-up or tear down, waiting for processor, etc.), Mechanical (equipment repair/maintenance, etc.), Other (personal, etc.)

With respect the productivity value "number of pieces yarded", transformations were required in order to provide a basis for comparison between the different processing methods (tree-length, whole-tree and cut-to-length) used in the cable yarding treatment units (1, 2 and 3, respectively). Using felling data collected during the study, adjustment factors of 1.25 for tree-length pieces and 2 for whole-tree pieces were applied to adjust the "number of pieces yarded" value into a number representing the number of pieces yarded after full processing had occurred.

In order to evaluate the economic feasibility for each of the treatments within the study, a detailed methodology was needed to accurately project the costs of the harvest systems. This was achieved through the machine rate method as laid out by W.D. Greene and B.L. Lanford (1999). The purchase price that was used within the cost analysis was based on the listed price for a new piece of equipment as provided by the contractor (Miller Timber Inc.). All other values were ascertained from industry standard prices and/or rates (these values can be ascertained from the authors).

Using the total cost developed for each machine via the machine rate method, the total cost for the harvest system in each treatment unit was found by combining each of the individual machine costs into a single cost representing the entire harvesting system for the treatment unit. An extra 18% was added to the total harvest system cost to account for overhead, profit and risk. Utilizing the productivity and cost data, a cost per load was developed to provide a consistent and identifiable basis for comparison. The number of pieces per load was found via the forwarder shift level data. On average there were 274 pieces (logs) within each log truck load. Using the value of 274 pieces per load, the per unit total cost was transformed from a cost per piece (log) into a cost per load for each treatment unit.

RESULTS AND DISCUSSION

The results from the shift level assessment of the harvesting systems (treatments) focused around the results from the forwarder and yarder, since the productivity of yarding component drives the economics of the system as a whole. The productivity of the forwarder was measured in the total number of bunks that were forwarded and the number of bunks that were forwarded in an hour. On average there were approximately 137 pieces (logs) per bunk. Table 2 summarizes the productivity values for the three forwarder treatment units.

Table 2. The shift level productivity values for the forwarder treatment units.

Treatment Unit	Total bunks	Bunks/hr	Pieces/hr
6 (Control, Flat)	17.5	1.66	238.19
4 (Adv. Haul)	7	0.70	100.47
5 (Fav. Haul)	17.5	1.57	192.74

The results of the shift level assessment of the forwarder showed that when the forwarder was operating on steep terrain (>35%) and was traveling loaded in an adverse direction to the landing (treatment unit 4) there was a 58% decrease in productivity compared to the flat terrain control unit (treatment unit 6) with pieces per hour values of 100.47 and 238.19, respectively (Table 2). Conversely, when the forwarder was operating on steep terrain (>35%) and was traveling loaded in a favorable direction to the landing (treatment unit 5) there was only a 19% decrease in overall productivity compared to the flat terrain control unit (treatment unit 6) with pieces per hour values of 192.74 and 238.19, respectively (Table 2). The “take home message” derived from the productivity assessment was that when a forwarder operates on steep terrain, land managers should look for every opportunity to avoid adverse skidding and adverse hauls to the landing. However, there will always be situations where the need for adverse skidding and adverse hauling may arise. Although the productivity of the forwarder was driven by the number of bunks yarded, the productivity of the yarder was driven by the number of pieces yarded and the number of turns per hour. The results of the shift level productivity assessment of the yarder are summarized in Table 3.

Table 3. The shift level productivity values for the yarder treatment units. (*Control = tree-length processing, manual felling; WT = whole-tree; CTL = cut-to-length; Harv. = harvester felling).

Treatment*	Turns/hr.	Pieces/turn	Pieces/turn (adjusted)	Pieces/hr. (adjusted)
1 (Control)	11	3.65	4.8	**51.35**
2 (WT, Harv.)	9	3.92	5.88	**50.15**
3 (CTL, Harv.)	13	7.14	7.14	**92.04**

The value of adjusted pieces per hour was the driving factor for the productivity of the yarder. The results showed that there was a 79% increase in productivity for the yarder when operating on skyline roads that had the harvester felling and pre-bunching cut-to-length stems (treatment unit 3) when compared to the control or standard operating procedure of manual felling with tree-length processing (treatment unit 1) with pieces per hour values of 92.04 and 51.35, respectively (Table 3). Conversely, there was little difference (2.4% decrease) when the yarder was yarding whole trees that were cut and pre-bunched by the harvester (treatment unit 2) when compared to the control (treatment unit 1) with pieces per hour values of 50.15 and 51.35, respectively (Table 3). The increase in productivity within treatment unit 3 is the product of the number of turns per hour and the number of pieces per hour both of which were the highest amongst the three yarder treatment units with values of 13 and 7.14, respectively (Table 3). Although the comparison of productivity is an integral part of determining the economic feasibility of a harvesting system, the most important aspect when determining economic feasibility is the cost of the harvesting system. The values of total cost and cost per load, including the percent change in cost against the controls are summarized in Table 4.

Table 4. The total and per unit (piece or log and per load) for the six different full treatments, including the % change with respect to the harvest system control.

	Treatment Unit (Harvesting System)*					
	1 (M-Y-TL)	2 (H-Y-WT)	3 (H-Y-CTL)	4 (H-F-ADV)	5 (H-F-FAV)	6 (H-F-FLAT)
Total Cost + OPR ($)	4,838.17	7,924.13	11,476.85	4,721.73	6,253.50	5,527.92
Cost per Load ($) (274 pieces/load)	**3,330.80**	**3,582.86**	**1,636.14**	**1,283.49**	**797.33**	**603.69**
% Change (cost/load) Against Control	**Control**	8%	-51%	113%	32%	**Control**

**M = Manual Felling, H = Harvester, Y = Yarder, F = Forwarder, WT = Whole Tree, TL = Tree Length, CTL = Cut-to-length, ADV = Adverse Haul, FAV = Favorable Haul, FLAT = Flat Terrain (<35%).*

The primary result that can be discerned from Table 4 is that the forwarder treatment units had lower per load costs than all of the yarder treatment units. Even though treatment unit 4 (adverse haul) had an increase in cost of 113% over the control (treatment unit 6) the cost per load of $1,283.49 was still lower than that of treatment unit 3 which had the lowest cost per load of the yarder treatment units with a cost per load of $1,636.14 (Table 4). Although the primary result is important, it should not be overlooked that treatment unit 3 had a reduction in cost of 51% with respect to the control (treatment unit 1, Table 4). Thus, the standard operating procedure that was mimicked within the control (treatment unit 1) was not the most cost effective manner in which to utilize the yarder. Conversely, it was found that the operation of the yarder was more cost effective with pre-bunching of cut-to-length logs by the harvester. Especially, when the number of ghost roads between each cable road was increased.

Although this study focused on the economics (productivity and cost) of steep terrain first-entry commercial thinning, it must be noted that there are two main considerations outside of the economics that could impact the adaptation or continuation of steep terrain ground based harvesting. This first consideration concerns the safety of steep terrain ground-based operations. The Oregon Occupational Safety and Health Administration (OSHA) regulate the safety of forest operations through the administrative rules outlined in Division 7 - Forest Activities Administrative Rules. Within subdivision J of the Division 7 rules, there are specific guidelines which restrict the operation of ground based machinery on steep terrain (OROSHA, 2010). For this study specifically, the operations forester and the operators themselves from Miller Timber Inc. walked the treatment units prior to the commencement of operations and assessed the areas to ensure that both the operation would be conducted in a safe manner and that all of the administrative rules from division 7 and subdivision J were followed. In summary, when ground based operations are pushed onto slopes that exceed the limits listed in Subdivision J of the Division 7 Administrative Rules (OROSHA, 2010), great care must be taken to ensure the safe operation of the equipment and to ensure that the administrative rules are followed.

The second consideration along with the economics of steep terrain ground-based operations is that of site impacts. The primary impact that can occur to a harvest unit from steep terrain ground based operations is soil disturbance both in the form of compaction and in the form of erosion/sedimentation. Concurrently with this study, another study was conducted on the soil disturbances generated by the operation of ground based equipment on steep terrain. The study was conducted by, R., Adams, P. and Sessions, J. and is currently a manuscript in review for the Western Journal of Applied Forestry.

CONCLUSIONS

The "big ticket" conclusion from the economic analysis was that under all scenarios considered within this study, the harvester/forwarder combination was the cheapest, most cost effective option for conducting first entry commercial thinning on steep terrain. However, land managers must also consider: the availability of the specialized Ponsse steep terrain equipment, the safety of crew members and machine operators as outlined in the forest activities administrative rules from Division 7 of the Oregon OSHA administrative rules (OROSHA, 2010) and the potential for soil impacts from operating ground based machinery on steep terrain. There were two other conclusions that could also be made from the economic analysis. First, when operating the forwarder on steep terrain, adverse hauls to the landing will cause drastic reductions in productivity and increases in cost. Second, by utilizing the harvester to process and pre-bunch stems for the yarder, productivity increased and cost decreased.

LITERATURE CITED

Greene, D.W., and Lanford, B.L. 1999. In Forest Harvesting and Roads. A Course Note Package compiled by Dale Greene. University of Georgia. Athens Georgia.

Kellogg, Loren D., Mark Miller, Jr., and Eldon D. Olsen. 1999. “Skyline Thinning Production and Costs: Experience from the Willamette Young Stand Project.” *Forest Research Laboratory, Oregon State University.* Research Contribution 21. Print.

OROSHA. *Division 7: Forest Activities Administrative Rules*. Revised Feb. 2010 "Operation of Ground Skidding Machines and Vehicles". Or. Admin. R. 437-007-0935

ACKNOWLEDGEMENTS

The authors wish to acknowledge: the planners and operators of Miller Timber Inc. for their hard work, dedication and patience throughout the course of the study; foresters and land managers at Starker Forests Inc. for their guidance and their willingness to allow the study to be performed on their land base; the efforts of Jeffery Wimer and Dr. John Sessions for their support and advice in the planning and execution of the field study; the efforts of Dr. Glen Murphy who aided in the cost analysis of the field data.

A Look at Logger Training after 35 years

Dr. John J. Garland, PE,
Consulting Forest Engineer, Garland & Associates;
Professor Emeritus, Oregon State U.;
Affiliate Professor, U. Washington,
johngarland49@gmail.com

ABSTRACT: Nearly thirty five years ago an assessment was made of logging training in the Pacific Northwest for the Pacific Logging Congress. Today logging training is still a paramount concern of the industry. With 55% of Oregon's logging workforce over age 45, there will be changes coming in the near term. Logging training has not been successful in institutions, in special training programs funded by government grants, nor in most firms who lack the resources to conduct the training they need. What has been tried? What had success? What failed? What are the best prospects for the future? What are the obstacles to training? What are the economic and other benefits of training for the firm and the forestry sector? This review covers 35 years of activities in the U.S., Europe and other countries. What will work in the future is also discussed and prospects for success are outlined.

INTRODUCTION

Nearly thirty five years ago, the author conducted a review of logging training in the Pacific Northwest (including Idaho, Montana, and California) to establish the status of logging training. The review set the research agenda for the author and associated colleagues in the region. Now as the PNW comes out of a deep recession, training needs are emerging as forestry workforces expand during the recovery. Safety issues and insurance costs remain as important issues in logging. For example, the workers compensation rate for non-mechanized logging (generally cable logging and manual felling) is set at $19.61 per hour worked making it equal to the prevailing wage for many logging jobs. It is instructive to look at the changes from the first assessment years ago to the current circumstances in a series of tables and commentary.

THE PEOPLE

Table 1. below compares some dimensions relating to the people involved in logging from the late 1970's to today. The original review characterized the typical worker of the day and is shown below in comparison to two characterizations of the logging workforce of today.

Worker of late 1970's

> *From the time he was old enough to help out around the place, he was picking up skills that would serve him as a logger. He learned to use hand tools, to use simple rigging to multiply his strength, and to grab a wrench to fix something mechanical that failed. Most importantly, he learned to work hard for long hours until the job was done. He started out in logging , successively acquiring skills in every area from choker-setting to timber falling. He worked for no fewer than ten different outfits and he learned from the men he worked with. Now in the twilight of his career, he notes some differences in the logging work force.(Garland, 1979)*

Dual Workforce of Today

> *Generation Y*

From the time he played his first video game, he operated all devices. He likes games but not hard work. He hasn't had to work at menial jobs and lacks fitness and stamina. He can read but prefers texting to people rather than talking face to face. He deserves a high paying job that allows time for friends and family.

Immigrant Worker

From the time his parents came here, he worked hard in the fields with them for long hours. His language and technical knowledge are not strong. He can work in difficult conditions but distrusts bosses and authority. He expects others to look out for themselves as he does. He prefers working with others like himself.

Another significant difference is that the current workforce is aging with loggers in PNW states reaching a level between 50-60% of workers over age 45. A review of Idaho log truck drivers found that in a group of 300+ drivers, over half were over age 66 (Garland, 2008). There are problems recruiting workers in logging making the age distribution worse compared to a balance age class of the first review. Also, the logging workforce has shrunk to less than half the size of the earlier workforce and loggers have lost comparative income and social standing of prior years. Now some of those supporting the mechanized logging industry as mechanics, computer technicians, machine shops are not recognized in the logging workforce statistics.

Table 1. The People

LATE 1970'S	TODAY
Greatest Generation WWII & Baby Boomers	Generation X & Generation WHY? Plus Immigrant Workers
Balanced Age Distribution	Aging Workforce
Adequate Recruitment of New Workers	Shortage of New Entrants to Workforce
Attitude: Work performance defines person	Attitude: Family, friends, social life as important as work
Above average income & social standing	Average or below income & diminished social standing
Workforce significant size compared to all workers, rural communities dependent on timber	Half the workforce remains, insignificant compared to all workers, understated support workers, eg mechanics, trucking

THE INDUSTRY

The forest industry has undergone radical changes from integrated forest and mill owners to real estate investment trusts using timber management organizations to contract for timber harvests. Corporate logging camps with large logging employment have been replaced with small contractors of 6-10 employees on average. Many logging firms are sole proprietors or small partnerships in felling, trucking or shovel logging. Table 2. Shows further differences.

Table 2. The Industry

LATE 1970'S	TODAY
Integrated forest and mill owners & federal timber dependent mills	Real estate investment trusts & timber industry management organizations
Corporate logging with workers exceeding 200 in logging camps & large contractors	Contractor firms with average firm size 6-10 employees, few corporate loggers
Forest Service timber sales & private industry logging with high harvest levels, little export	Half the harvest levels, little government timber except state sales, shift to South for timber, export markets
Many mills, many markets, many products	Limited markets, few mills, and emerging products, eg, biomass

THE OPERATIONS

This review cannot chronicle the technological changes in logging ranging from lighter, faster chainsaws, mechanical harvesting machinery, or synthetic rope to replace wire rope, but it does need to make general observations. Table 3. contrasts the mechanization trend away from motor manual operations and the reduction in the size of timber harvested. Less obvious trends in the PNW are the major uncertainties facing logging owners where the planning horizons are so short as to make equipment replacement a real challenge and profitability of the firm in doubt. Some good logging firms did not weather the recession.

Table 3. The Operations

LATE 1970'S	TODAY
Motor manual operations on flat, moderate & steep slopes w/beginning mechanization	Cable/motor manual on steepest slope, mechanized operations on flat to steep slopes, inc. felling with machines
Timber size often meter plus in diameter,	Timber size around 30-50 cm diameter, low

high volumes per area, log length operations	volumes per area in thinning, partial cuts, tree length operations
Consolidated operating areas & year plus planning horizons	Widely scattered operations & uncertain planning horizons, eg, next unit ????
Well managed operations profitable	All operations marginally profitable, recession caused firms to fold
Machine replacement scheduled	Old machines, run to failure, new machines needed

SAFETY

Table 4. shows trends relating to safety. Logging safety and training are linked but definitive studies to show cause and effect have not been prevalent. It is difficult to show the accident that did not happen was due to some preventive measures. Still progress has been made particularly in fatal logging accidents as shown in Figure 1. for Washington state which mirrors the progress in the other states as well. Figure 2. shows the Oregon claims over time with the recession year of 1980 evident where It took 6 years for the number of incidents to return to levels prior to the recession and 4,920 additional loggers were injured in next 4 years with direct cost of claims reaching $63,960,000. If a similar trend were to occur for this recession, the new workers getting themselves injured would severely impact the existing experience workers and jeopardize the knowledge base in logging.

Finally, older workers have traditionally been safer workers; however, Figure 3. shows an increase in the share of accidents by older workers even as the total number of accidents decreases. From 2000 to 2009 half the logging fatalities occurred to workers over age 45, and the claims for workers over 45 have increased from 22% to 40% (2000 to 2011).

Table 4. Safety

LATE 1970'S	TODAY
High accident rates, high fatality rates	Improved accident rates, much lowered fatal rates
Logging seen as dangerous and difficult	Logging seen as difficult, dangerous, dirty and declining
High workers comp rates	Lower workers comp rates in mechanized class but high in motor manual class

Older workers safer workers	Older workers having accidents and health problems, musculoskeletal injuries
1980's recession had high accidents during recovery	Current recession may have high accidents during recovery
Search for relation between accidents and safety improvement measures	Cause and effect between safety improvements difficult to establish

TRAINING

The previous discussion documenting changes in the forestry sector informs our understanding of the changes to training in logging over the past years. Table 5. again highlights the changes. Prior to the 1970's the on-the-job, work by me training was the dominant form of passing knowledge and skills to the new workers who were often related to other crew members. It is not true that there was no learning taking place with this approach but there was little technical training. From the late 1970's to the present, many training approaches were tried in the PNW and around the world but still today an objective comparison of logging to construction, for example, would conclude there is still a low level of training in logging. Even in developed European forestry countries and in the US, there is less training today than in the past although there are many different ways to provide the training.

The author's first article documented the obstacles to training for firms and found the following:

32% lacked time to conduct training
17% felt the size of operation was unsuitable to conduct training
17% felt training would be too expensive
8% liked the informal on-the-job training model
6% lacked personnel to do training
5% saw risks and insurance problems associated with training
5% saw union problems associated with training
4% felt it would be difficult to interest workers in training
3% felt workers would leave after being trained.

Over the years some of these obstacles were addressed by research, eg, Garland (1990) found firms could recoup the costs of training within such a short time frame that workers would be unlikely to leave before the payback for the training. Some obstacles were made irrelevant by changes in the industry. Union problems with training is nonexistent as the workforce is almost non-unionized, plus unions supported training. Insurers are now supporting logging training efforts and what is the greater risk a worker in supervised training or an untrained worker attempting the job without any skills or guidance? To be sure, small firms lack the time, resources, personnel, for potentially expensive training and because they were trained on-the-job, they prefer that method. Firms miss the point that designed on-the-job , field-based training can be effective.

With the highly competitive market among logging firms today, other obstacles have been stated by some leaders in the logging community. These include:

No capacity for training—minimal crews and can't find workers for jobs at all
If I train workers, I put a target on them for hiring away
I am in competition and don't want to have to compete with those who train
Can't send them off to school
They don't pay me enough to train

When leaders express such force for obstacles, it has the strength of a groundswell rather than cooperative efforts among firms to have the rising tides lift all boats in the logging sector.

The unsustainability of logging training is particularly evident for the institutions over time. There have been numerous attempts by educational institutions, non-profit organizations, and industry consortiums to conduct logging training. For example, in the late 1970's Oregon had about 25 forestry programs, most of which provided training so high school graduates might get a safe start in a logging job. Today there are 45 natural resources/forestry programs and only 5 have teachers with skills or interest in teaching logging skills. Community colleges often started logging training programs with local industry support but found them expensive and when the grants ran out, so did the training. Grant funded examples abound with the grantees getting the funds and the trainees getting the short stick (log?). Among the worst programs were the workforce redeployment schemes that would take the chronically unemployed, put them in a logging/conservation, pay-while-training course taught by pseudo-ecologists. Few trainees made it to a woods job and the author is chagrined at trying to help such programs. There was even a futile federal attempt to impose apprenticeship concepts on logging similar to those in plumbing or electrical work.

One significant improvement for logging training over time is the development of training approaches centered on the learner. Rather than have the trainee watch an experience worker and guess at the principles and techniques involved, training materials ranging from plastic cards to DVDs used in the field are available for training. Some materials are in the languages of the immigrant workers found in the workforce. Many good training materials are available with little or no charge although a central clearinghouse is still lacking. Equipment companies have made logging a priority and provide simulator training along with "You-Tube Videos" to help in training. In fact there is competition among the large logging equipment firms to provide the best simulator training.

After more than three decades of attempts by educational institutions and government funded logging training programs with their limited success, some new concepts of logging training are in order.   It has come to the author's understanding that the locus of training needs to be the firm itself. One-size- fits- all classroom training of groups of trainees modeled after the schooling that many logging employees found unattractive is not the way to successful logging training. Each firm and individual needs skill development differently that that offered by group training. Certainly some group training events make sense but not entirely as a program for the logging industry After years of limited successes and many failures, th e author believe training within the firm by individuals called "Logging Masters" may be the only potentially successful approach. Logging Masters are competent loggers who have been coached on how to train the new workers in the firm. They would tailor the training to what the firm needs and the employees already committed to work at the firm. Logging Masters would receive initial training themselves and then they as a group would form a "Logging Masters Association" to provide mutual support within the sector to each other. There is precedent in the author's Extension work with the Master Woodland Manager program he helped create and continues to provide peer-to –peer informal education on managing woodland properties among landowners. Several proposals have been made for such a project but funding for start-up has been missing to date.

For decades, supporters of logging training have hoped to show that training can reduce accidents in logging. While some studies show changes in risk behaviors result from logger training, the research difficulties in showing cause and effect relationships are formidable. Bell and others have shown that mechanization which includes the necessary training to function can reduce accident rates in felling (Bell et al, various dates).   Productivity gains can be demonstrated and when all benefits of training are considered, there are significant documented gains from training (Garland, various dates). What can be significant is that for safety codes for forest activities in Oregon, training and supervision requirements have replaced many of the unwieldy prescriptive "don't do that" codes.   The neighboring states often base their logging safety codes on Oregon's codes. The larger forest industry mandates training for safety and environmental issues through the voluntary Sustainable Forestry Initiative (like other certification schemes) but that training does generally not include skill training for actual workers.

There is still limited capacity for training within the forestry sector of the PNW but there has never been greater need for training forest workers. What continues to be lacking is the commitment to cooperative efforts among firms and organizations to implement a firm-based training strategy like "Logging Master."

Table 5. Training

LATE 1970'S	TODAY
Low level of designed training: work by me	Low level of training but more different

training predominates	training modes used
Obstacles to training identified: most still remain	Obstacles to training remain and new obstacles emerge
Institutional training attempted	Institutional training not sustainable
Training medium limited to classroom & field: few simulators	Training medium offers many options: pubs to internet and age of simulators
Government and educational institutions seen as location of training	Training within firm may be only way to achieve with association support
Training seen as key to safety but linkage not established	Training to achieve safety, productivity, quality & environmental performance
Limited training capacity in trainers & institutions	Greater capacity for training with commitment of the firm & sector

CONCLUSION

While nothing stays the same and changes have occurred, too many of the strategic obstacles to logging training remain. Greater needs and possibilities for logging training exist today than ever. Leadership to make logging training the force for the good of the sector it can become.

REFERENCES

Bell JL. Changes in logging injury rates associated with use of feller-bunchers in West Virginia. Journal of Safety Research, 2002;33(4): 463-471.

Bell JL, Helmkamp JC. Non-fatal injuries in the West Virginia logging industry: using workers' compensation claims to assess risk from 1995 through 2001. American Journal of Industrial Medicine, 2003;44(5),502-509

Bell JL, Grushecky ST. Evaluating the effectiveness of a logger safety training program. Journal of Safety Research, 2006;37, 53-61

Bureau of Labor Statistics. Census of fatal occupational injuries, Summary. 2010. http://www.bls.gov/iif/oshcfoi1.htm

Garland, J.J. 1979. A Look At Logger Training. Loggers Handbook Vol. XXXIX, 6p.

Garland, J.J. 1990. Assessing Gains from Woodsworker Training: A Methodology. Int. Jour. Industrial Ergonomics. (5) 1990. P. 227 242.

Garland, J. 1990. Structural changes needed to improve logging safety. Forest Industries. September. p. 26-27.

Garland, J. 1990. Observations on the Logging Labor Forces of the U.S. and the Nordic Countries. Proceedings Council on Forest Engineering Annual Meeting. NC State University.

Garland, J. 1992. Designing Successful Logger Education Programs in Promote and Develop Alternative Strategies for Logger Education in the South: A Workshop Proceedings. Cooperative Extension Service, Univ. of GA, Ext. For. Resources Dept. Pub. No. FO 92-11, May, 1992.

Garland, J.J. 1996. State of the art in logger education: Emerging roles and responsibilities. in Planning and implementing forest operations to achieve sustainable forests. Proceedings of the joint Council on Forest Engineering and IUFRO Research Unit 3.04 Meeting, Marquette, MI. July 29-August 1, 1996. USDA , Forest Service, General Technical Report, NC-186. p 32-38.

Garland, JJ. 1997. Contractors in forest harvesting and silviculture: Oregon and the United States. Labor Education, 106-107, 78-88.

Garland, J.J. 1998. Accreditation, certification and licensing of the forestry workforce in caring for the forest: Research in a changing world. p.140-145. In: Proceedings, Ergonomic papers and posters presented at the XXth IUFRO World Congress. August 6-12, 1995. Tampere, Finland. Wageningen Agricultural University, The Netherlands

Garland, J. 2004. Diez conceptos clavos para reducir riesgos en faenas forestales. Forestal Mundial. Assoc. Ingieneros Forestales Chileno. Marzo. P 32-34.

Garland, John J. 2005. Glossaries of English to Spanish: Forest activitities terms and Division 7 selected terms. Oregon Occupational Safety and Health Administration. Training Grant.available at www.orosha.org 27 p.

Garland, John. 2008. Sustainable Forestry? Not without a Sustainable Workforce. Western Forester. Society of American Foresters. Vol. 53. No. 6 p.14-15.

Garland, J. 2008. Four Reports on the Idaho Timber Workforce Development Project: Comprehensive Idaho Timber Workforce Overview, Report of a Survey of Idaho Timber Workforce Issues, and Report on the Idaho Timber Workforce Summit. Project sponsored by

Idaho Forest Products Commission, the Associated Logging Contractors of Idaho, and the Intermountain Forest Association. Available at www.idahoforests.org. various pages.

Helmer, Gary A. 1997. Summary of Workers' Compensation Claims Characteristics, Oregon, 1976-1996. Worker's Compensation Board, Oregon Div. of Consumer & Business Affairs.

Mochida, Haruyuki, Garland, J. and M. Sunasaka, 2000. Characteristics of Loggers in Oregon in the early 1990's. Journal of Forest Economics (Japan) Vol. 46, No. 2. p. 17-24.

Roberts TE, Bolding MC. A ten year analysis of timber harvesting injuries in the southeastern United States. Final report presented to the National Timber Harvesting and Transportation Safety Foundation. August 31, 2012

Scott DF. A study of logger fatalities from 1992-2000. Injury Prevention, 2004;10, 239-243

Rummer B. Models for Analyzing Logging Safety. Journal of Forest Engineering, 1995;63-71.

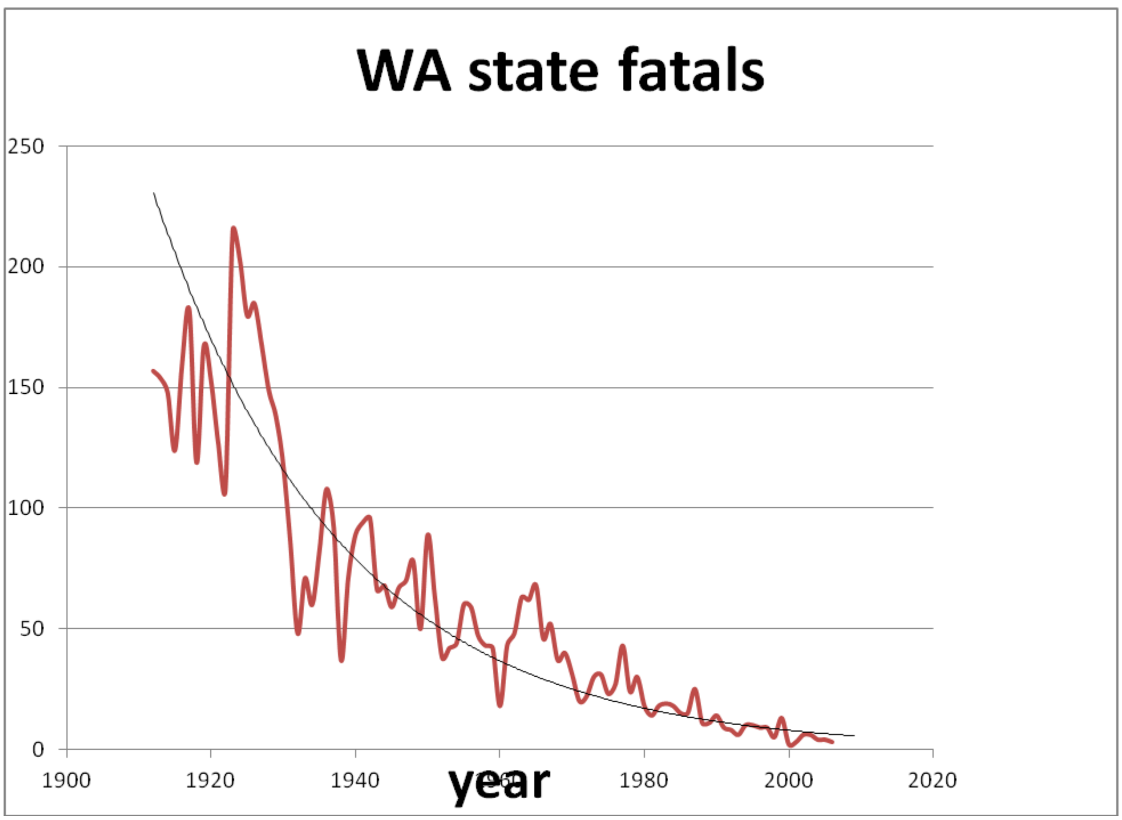


Figure 1. Logging fatalities in Washington State over time (WA Dept. of Labor & Industries)

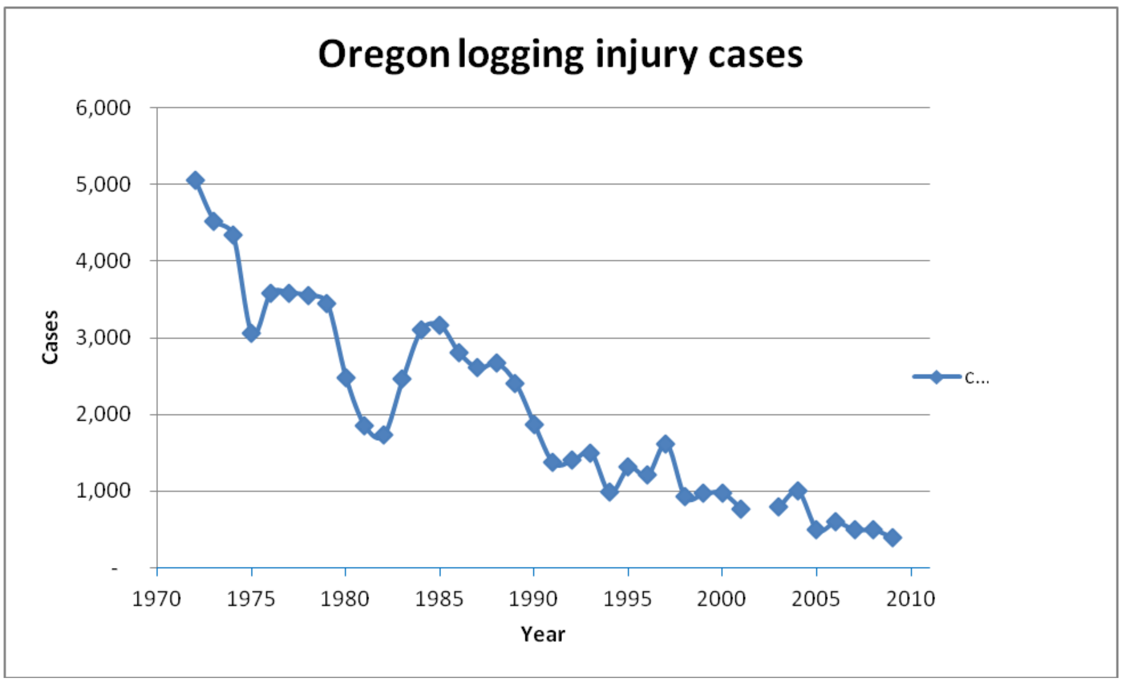


Figure 2. Logging claims over time with recession years of 1980-81 shown

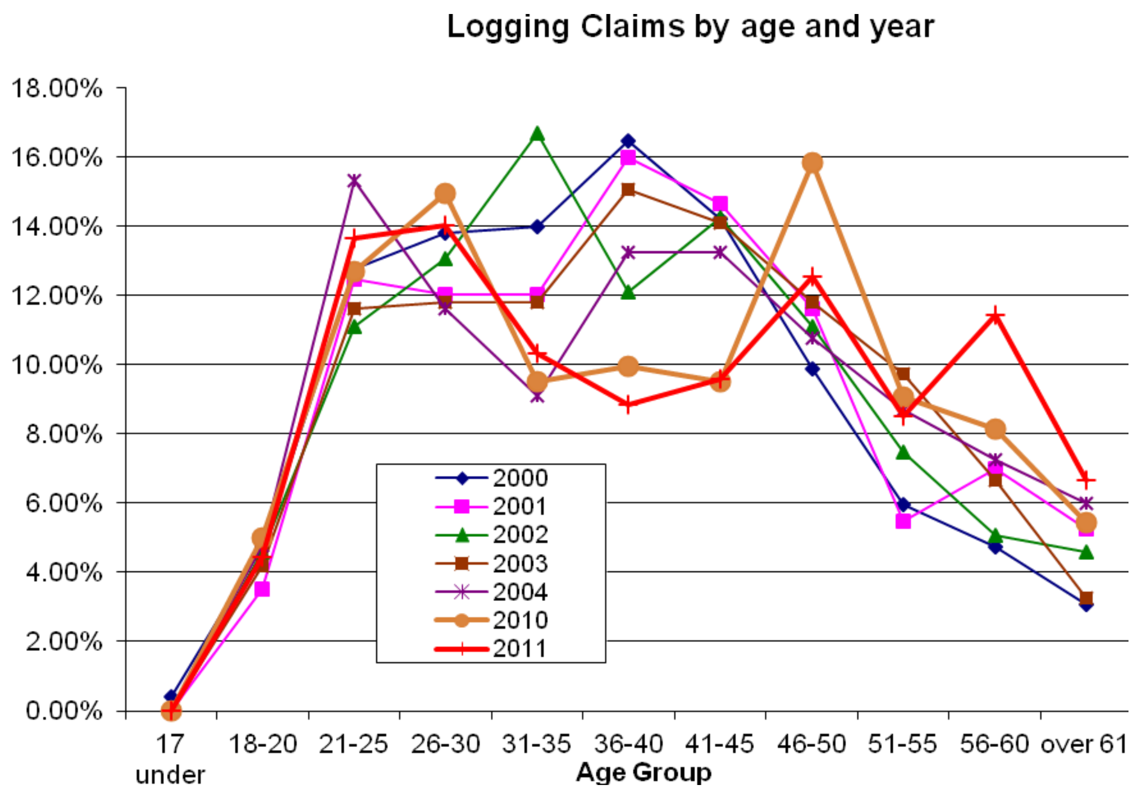


Figure 3. Oregon logging claims by age with older workers having increasing share of accidents.

Changes in Logging Firm Demographics and Logging Capacity in the US South

W. Dale Greene[1], Samantha C. Marchman[2], Shawn A. Baker[3]

Abstract

Timber harvesting operations in the US South are predominately operated by small businesses that run mechanized tree-length systems. They are highly productive and are an essential component in a wood supply system that is competitive on a global scale. We review these businesses and operations based upon 25 years of mailed surveys conducted on a 5-year interval and recent in-depth interviews with dozens of southern contractors to assess the cost factors in their businesses.

Despite dramatic shifts away from clearcuts and toward more frequent thinnings, average weekly production more than doubled over the past 20 years due to greater reliance on mechanization and planted stands. There is today little difference between the average weekly production of thinning crews and clearcut crews. The age of logging firm owners has increased nearly 10 years over the past two decades, although this reflects to some degree the aging of the US population generally. Capital investment per crew or firm is high and steadily increasing, but returns to capital are flat reflecting the economic reality that our industry is largely fully mechanized in the South and additional capital no longer buys significant additional productivity.

However, since the economic recession began in 2007, the average age of logging machines in the woods has increased substantially reflecting the decision by owners to delay replacement or new investment. Logging capacity by our estimates is down 15-20% since 2007 and we also see that the surplus of logging capacity versus harvest levels has decreased. While this is worrisome to wood-using industries that prefer to keep some “surge capacity” available, this tightening gap should improve the ability of logging contractors to negotiate higher logging rates for their services.

[1] Professor, Warnell School of Forestry & Natural Resources, University of Georgia Athens, GA 30602
[2] Research Assistant, Warnell School of Forestry & Natural Resources, University of Georgia Athens, GA 30602,
[3] Research Professional, Warnell School of Forestry & Natural Resources, University of Georgia Athens, GA 30602

Introduction

Loggers across the eastern United States face challenging economic impacts following the recent housing market collapse and economic recession. U.S. logger survey data from *Timber Harvesting* outlined general demographic changes since 2001: an aging and economically challenged workforce, increasing mechanization and associated financial strains, and increasing logger training, testing, and continuing education (Knight 2006a, 2006b, 2011). In the most recent survey from *Timber Harvesting* (Knight 2011), half the respondents stated that they made no profit in 2009. Labor issues were a concern as highly qualified workers sought other employment following business shutdowns. Loggers reported that market factors were keeping increases in efficiency from translating into higher profit margins. Slow market improvements, aging owner demographics and firm succession concerns remained, alongside efforts to improve efficiency in trucking and associated challenges to reduced tract size.

Results from the last survey of Georgia logging contractors in 2007 revealed increases in thinnings and partial cuts with fewer clearcuts, decreased volume harvested per tract, and higher moving costs per ton (Baker and Greene 2008). Highly mechanized tree length operations showed increased productivity per labor and capital input. A large cohort of owners was approaching retirement and a paucity in recruitment raised concerns about the sustainability of the industry without new owners entering the business. A recent survey of South Carolina logging contractors revealed very similar industry characteristics (Moldenhauer and Bolding 2009).

We report findings of the 2012 survey of logging businesses in Georgia with responses gathered simultaneously from South Carolina logging contractors.

Methods

During the spring of 2012, 1251 logging contractors in Georgia and South Carolina were mailed a two-page survey covering timber harvesting operations and practices, production levels, contract specifications, equipment fleet, and demographics. A similar survey has been distributed by mail to Georgia loggers every 5 years since 1987. South Carolina loggers were also included to expand the dataset and allow for comparisons. A follow-up mailing was sent two weeks after the initial mailing. Responses were entered into an Excel spreadsheet and the response data were evaluated using SAS. Data from the US Forest Service on annual timber harvest volumes and wood use were combined with data on employment and businesses from the Bureau of Labor Statistics to estimate the change in logging capacity in the state over time.

Results

Surveys were completed and returned by 27% of Georgia and South Carolina logging firms who were mailed the survey. Approximately 70% were members of one or more state professional forestry or logging association. The average age of business owners continued to increase as was noted in previous surveys (Figure 1). The median age among respondents was 53 years with a median ownership length of 23 years.

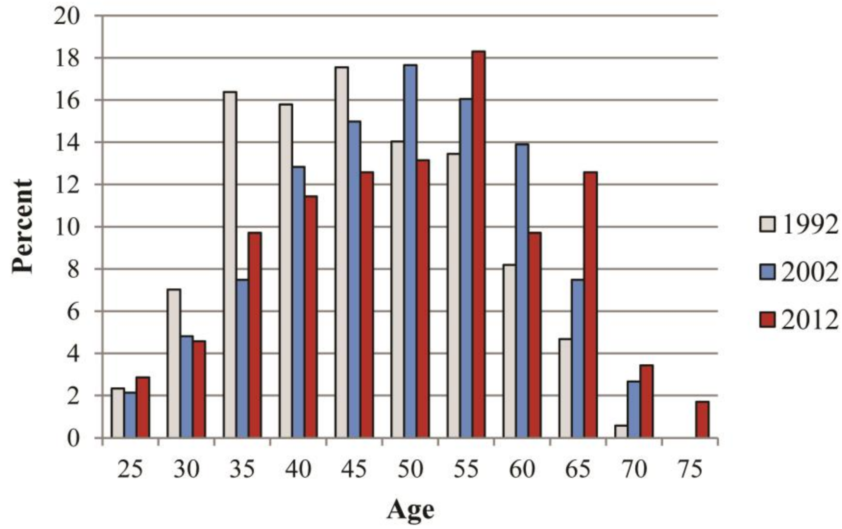


Figure 1. Georgia logging business ownership distribution by age, 1992-2012.

Business owners in 2012 indicated a typical (median) investment of approximately $783,000 in Georgia and $863,400 in South Carolina while employing between 7 and 8 people on average. Roughly 60% operated through a wood dealer or supplier, 40% operated directly through a mill, and 2 to 3% operated through a TIMO or REIT. Written contracts (70%) and harvest plans (60%) were used at the same rates in both states and at the same rate as they were among Georgia businesses in 2007.

Contract trucking is used by 78% of Georgia firms and 71% of South Carolina firms. Standing timber is bought directly by 43% of Georgia logging companies and 29% of South Carolina companies. A wood dealer purchases the timber cut by 43% of Georgia contractors and 51% of South Carolina contractors, and mill companies purchase the timber for 10% of contractors while 5% cut on company land.

Respondents were asked the acreage of the tract currently being harvested by their largest crew. Georgia contractors reported a median tract size of 117 acres while South Carolina contractors were harvesting smaller tracts of 75 acres. Tree lengths (93% in GA and 94% in SC) and log lengths (74% and 80%) were the major products hauled to mills. This year, we also saw both clean and dirty chips reflected in survey data. Just over 10% of all firms were hauling fuel chips. In addition, respondents reported the following biomass markets were available in their area: one-third of contractors had access to whole-tree chip markets, 33% and 42% to markets for chips from logging residues, 13% and 19% could sell grindings from residues, and 21% and 14% could sell tree-length stems to biomass markets in Georgia and South Carolina, respectively. About a third of all respondents reported that they had no access to any fuelwood or biomass markets. Loggers most commonly sorted 4 to 6 products in an operation. Just 14% of Georgia respondents and 7% of South Carolina respondents sort more than 7 products in a typical week.

Clearcut operations have decreased from 82% in 1987 to 28% in 2012 in Georgia (Figure 2), but over the same time period, average weekly production has doubled to 1615 tons. This has increased average worker productivity from 3.4 tons per man-hour to 5.5 tons per man-hour. Productivity per $1000 invested has fluctuated, from almost 200 tons in 1987 to 125 tons in 2002 and is now hovering around 140 tons per $1000 (Figure 3). Over the last 20 to 25 years, labor increased in efficiency with increased capital investment as firms shifted towards mechanization. However, as expected as full mechanization is nearly achieved, firms no longer appear to be realizing increasing marginal rates of return from additional investment in equipment.

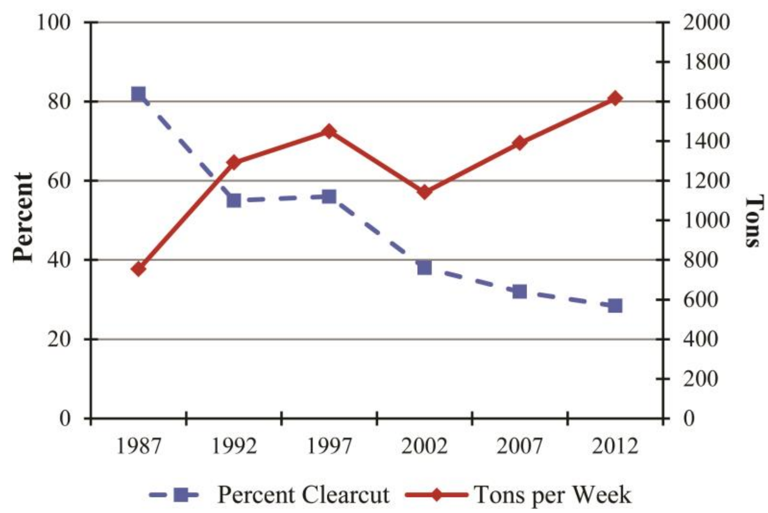


Figure 2. Average weekly production in tons and percent clearcut operations in Georgia from 1987 to 2012.

Logging businesses have also increased payloads substantially by investing in lighter-weight tractor-trailers and to a lesser extent in truck scales. Median empty tare weights reported for their lightest truck and trailer combinations were 27,500 lbs in Georgia and 28,000 lbs in South Carolina. Only 7% of Georgia businesses and 20% of South Carolina businesses cited tare weights at or above 30,000 lbs. Still, the majority of contractors have not invested in either platform or on-board scales. In Georgia and South Carolina, respectively, 11% and 6% use platform scales, 8% and 4% use on-board scales in some of their trucks, and 3% and 2% use on-board scales in all trucks.

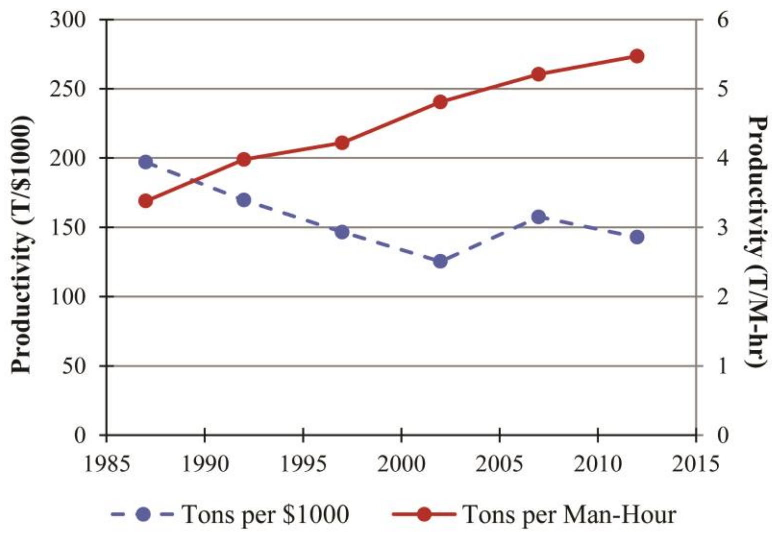


Figure 3. Average productivity in tons per $1000 and tons per man-hour invested by Georgia logging contractors from 1987 to 2012.

Over the years, contractors have been asked to report the biggest problem facing their business. Logging rates and general finances have always been a major struggle in this business, and this year was no exception. Unsurprisingly, the biggest problem faced in 2012 was fuel prices, cited by half of both Georgia and South Carolina loggers. Equipment, quotas, timber prices, labor, insurance and mill practices were also listed as problems contractors faced.

Since 2007, some loggers have received rate adjustments from some mill companies or landowners in response to increasing fuel prices. In 2012, adjustments based on fuel cost were reported being received by 24% of Georgia contractors and 18% of South Carolina contractors. Interestingly, off-road fuel consumption was reported as being tracked by only about 40% of logging firms from each state, with half of those tracking usage on a per-machine basis and the other half on a per-crew basis.

Discussion

In 1987, 73% of Georgia logging firms delivered 1000 tons per week or less compared to only 35% today. By contrast, firms that deliver 2500 tons per week or more have increased from less than 1% to 19% and those that produce 1000-2500 tons weekly have increased from 27 to 49% of the population. As a result, today the largest firms

(2500 tons per week or more) represent just 19% of the contractor force but deliver 51% of the wood each week. The effects of the recent economic recession have probably further accelerated these changes.

Since 1999, Georgia has experienced a 28% decline in the number of logging employees and the number of logging firms – much of this experienced after 2007. However, given the steady and significant productivity increases over this period the production capacity of the logging sector continued to increase up until the recession in 2008. While employment and firm counts are down nearly 30% compared to 1999, we estimate that logging capacity is only down about 15-20% (Figure 4). This clearly indicates that firms with higher production capacity were better able to survive the recession.

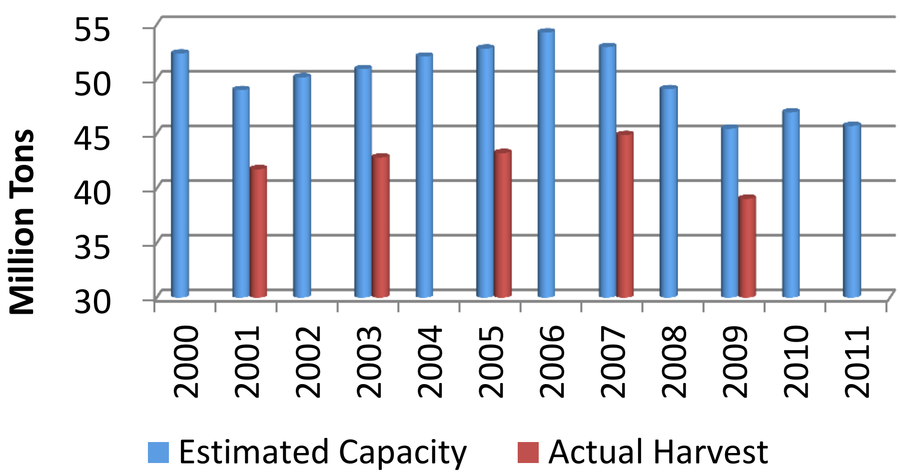


Figure 4. Estimated logging capacity and actual timber harvest reported by USFS for Georgia since 2000.

It appears that a greater number of the survivors also field multiple crews. These financially stronger, better managed firms will be able to quickly staff additional crews and be more likely to obtain financing for the equipment needed. In addition, by mixing experienced labor with new hires, they will likely be able to ramp up production on new crews much more quickly than newly created firms. As markets for timber continue to strengthen, we expect most of the logging capacity that will be added to handle this demand will be associated with these survivors from the recent recession.

One issue across the logging force is the age of the equipment fleet. While many people feel that today's equipment is capable of serving a longer operating life, we observed a sustainable increase in the age of equipment reported in the 2012 survey (Figure 5). Some of this is likely due to firms delaying replacement due to soft markets and financing challenges. It may also reflect the purchases of used equipment from crews that left the industry during the recession. To some degree, it also represents decisions to delay replacement until newer engine designs mandated to meet lower emission standards are proven in actual service and experience is available about them. In any case, we found feller-bunchers to be twice as old and haul trucks to be 40% older in 2012 than in 2007. At some point, significant re-investment in rolling stock will be required to sustain the industry especially as demand recovers.

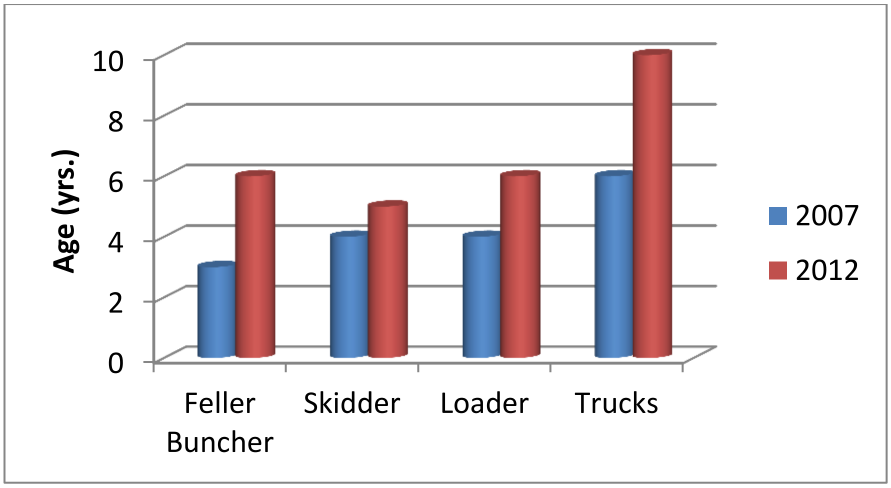


Figure 5. Mean age by machine type of equipment owned by Georgia logging contractors in 2007 compared with 2012.

We also expect logging rates to increase in order to attract additional investment in new capacity by these firms and for them to be able to obtain financing in today's more challenging lending environment. However, adding capacity to these larger firms will likely create less upward price pressure since these firms enjoy significant economies of scale over their competition in the sector with much lower weekly production.

References

Baker, S.A. and W.D. Greene. 2008. Changes in Georgia's Logging Workforce, 1987-2007. Southern Journal of Applied Forestry 32(2): 60-68.

Knight, D.K. 2006a. Employee woes/praises. Survey: More loggers fret over labor; others count themselves fortunate. Timber Harvesting March/April, p. 11-16.

Knight, D.K. 2006b. Deeper Hole? Survey: Loggers wrestle big gorilla, reel from soaring costs. Timber Harvesting May/June, p. 10-14, 40.

Knight, D.K. 2011. 2011 Nowhere to Turn. Timber Harvesting May/June 2011, p. 10-19.

Moldenhauer, M.C. and M.C. Bolding. 2009. Parcelization of South Carolina's private forestland: Logger's reactions to a growing threat. Forest Products Journal 59(6):37-43.

The Impact of Natural Gas Development on Forest Operations in West Virginia

Shawn T. Grushecky[1] and Jingxin Wang[2]

Abstract

The shale deposits found in the Appalachian region have been known to contain significant volumes of natural gas, but this resource has never been economically recoverable. As natural gas prices began to increase early in this decade, drillers experienced with the shale formations began to explore this resource. Between 2000 and 2010, shale gas increased from 1% of the U.S. gas supply to 20%. West Virginia is nearly completely contained in the Marcellus Formation and has almost half of the state represented in the Utica formation. The exploration of natural gas has already begun in these formations and has been increasing at a significant rate. Increased development of natural gas resources has significant implications on forest operations in West Virginia. Large volumes of roundwood are being harvested during the development of well pads and access roads to these sites. As the wells are drilled, an ever-expanding infrastructure of pipeline right-of-ways is being constructed to transport gas. These right-of-ways rely on traditional operators to do the clearing, but do not include the same fore-thought as traditional harvesting operations. Likewise, many operators are leaving traditional forest operations for more lucrative work in the natural gas sector. Through an analysis of harvesting trends and operator surveys we will describe the current and potential future impacts natural gas development has and will have on forest operations in West Virginia.

Introduction

The shale deposits found in the Appalachian region have been known to contain significant volumes of natural gas, but this resource has never been economically recoverable. As natural gas prices began to increase early in this decade, drillers experienced with the shale formations began to tap this resources. Between 2000 and 2010, shale gas increased from 1% of the U.S. gas supply to 20% (Kerr 2010). In 2012, shale gas made up 40 percent of the total natural gas production in the United States. Recently, the Energy Information Administration reported that the U.S. had the fourth largest technically recoverable shale gas reserve at 665 trillion cubic feet behind China, Argentina, and Algeria. The U.S. follows only Russia in the total estimates of technically

[1] Associate Director, West Virginia University, Appalachian Hardwood Center; [2] Professor of Wood Science and Technology, West Virginia University, Division of Forestry and Natural Resources

recoverable shale oil at 58 billion barrels. (U.S. EIA 2013).

Advancements in drilling technology to that aided in the recovery of shale gas resources sparked the natural gas boom that the Appalachian region of the United States is currently experiencing. The advancements included the use of horizontal drilling technologies as well as fracing that both helped to increase the amount of recoverable gas from these shale formations. In the Marcellus play alone, where activity is focused on reserves in NY, WV, Oh and PA, upwards of 141 trillion cubic feet of gas may be recoverable (U.S. EIA 2012). The increased activity in shale drilling in the Appalachian region has also brought major investments in the form of mineral rights leasing, infrastructure improvements, drilling and completion as well as post production investments (Thomas et al. 2013).

Along with the significant economic development in the region, there has also been an increased focus on the impacts of natural gas extraction on the environment. Much of this focus has been related to the migration of brine water, chemicals and methane to shallow water aquifers (Osborn et al. 2011; Warner et al. 2012). Other sources of environmental concern include the disturbance of surface lands during the development of drilling pads and resulting natural gas transportation infrastructure. In PA, shale gas development was found to be greatest on public lands and is dominated by pads with 1-2 wells. Roughly 45-62% of pads have occurred on agricultural land and 38-54% on forest land (Drohan et al. 2012). However, shale gas exploration in the region may be less environmentally damaging than the extraction of coal, which is the top energy source traditionally developed in the Appalachia Region (Jenner and Lamdrid 2013).

While there has been significant work to date on the potential economic and environmental impacts of shale gas development, there has been little information on the impact of exploration on the forest-based economies of the Appalachian region. Large volumes of roundwood are being cleared during the development of well pads and access roads to drilling sites. The well pads and right-of-ways rely on traditional operators to do the clearing, but do not include the same fore-thought as traditional harvesting operations. Likewise, operators may be leaving traditional forest operations for more lucrative work in the natural gas sector. The objectives of this research are to 1) determine the impact on the number of traditional harvesting operations in the shale gas region of WV, 2) to determine the amount of forestland that is being impacted by well pad development, and 3) to determine the impact of increased exploration on the logging workforce in the region.

Methods

<u>Drilling and Harvesting Trends</u>

While the Marcellus shale is found underlying the majority of WV, extraction costs have limited development to only the eastern and northern portions of the state. To better determine which counties had most intensive development, well completion data were acquired from the WV Geological and Economic Survey (WVGES) for the period of 2009-2012 (WVGES 2013). This time frame was selected because it represents the period where vertical drilling switched to a horizontal approach and when increased exploration of the resource became prevalent. Data on horizontal well completions were summarized by county and counties were ranked in order of decreasing magnitude of well completions. The top four counties in sheer number of completions were subset and used for subsequent analyses and were considered the epicenter of shale gas development in WV.

Harvesting records were obtained from the West Virginia Division of Forestry for the four year period preceding increased exploration (2005-2008) and the four-year period following (2009-2012). Notification of timber harvesting in West Virginia is mandated under the 1992 Logging Sediment Control Act. Under this act, all loggers are required to submit a harvest plan within 3 days of starting a new timbering operation. The number of harvests and the acreage of harvests were summarized for the epicenter region as well as for all other counties combined. Comparisons were then made between those counties with significant Marcellus development and those without.

Landcover Change

To characterize surface land disturbance, all well pad locations completed during the 2009-2012 time frame were spatially located using data provided by the WVGES. Because the WVGES included approximately 352 completed Marcellus episodes in the four-county epicenter, a 10% subsample was randomly selected for further analyses. A GIS analysis routine was then developed using both 2003 and 2011 USDA NAIP photography, both readily available for use in the ESRI ArcGIS 2010. A total of 35 well pad sites were then overlayed with both 2003 and 2011 data and the extent of forestland disturbance and well pad acreage were delineated using visual interpretations. The method employed follows those used by Drohan et al. (2012). The 2003 and 2011 imagery years were chosen to represent land cover before and after significant Marcellus pad development. Associated well-pad disturbance was recorded for each of the 35 samples that were randomly selected from the WVGES dataset.

Logger Characteristics

A case study approach was used to determine the impact of increased shale exploration on the logging workforce in the four-county epicenter. Purposeful sampling was used to illicit insight from the cases chosen. This is a qualitative approach using an in-depth interview allow researchers understand targeted issues of those surveyed without incorporating a priori directions (Patton 1990). For this approach, subjects were selected deliberately because they possess characteristics of interest to the study objectives. To understand the impacts of shale development on the logging in the epicenter counties, we targeted both WV Division of Forestry county foresters as well as industrial foresters working in the region. Four WV Division of Forestry foresters were chosen, each of which was responsible for monitoring logging jobs in an epicenter county for compliance with BMP regulations mandated by the 1992 WV Logging Sediment Control Act. They were felt to be the best subjects for this approach because they interacted on a daily basis with all loggers operating in the epicenter region. Likewise, two industrial foresters were chosen for the sampling protocol. Each of these foresters was responsible for logging and procurement for a hardwood sawmill located in the epicenter counties. Only 2 industrial foresters were chosen because they represented the only primary producers operating in the top drilling counties.

A survey instrument was developed and completed by the researchers during in-depth phone interviews with the respondents. A total of 15 questions related to logging in the top four drilled counties were developed. These research results report on the following five question subset that are directly related to shale exploration and its impact on forest operations in the region:

1. How much of the decline in logging jobs and acres harvested is due to the economy versus shale exploration?
2. What factors are important in loggers making a decision to work in oil and gas?
3. What percentage of your loggers do you feel have worked on oil and gas jobs?
4. Have you seen a change in forest product markets that loggers are using?
5. Have loggers you work with been successful at utilizing roundwood that originates from shale gas exploration?

Results and Discussion

<u>Drilling and Harvesting Trends</u>

A total of 584 horizontal Marcellus completions were recorded in 20 counties during the period of 2009-2012. The top four counties in terms of horizontal completions during this time period included Harrison, Wetzel, Marshall, and Doddridge, representing 60 percent of the total completions. Harrison county had the most of the four county epicenter with 127 completions followed by Wetzel county with 78 completions.

A total of 12,170 harvesting operations representing 861,424 acres were conducted statewide during the period of 2005 through 2008. This was reduced to 8203 jobs representing 545,565 acres during the period of 2009 through 2012. Much of the 32.6 percent reduction in active jobs can be attributed to the economy and the significant retraction of the U.S. housing industry. Between 2005 and 2010 forest products employment in the Northeast retracted by almost 30 percent (Woodall et al. 2011).

However, the magnitude of change was quite different when the drilling epicenter counties were compared to all other counties combined. There was a 57.6 percent decline in the number of jobs in the epicenter counties between the years of 2005-2008 and 2009-2012 compared to a 30.4 percent decline in all other counties combined. Likewise, the number of acres in the epicenter counties pre and post- Marcellus development declined by 57.3 percent compared to 35.0 percent in the less-impacted counties.

Individual timber harvest size remained the same in the epicenter counties at 64.4 acres during the pre-Marcellus period to 64.8 during the years after development was initiated. In all other counties, individual harvest sized declined by 7 percent from 71.6 acres during 2005-2008 to 66.5 acres during the period from 2009-2012.

Landcover Change

Each of the 35 well locations subsampled from the 352 completions had evidence of natural gas development from the pre-period to the post-period. Completion records ranged from early spring of 2009 through the fall of 2012. Two of the 35 locations represented multiple horizontal lateral legs from the same well-pad, so individual disturbance acreages were only recorded once for these episodes, reducing our sub-sample to 33 completed well-pads. A total of 247.6 acres were recorded as disturbed for the 33 pad sites. Approximately 154 acres of the well-pad sites were previously in forest cover. The average well pad disturbed 7.5 acres (st.dev = 6.0 acres) and on average approximately 4.7 acres (st.dev. = 6.0 acres) of the disturbed area was previously in forest cover. The largest well pad sampled totaled 24.9 acres and the smallest was 0.4 acres. On the 24.9 acre site, the entire well pad location was in a forested tract therefore it also represented the highest amount of forest disturbance.

These results are similar to those found by Drohan and Brittingham (2012) who observed an average well pad of 6.7 acres that ranged from 0.25 to 50.6 acres in Pennsylvania. Conversely, Drohan et al. (2012) found that upwards of 54 percent of well-pads occurred in forested land as opposed to the 62 percent found in this research. The difference in land cover occurrence in PA versus WV is likely due to the increased forest cover found in WV.

Logger Characteristics

Overall, all of the foresters attributed approximately 33 percent of their counties increased downturn in the number of logging jobs and acres to shale-gas exploration. However, industrial foresters, on average, felt that 62.5 percent of the downturn was drilling related while the WVDOF foresters felt only 18.8 percent was drilling related. The difference in feelings was likely related to the industrial foresters closer business ties with loggers in the region. As loggers began to work on natural gas infrastructure jobs, their loss was much more detrimental to the industrial foresters bottom line and thus likely more visible.

When asked what factors were important in loggers making a decision to work in the natural gas field, all of the forester's first response was related to the increased revenue associated with shale exploration. Other reasons included less worry about managing their business because they were subcontracting for gas companies; less equipment issues, since most of their work required only a bulldozer; and finally decreased business liability for insurance as well as environmental regulations, in particular forestry BMPs. As loggers move to shale-gas development, they were able to increase their revenue while at the same time decrease their expenses.

Overall, all of the foresters felt that 41 percent of the loggers they work with have worked on natural gas related clearing jobs. As with the feelings on the decline in logging jobs and acreage, the industrial and WVDOF foresters responses were quite different. The industrial foresters reported that on average 67.5 percent of their loggers worked on shale jobs. The WVDOF county foresters felt that on average only 27.5 percent of their loggers had worked these jobs. This response was likely due to the fact that the industrial foresters worked with loggers working in shale exploration and traditional harvesting jobs, while the WVDOF foresters are only required to inspect only traditional harvesting jobs that require notification under the LSCA.

Only three of the foresters interviewed had seen changes in the markets loggers were selling material to since shale-gas exploration started in the region. Both an industrial forester and WVDOF forester, that worked primarily in the same county, saw a large increase in the amount of roundwood that was being delivered for the production of gasline blocking and equipment mats. Likewise, a second WVDOF forester felt that much more roundwood was being sold into pulp markets that may have gone for sawlogs or scragg wood in previous years. It is interesting to note that neither the equipment mat or pipeline blocking markets were identified in a 2008 study of roundwood markets in West Virginia (Grushecky et al. 2013). As the shale-gas industry continues to develop, these markets, as well as others, may provide increased opportunities for loggers in the region.

All of the foresters interviewed felt that there could be a higher degree of utilization of roundwood on shale-gas development sites. It was reported that a majority of the roundwood was being marketed during drilling pad construction; however a tremendous amount of material was being left in the woods after pipeline clearing work. One of the WVDOF foresters reported that one pile of wood left to be burnt on a pipeline job contained at least 70 MBF of useable sawlog material. Likewise, one of the industrial foresters reported that they furnished sawlogs to their mill during December-March of 2013 without felling a single tree. All of the wood they procured was from roundwood piled during a recent pipeline install. During traditional timber harvesting jobs in WV, 95 percent of the roundwood that is 4 inches in diameter and greater is utilized once it is severed (Grushecky et al. 2013), therefore, this is one area of shale-gas exploration that could benefit from more interaction with the forest products sector in the region.

Shale gas development has increased substantially over the past four years in West Virginia. This development has impacted the degree of timber harvesting being reported, forestland cover, and logging operations in the most heavily drilled counties. As natural gas exploration continues to increase in the region, more integration between traditional forest products companies and shale exploration and related businesses is needed. Increased integration will lead to proper planning which could benefit both surface properties in this forest-dominated region as well as the industry that relies on these resources for its survival.

Literature Cited

Drohan, P. J. M. Brittingham, J. Bishop, and K. Yoder. 2012. Early trends in landcover change and forest fragmentation due to shale-gas development in Pennsylvania: A potential outcome for the northcentral Appalachians. Environmental management, 49(5), 1061-1075.

Drohan, P. J. and M. Brittingham 2012. Topographic and Soil Constraints to Shale-Gas Development in the Northcentral Appalachians. Soil Science Society of America Journal, 76(5), 1696-1706

Grushecky, S.T., J. Wiedenbeck, and C.C. Hassler. 2013. Examination of roundwood utilization rates in West Virginia. For. Prod. Journ. (*in press*)

Jenner, S. and A. J. Lamadrid. 2013. Shale gas vs. coal: Policy implications from environmental impact comparisons of shale gas, conventional gas, and coal on air, water, and land in the United States. Energy Policy. 53:442-453

Kerr, R.A. 2010. Natural gas from shale bursts onto the scene. Science 328(5986):1624-1626.

Osborn, SG, A. Vengosh, NR Warner, and RB Jackson. 2011. Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. Proc. Natl. Acad. Sci. USA 108:8172-8176.

Patton, M. Q. 1990. Qualitative evaluation and research methods. Sage Publications. Newberry Park, CA.

Thomas, A.R., I. Lendel, E. W. Hill, D. Southgate, and R. Chase. 2013. An Analysis of the Economic Potential for Shale Formations in Ohio. Ohio Shale Coalition, (Mar. 2,2012).http://urban.csuohio.edu/publications/center/center_for_economic_development/Ec_Impact_Ohio_Utica_Shale_2012.pdf

U.S. Energy Information Administration. 2012. 2012 Annual energy outlook. http://www.eia.gov/forecasts/aeo/pdf/0383(2012).pdf

U.S. Energy Information Administration. 2013. Technically recoverable shale oil and shale gas resources: an assessment of 137 shale formations in 41 countries outside the United States.

Warner, N. R., R. B. Jackson, T.H. Darrah, S.G. Osborn, A. Down,K. Zhao, A. White and A. Vengosh. 2012. Geochemical evidence for possible natural migration of Marcellus Formation brine to shallow aquifers in Pennsylvania. Proceedings of the National Academy of Sciences. 109(30), 11961-11966.

Woodall, C.W., R.J. Piva, K.E. Skog, P.J. Ince, and W.G. Luppold. 2011. An assessment of the downturn in the forest products sector in the Northern Region of the United States. For. Prod. J. 61(8):604-613

WVGES 2013. West Virginia Geologic and Economic Survey. Selected references about Devonian shales. http://www.wvgs.wvnet.edu/www/datastat/devshales.htm

Effects of grate size on grinding productivity, fuel consumption, and particle size distribution

Sang-Kyun Han[1], Han-Sup Han[2], Joel A. Bisson[3], and Timothy D. Montgomery[4]

1. Assistant Professor, Department of Forestry and Landscape Architecture, Korea National College of Agriculture and Fisheries, Hwaseong-si, Gyeonggi-do, South Korea
2. Professor, Department of Forestry and Wildland Resources, Humboldt State University, Arcata, California, U.S.A
3. Research Associate, Department of Forestry and Wildland Resources, Humboldt State University, Arcata, California, U.S.A
4. Graduate Research Assistant, Department of Forestry and Wildland Resources, Humboldt State University, Arcata, California, U.S.A

Comminution is an important pre-processing step required in biomass feedstock preparation for various forest biomass energy conversion technologies. There are several different forest biomass conversion technologies being developed (e.g. combustion, gasification, and pyrolysis) and each system demands specific feedstock particle length and thickness dimensions. Therefore, selecting the appropriate equipment and processing configuration for size reduction is a crucial factor to consider in the production of bioenergy from forest biomass. Matching the right fuel quality to a biomass conversion technology effectively facilitates the energy conversion process and improves the economic feasibility of forest biomass for energy production. In this study, we conducted a controlled experiment on a horizontal grinder to evaluate the effect of three different grate combinations on machine productivity, fuel consumption and particle size distribution for two different biomass types (mixed conifer slash vs. hardwood whole-tree). Mixed conifer slash resulted in higher grinding productivity and a lower fuel consumption rate than did hardwood whole tree. Small grate size configurations in the grinder had low grinding productivity and higher fuel consumption rates compared to large grate size configurations. High grinding productivity and low fuel consumption rates were accomplished by using a new anvil type which is manufactured with holes in the plate. The study also showed that production of small feedstock particles from logging slash was operationally feasible by using small grates and a newly designed anvil. Additional studies are needed to further control over-sized materials and improve our knowledge on the effect of moisture content on grinding productivity, especially with a wide range of grate size combinations.

Keywords: biomass energy, forest biomass, comminution, grinder grate, grinding quality.

INTRODUCTION

With rising fuel costs and enhanced environmental concerns, biomass energy from a wide range of materials is receiving considerable attention globally as a valuable renewable alternative to the use of finite fossil fuels (Han and Murphy 2012). Forest biomass produced from mechanical thinning and conventional saw-timber harvesting operations are one of the major feedstocks for bioenergy and biobased forest products that can be processed and converted into valuable chemicals, heat, fuel and other materials.

Forest biomass in its original state has wide range of moisture content (25-60%) and feedstock types (unmerchantable trees, small-diamater trees, tops, limbs and chunks)

(Suadicani and Gambrog 1999). Variability in material size and moisture content creates difficulties in handling and storage, therefore, matching the right fuel size and quality to current conversion systems is important for improving consumer confidence in fuel quality assurance. There are several different conversion technologies currently available including combustion, gasification, pelletization, densification, pyrolysis, and torrefaction. Each system requires specific size, moisture content, species, and contamination level.

Size reduction is the first step required for most biomass energy conversion processes. The ideal wood fiber length and thickness varies widely by process. If a small particle size is necessary, the energy used to reduce the biomass can be significant so it is important that the most efficient reduction processes are used. The primary machinery used for biomass reduction are chippers (disc and drum) and grinders (horizontal and tub). Each machine type has its advantages and disadvantages. Chippers are better designed to process solid wood fiber such as whole trees, large limbs, and chunks, by cutting woody material with a slicing action. However, chippers generally have difficulty feeding and chipping material of mixed dimensions, including tangled piles of tree stems and small-diameter branches. If the material is pliable it can pass through a chipper as long slivers (spears), rather than chips. Chippers are most efficient and best suited for high moisture wood (Jackson et al. 2007). The energy required to chip low moisture content wood can be higher than green wood (Suadicani and Gamborg 1999). Dry wood may require cooling water to be sprayed on the knives in order to prevent overheating. Chippers also require clean wood to get satisfactory knife life. They rely on sharp knives which are susceptible to knife wear from high soil content, metal contamination, rocks, and stones.

Grinders reduce the size of woody biomass particles by repeatedly pounding them into smaller pieces through a combination of tensile, shear and compressive forces. They usually accept a wider range of grinding material types including whole trees, stumps, tops, brush, and large forked branches. In addition, grinders are not as sensitive to contamination but bit and grate life may improve with clean material. Grinders usually have lower energy requirements with dry wood. Brittle wood typically fractures with less energy compared to fresh more ductile wet wood. Grinders however, can produce undesired “fuzzy” products with certain hardwoods, and other fibrous woods such as Palm and Juniper.

The quality of forest biomass for most conversion systems is normally connected to size distribution, moisture content, tree species, contamination level, and ash content. Particle size distribution is one of the most important issues in forest biomass energy because it particularly affects transportation costs and combustion efficiency at the end-use location. It also affects caloric value and durability during storage in the biorefinery (Nati et al. 2010). In addition, particle size affects the energy requirement of the hydrothermal pre-treatment needed for the conversion of woody biomass into liquid biofuels (Hosseini and Shah 2009). They also have greater combustion time than smaller sized particles which reduces the net utilization of the fuel. For energy production, the optimal particle size of biomass depends upon the type of burners used and biomass conversion system. In Canada, a particle size of < 1 in. is required for small boilers (< 1 MW) while a particle size of < 2 in. is enough for large boilers (> 1MW) (Naimi et al. 2006). In Pacific Northwest of the United States, most biomass energy plants generally require their fuel to be < 3 in. In addition, several fast pyrolysis biofuel facilities simply specify that their feedstocks must be processed to a particle size of 2 inches or less because oversize or overlong particles can clog the auger feeding the conversion facilities (Wechsler et al. 2010).

Particle size distribution is influenced by a number of factors such as machine type, feeding material, moisture content, knife/bit setting and screen/grate sizes. Chippers usually produce highly uniform particle size compared to grinders. For whole trees and tree tops, chippers are often used to produce uniform sized chips with low contamination. For limbs and chunks, grinders are generally used to produce fuel that is typically characterized by having a “wide” size distribution of material. They are also capable of handling material with a higher amount of contamination in the form of soil aggregates.

Moisture content of biomass feedstocks directly affects particle size distribution during comminution for energy production. Suadicani and Gamborg (1999) examined the size distribution of chips from freshly felled and summer dried trees in Western Denmark. They found that summer dried trees produced less fine fractions (1/8 inches) and a more homogeneous size distribution of chips than freshly felled trees. However, more coarse (oversize) chips were produced from summer dried trees compared to chips from freshly felled trees.

Feedstock species (i.e. hardwood or conifer) and types (i.e. limbs, tops, stems, etc.) also have an influence on the particle size distribution of fuel. Many hardwoods such as oak, beech, ash and sycamore have stiff branches, which will produce long particles and small birch trees have pliable brances, which will give many thin overlong particles (Kofman 2006). Nati et al. (2010) investigated the effects of different tree species (poplar and pine) and tree parts (branches and logs) on chipping productivity and particle size distribution. They found that poplar chips tend to be larger than pine chips and contain a higher proportion of oversize particles. Chips produced from logs contained a smaller proportion of oversized particles and a higher proportion of acceptable sized particles.

The different equipment options such as knives, bits, anvils, and screen sizes can also have a significant impact on particle size distribution, machine productivity, and fuel consumption. Chippers generally require clean wood to get a satisfactory knife life. Dull or damaged knives in chippers will usually result in increased and inconsistent particle sizes. Additionally, knife wear after chipping 215 GT of wood caused a significant reduction in chipping productivity of up to 15% and a remarkable increase of fuel consumption of up to 60%, compared to new knives (Nati et al. 2010). Smaller screen sizes tend to reduce particle size of chipped or grinded materials but the installation of such screen causes a significant reduction of machine productivity and a remarkable increase in fuel consumption.

Literature on how to achieve specific feedstock particle sizes for different forest biomass conversion systems is limited. Therefore, the aim of this study is to investigate the effect of three different grate combinations on grinding productivity, fuel consumption and particle size distribution for two different biomass types (mixed conifer slash vs. hardwood whole tree).

MATERIALS AND METHODS

Field studies were conducted in June and September 2012 on private industrial timberland in northern California. A track mounted horizontal grinder (Perterson Pacific 5710C) was used to comminute forest residues including limbs, chunks, tops, and small diameter trees of mixed conifer and whole-tree hardwoods. The grinder was powered by a Caterpillar C13 engine at 1050 horsepower with a drum rotor (32” diameter, 59 3/4” wide, with 20 sets of bits) designed for land clearing, logging slash, and scrap board. The grinder was fitted with a solid anvil, 3 inch grate, and two 4 inch grates to produce hog fuel for energy plants. The loader (Linkbelt 3400) used to feed the grinder had a rotating 7 tine grapple, which swung dumped onto the grinder’s infeed conveyer. After processing, the hogfuel was fed via conveyor into a positioned chip trailer.

Grinding operations were carried out on two different feedstock types: mixed conifer slash and hardwood whole-tree (Table 1 and Figure 1). There were two different material ages (2-month old vs. 1-year old) in each feedstock type. We selected four different units for this study. Mixed conifer slash was collected from two different units. The stand composition of the both units ranged from 51 to 61% redwood (*Sequoia sempervirens*), 18 to 30% Douglas-fir (*Pseudotsuga menziesii*), 1 to 7% western hemlock (*Tsuga heterophylla*), and 7 to 13% tanoak (*Lithocarpus densiflorus*). Two units were selected for hardwood whole trees and consisted of tanoak (46 – 68%), Douglas-fir (26 – 34%), redwood (8 – 13%), and western hemlock (3 – 5%). For each feedstock type, 1-year old materials were felled in May 2011 and used for our grinding study in June 2012. Two-month old materials were harvested in July 2012 and comminuted using a grinder in September 2012. The raw material composition used in this study varied with feedstock type and date of saw-timber harvest (age) (Table 1). Moisture content was also different with grinding operation times. Freshly felled trees generally have higher moisture content than year old trees or summer dried trees (Suadicani and Gamborg 1999). In our study however, 1-year old mixed confer slash had higher moisture content than 2-month old slash because the former hadn't dried after winter while the later dried during summer (Table 1).

Table 1. Age, raw material composition, and moisture content of feedstock types used in this experimental study.

Feedstock type	Age	Raw material composition (%)			Moisture Content (%)
		Conifer limbs & chunks	Conifer stems (> 4 in. in diameter)	Hardwood whole tree	
Mixed conifer slash	2-month	64 – 71	29 - 36	-	28
	1-year	43 – 71	29 – 57	-	42
Hardwood whole tree	2-month	13 – 15	-	85 – 87	27
	1-year	10 - 18	-	82 – 90	23

Figure 1. Mixed conifer slash (top) and hardwood whole trees (bottom) piled in the unit: 2-month old (left) vs. 1-year old (right)

In our study, four different types of feedstock were comminuted separately using the same grinder with the same operators. For each feedstock type, three different treatments were applied with three different grate combinations (3-4-4 inch grates with solid anvil, 2-3-3 inch grates with solid anvil, and 3-4-4 inch grates with holed anvil). Five replications (truck loads) were applied for each treatment. In each replication, a time-motion study was conducted to measure grinding time that corresponded to the time required to fill up a standard chip van (maximum payload of 25 GT). Load weights were collected by scaling tickets recorded at energy plants. Average fuel consumption rates for each treatment were calculated using fuel level differences between the starting and ending points of daily grinding operations.

Grinding samples were taken to determine particle size distribution and moisture content. From each truck load, three sub-samples (app. 2.2 pounds for each sub-sample) were collected from the top of the chip trailer at the front, middle, and end, and were then mixed, weighed, and sealed in a plastic bag. The bags were tagged in order to identify the slash type and treatment applied to each sample. In the laboratory, the samples were placed in aluminum trays and put in a dry oven at 221°F for 24 hours and reweighed. Moisture content was determined by a wet-based method.

Grinding particles for each dried sample were screened roughly by length using a chip classifier (Model: BM&M Chip Classifier) with six screen trays (2, 1, 1/2, 3/8, 1/4, and 1/8 inch) and a fines tray, to obtain grinding particles distributed in five size classes (< 0.5 inches, 0.5 – 1.0 inches, 1 – 2 inches, 2 – 3 inches, and > 3 inches). Wrongly classified particles were manually sorted by length. The length was measured as the longest dimension of the particle. Each of the five sorted classes was weighed separately. In the size distribution analysis, the particle size of each class was based on its mass and expressed as a percentage of the total mass of all five classes.

Data analysis was performed using Statistical Analysis System (SAS) (SAS Institute Inc. 2001) and Statistical Package for the Social Sciences (SPSS) (SPSS Inc. 1998). Data was evaluated for normality before running the analysis. The effect of feedstock types on grinding productivity was tested using a one-way analysis of variance (ANOVA). Regression analysis was conducted to find the effects of feedstock type, age and grinder grate size on particle size distribution. This simple and reliable approach is often used to check the effect of these variables in forest engineering studies (Olsen et al. 1998). The significance level was set to 5% ($\alpha = 0.05$).

RESULT AND DISCUSSION

Grinding productivity

Grinding productivity was significantly influenced by the feedstock type (mixed conifer slash vs. hardwood whole tree) and by the grinder grate size ($p<0.001$; Table 2). The effect of feedstock age (freshness), however, had no statistical significance because there was no difference in moisture content between the 2-month old and 1-year hardwood whole trees. Therefore, we could not reject the hypothesis that the productivity obtained when grinding freshly felled feedstock was different from that obtained when grinding 1 year-old feedstock.

For both feedstock ages and for all grate size combinations, the grinder was able to fill a chip van with mixed conifer slash significantly faster (21 minutes) than with hardwood whole tree (28 minutes) ($p<0.001$). There were statistically significant differences in productivity when grinding mixed conifer slash and grinding hardwood whole trees ($p<0.001$). Mixed conifer slash was consistently more productive by up to 31 percent compared to hardwood whole tree (Table 2). The average productivity for grinding mixed conifer slash was 42.7 BDT/hr and the average productivity when grinding hardwood whole trees was 34.1 BDT/hr. There are several factors that influenced productivity. The main factor influencing grinding productivity was the feedstock type. The grinder had more difficultly comminuting hardwood whole tree due its hardness and larger diameter stem pieces. Similar results were reported by Spinelli et al. (2011). They investigated the effect of feedstock species on chipping productivity and found that softwood had a higher chipping productivity than hardwood.

Different grate size combinations significantly affected grinding productivity in both feedstock types, with exception of 1-year old mixed conifer slash (p<0.05; Table 2). Grinding productivity (BDT/hr) was dramatically decreased by up to 30% when grinding using a smaller grate size combination. Arthur et al. (1982) also found substantial increases in grinding productivity that resulted from increasing the size of the holes in screens. Grinder anvil type also influenced grinding productivity. The use of holed anvils produced slightly higher productivity than the use of solid anvils but there were no statistically significant differences in productivity between the solid anvil and the holed anvil. More experimental studies will be needed to more precisely determine the effect of grinder anvil type on machine productivity.

Table 2. Average moisture content, productivity in bone-dry metric tonnes (BDmT) per productive machine hour (PMH), and fuel consumption rate (gallon per BDT) of a grinder for different feedstock types, ages, and grinder grate combinations.

Feedstock type	Feedstock age	Grinder grate combination (inches)	Average moisture content (%)	Average grinding productivity (BDmT/PMH)	Average fuel consumption rate (Gal./BDmT)
Mixed conifer slash	2-month old	SA–3– 4–4	26.8a[1] (5.53)[2]	43.0a (4.20)	0.74
		SA–2– 3–3	27.1a (4.19)	39.0b (2.03)	0.80
		HA–3– 4–4	25.9a (1.11)	45.3a (3.63)	0.69
Mixed conifer slash	1-year old	SA–3– 4–4	41.4a (2.63)	42.6a (3.40)	0.69
		SA–2– 3–3	40.9a (5.02)	41.1a (4.01)	0.90
		HA–3– 4–4	42.9a (3.59)	45.1b (3.91)	0.57
Hardwood whole tree	2-month old	SA–3– 4–4	24.8a (2.93)	38.2a (4.32)	1.03
		SA–2– 3–3	26.0a (2.40)	27.2b (1.21)	1.72
		HA–3– 4–4	25.2a (4.42)	39.5a (2.69)	0.84
Hardwood whole tree	1-year old	SA–3– 4–4	21.6a (3.73)	37.2a (3.76)	0.96
		SA–2– 3–3	20.8a (3.80)	31.7b (2.68)	1.57
		HA–3– 4–4	22.6a (1.57)	29.7b (2.54)	1.02

[1]Different letters within a column indicate significant differences between values within each feedstock type and age (p<0.05)
[2]Standard deviation

Fuel consumption rates

Fuel consumption rates (gal/BDmT) for each treatment are presented in Table 2. Fuel consumption rate was influenced by feedstock type, grate size, and grate type. In this study however, no statistical analysis was performed to find the effect of these variables on fuel consumption rates because the average fuel consumption rate for each treatment was determined by dividing the total fuel consumed by the total feedstock weight produced during each of the five replications per treatment.

In both feedstock ages, hardwood whole trees had higher fuel consumption rates than mixed conifer slash. The average fuel consumption rate when grinding hardwood whole trees was around 64% higher than when grinding mixed conifer slash (Table 2). Similar results were also reported by Spinelli et al. (2011). Their study investigated fuel consumption rates when chipping softwood stems and hardwood stems and reported that hardwood stems had 7 to 14% higher fuel consumption rates than softwood stems. These results can be attributed to the physical properties of hardwoods such as high bending strengths, stiffness, specific gravity, and hardness. These properties vary with species and region but generally hardwood are more dense, fibrous, and harder than softwood (Haygreen and Bowyer 1982). Therefore, hardwood is more difficult to grind and requires more fuel to comminute.

Grinder grate size and type also affected fuel consumption rates in all of the feedstock types (Table 2). As expected, fuel consumption rate increased with smaller grate sizes. SA-2-3-3 inches grate combinations had 20 to 65% higher fuel consumption rates than SA-3-4-4. The differences between both grate combinations were especially higher in hardwood whole trees (65%) than in mixed conifer slash (20%). In different anvil treatments, the use of a holed anvil resulted in less fuel consumption than the use of sold anvil in all treatments, except 1-year old hardwood whole tree. Conversely, the solid anvil had slightly lower fuel consumption rates than the holed anvil in 1-year old hardwood whole tree.

Particle size distribution

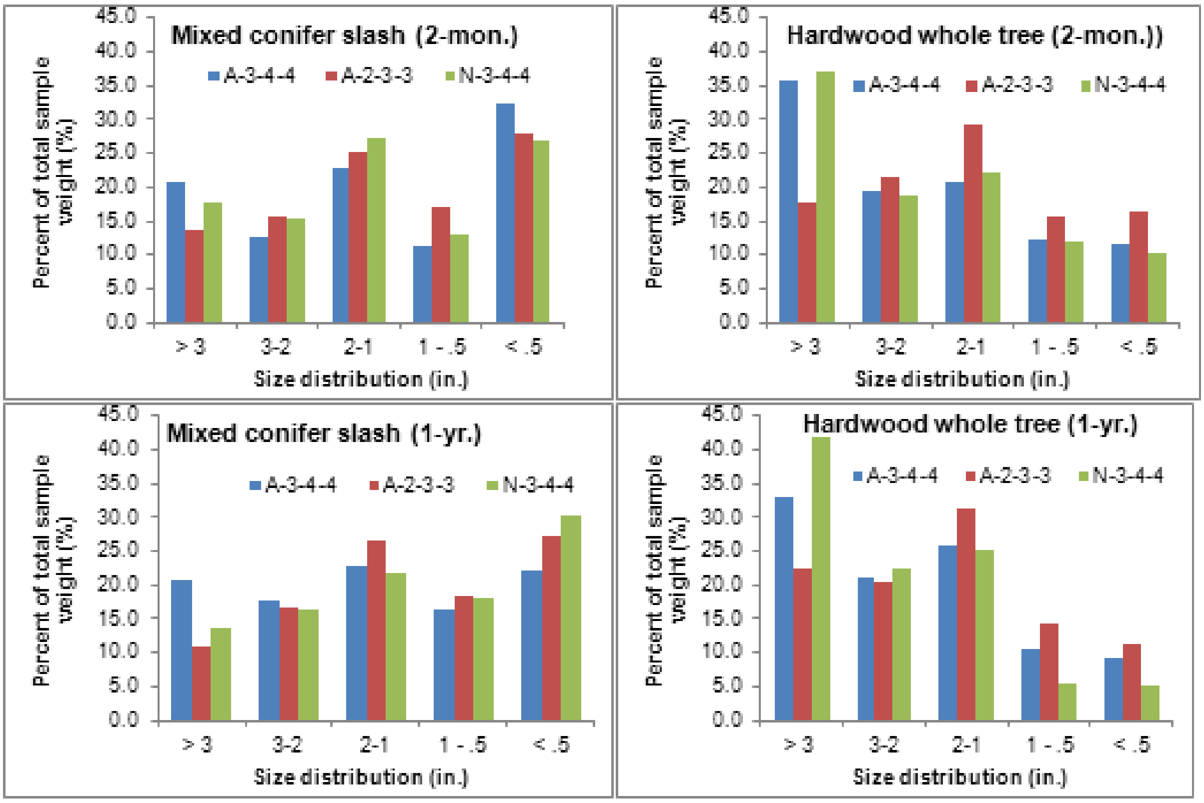


Figure 2. Particle size distribution in % for different feedstock types and ages and grinder grate combinations

The results of the particle size distribution analysis are reported in Figure 2. On average, all treatments produced a significant proportion of acceptable sized particles (< 3 inches: particle size required for most of the biomass energy plants in Pacific Northwest), which varied from 51 to 89%, of the total sample weight (Figure 2). Mixed conifer slash produced a higher proportion of acceptable particle sizes (84%) than hardwood whole tree (69%) for all treatments. In addition, the smaller grate size increased the proportion of the acceptable particle size by as much as 89% in mixed conifer slash. However, the results of our grinding study show a lower acceptable size proportion compared to past chipping studies. Nati et al. (2010) found that pine logs and limbs had high percentage of acceptable size chips of up to 95% of total chip size distribution.

Table 3. Regression equations relating the percentage of a given particle size class in different feedstock types and ages and grinder grate combinations. Only variables with a significance level of $p<0.05$ were included in the regression equations.

Particle size class (in.)	Adjusted R^2	*F*-value	*P*-value	Intercept	Mixed conifer slash[1]	1-yr old material[2]	SA– 2– 3–3 in. grate combination[3]
> 3	0.70	32.3	<0.0001	34.9	-14.9	No effect	-11.3
3 – 2	0.46	11.7	<0.0001	19.6	-4.8	2.0	0.4
2 – 1	0.24	4.4	<0.005	24.2	-1.4	No effect	4.1
1 - 0.5	0.29	5.6	<0.005	10.0	3.9	No effect	4.2
< 0.5	0.76	43.7	<0.0001	11.2	17.1	-3.4	2.6

[1]Indicator variable for mixed conifer slash, equals 1 if feedstock type is mixed conifer slash, 0 if hardwood whole tree

[2] Indicator variable for 1-yr old material, equals 1 if feedstock age is 1-yr old, 0 if 2-month material

[3]Indicator variable for SA-2-3-3 inch grate combination, equals 1 if grate combination is SA-2-3-3, 0 if SA-3-4-4 or HA-3-4-4.

Regression analysis was conducted to investigate the significance of different feedstock types and grate sizes on particle size distribution. The results of the regression analysis are presented in Table 3. Only variables with a significance level of $p<0.05$ were included in the regression equations. Mixed conifer slash produced smaller particles than hardwood whole trees. Oversized particles (> 3 inches) were significantly more frequent in hardwood whole trees and the amount of oversized hardwood particles increased with smaller grate size combinations. The quantity of fine particles (< 0.5 inches) was significantly higher in mixed conifer slash than in hardwood whole trees. These results were probably related to species and tree part. Similar results were reported in past chipping studies. Nati et al. (2010) and Spinelli et al. (2011) reported that chips produced from softwood tend to be smaller than chips produced from hardwood. In addition, the amount of fine particles was significantly higher in chips produced from branch material and from pine. Kofman (2006) also reported that hardwood species with stiff and pliable branches will produce thin overlong particles that may easily pass through the small screen or grate.

The moisture content of feedstocks in grinding operations has significant effects on particle size distribution. In general, the content of fines decreased with increasing moisture content and a more coarse size distribution was produced from summer dried trees, compared to freshly felled trees (Suadicani and Gamborg 1999; Spinelli et al. 2011). In our study, the age (freshness) of feedstock did not have any significant additional effect in the oversized class. The effect of feedstock age was only found in large (3 – 2 inches) and fine (< 0.5 inches) particle classes. As expected, fresh feedstock type showed a tendency to produce a smaller proportion of large particles and a larger proportion of fine particles.

The effect of different grate size combinations on particle size distribution was apparent in all of the feedstock types. The smaller grate size combination significantly reduced the proportion of oversize particles and produced a higher proportion of acceptable particle sizes. Contrary to our expectations, the use of holed anvil on a 3-4-4 grate combination did not have a significant effect on size class distribution. However, the holed anvil tended to reduce the amount of oversized particles and increased the amount of particles that were one inch or less when grinding mixed conifer slash.

CONCLUSION

Currently, several biomass conversion technologies (e.g. combustion, gasification, and pyrolysis) have been developed for biomass energy production; most of which have specific fuel classification guidelines (e.g. size, moisture content, and contaminants) that are unique to each facility. Therefore, matching the right fuel quality to the appropriate conversion technology may enhance the economic viability of forest biomass utilization. In this study, we conducted a controlled experiment on a horizontal grinder to evaluate the effect of three different grate combinations on machine productivity, fuel consumption and particle size distribution for two different biomass types (mixed conifer slash vs. hardwood whole-tree).

Grinding productivity was significantly influenced by the feedstock type and grinder grate size. Mixed conifer slash had a higher grinding productivity than hardwood whole tree. The average productivity for grinding mixed conifer slash was 42.7 BDT/hr and the average productivity when grinding hardwood whole trees was 34.1 BDT/hr. Grinding productivity was also dramatically decreased by up to 30% when grinding using a smaller grate size combination. The use of holed anvil produced slightly higher productivity than the use of solid anvil but there was no statistical significance. Therefore, more directed studies will be needed to determine the effect of grinder anvil type on machine productivity.

Fuel consumption rate was influenced by feedstock type, grinder grate sizes and grate type. Hardwood whole trees had higher fuel consumption rates than mixed conifer slash. Fuel consumption rate increased with smaller grate sizes. SA-2-3-3 inches grate combinations had a 20 to 65% higher fuel consumption rate than SA-3-4-4.

In the particle size distribution analysis, mixed conifer slash produced a higher proportion of the acceptable particle size than hardwood whole tree. The smaller grate size combination was beneficial in significantly reducing the proportion of oversize particles while producing a higher proportion (89%) of acceptable particle sizes in mixed conifer slash. The use of holed anvil tends to reduce amounts of oversize particle and increase amounts of particles that were one inch or less when grinding mixed conifer slash but it was not statistically significant. Therefore, further experiment will be needed to find stronger evidence for the effect of holed anvils on particle size reduction. If our results are supported by future researches, the use of hold anvil will be the most efficient grinding methods because the test conducted with holed anvil had higher grinding productivity and lower fuel consumption rates with efficient size reduction of particles.

Moisture content of forest biomass is often considered a critical factor affecting grinding operations. In our study, however, the effect of moisture content on grinding productivity, fuel consumption, and particle size distribution was not examined because the moisture content of freshly felled trees had been quickly reduced, by up to 25% within 8 weeks of summer. Therefore, further research is needed to determine the effect of moisture content on grinding operations.

ACKNOWLEDGEMENTS

The research was funded by 2010 Biomass Research and Development Initiative Grant (Grant Number: 11-DG-11221636-203), USDA, U.S. and by the Research Center for Advanced Forest Technology Project, Korea Forest Service, South Korea.

REFERENCES

Arthur, J.F., R.A. Kepner, J.B. Dobie, G.E. Miller, and P.S. Parsons. 1982. Tub grinder performance with crop and forest residues. Transactions of the ASAE 25(6): 1488-94.

Han, S.-K. and G.E. Murphy. 2012. Solving a woody biomass truck scheduling problem for a transport company in Western Oregon, USA. Biomass and Bioenergy 44:47-55.

Haygreen, J.G. and J.L. Bowyer. 1982. Forest products and wood science: An introduction. The Uowa State University Press. 495pp.

Hosseini, S. and N. Shah. 2009. Multiscale modeling of hydrothermal biomass pretreatment for chip size optimization. Bioresource Technology 100: 2621–2628.

Jackson, B., R. Schroeder and S. Ashton. 2007. Pre-processing and Drying Woody Biomass. *In* Sustainable Forestry for Bioenergy and Bio-based Products: Trainers Curriculum Notebook. Athens, GA: Southern Forest Research Partnership, Inc. p. 141-144.

Kofman, P.D. 2006. Quality wood chip fuel. http://www.woodenergy.ie/media/coford/content/publications/projectreports/cofordconnects/finalfuelquality.pdf. Accessed February 28, 2013.

Nati, C., R. Spinelli, and P. Fabbri. 2010. Wood chips size distribution in relation to blade wear and screen use. Biomass and Bioenergy 34: 583-587.

Olsen, E., M. Hossain, and M. Miller. 1998. Statistical comparison of methods used in harvesting work studies. Corvallis, OR: Oregon State University, Forest Research Laboratory, Research Contribution n. 23, p. 41.

SAS Institute Inc. 2001. SAS for Windows. Version 8.2. SAS Institute, Cary, N.C.

Spinelli, R., N. Magagnotti, G. Paletto and C. Preti. 2011. Determining the impact of some wood characteristics on the performance of a mobile chipper. Silva Fennica 45(1): 85–95.

SPSS Inc. 1998. SPSS for Windows. Version 9.0.0. SPSS Inc., Chicago, Ill.

Suadicani, K. and C. Gamborg. 1999. Fuel quality of whole-tree chips from freshly felled and summer dried Norway spruce on a poor sandy soil and a rich loamy soil. Biomass and Bioenergy 17:199–208.

Wechsler, M., A. Shulenberger, C. Wall, and J. Braig. 2010. White paper: Torrefaction - Mobile system for producing BioCoal from waste biomass. Torrefaction Method and Apparatus, Technology and progress report, Renewable Fuels Technology. 17p.

Modelling Dynamic Skyline Tensions in Rigging Configurations: North Bend, South Bend, and Block in the Bight Case Studies

Hunter Harrill[1] and Rien Visser[2]

Abstract

In New Zealand the proportion of forest land requiring cable extraction is likely to increase from a current 40% to more than 60% in the next 10 year period. Previous studies have shown that there are a number of different rigging configurations used, and some are more preferred than others in a given location. This study attempted to quantify the skyline tensions due to dynamic (i.e. shock) loading for each of the Fall Block rigging configurations: North Bend, South Bend and Block in the Bight. The effect of choker length was also tested. Simulated yarding tests were performed using the University of Canterbury's School of Forestry Model Yarder. Skyline tension was measured using a load cell connected to a laptop computer recording skyline tensions to the nearest gram continuously at 20 reading per second. The laptop computer also recorded video of operation and line tensions simultaneously using Snagit video capturing software. The video was later used for time study analysis. Results indicated that compared to others the North Bend configuration had the lowest peak tensions when the load was dropped into full suspension and when bridling. South Bend was found to have the lowest peak tensions during simulated collisions with ground objects. A two-way ANOVA performed for each yarding simulation, indicated that the drop test was the only case where rigging configuration was a statistically significant variable. Longer chokers increased the magnitude of shock loading significantly in most cases.

Introduction

Cable logging is the process of extracting trees using winch and cable systems. This practice is often used on steep terrain where more cost-effective ground-based methods are not feasible or safe. In New Zealand the proportion of forest land requiring cable extraction of logs will increasing from a current 40% to more than 60% in the next 10 year period (FFR 2010, MAF 2010). The total annual harvest volume is also expected to increase from 23 to 30 million m^3 (NZFOA, 2012). The number of yarders (i.e. machines used for cable logging/yarding) and cable yarding crews is growing to meet the increasing demand for this extraction process. Visser (2013) indicated that in the last 10 year period on average two yarders per month have been imported into New Zealand. To keep up with the future increase in harvest volume over the next decade and the increasing percentage of steep terrain, there will have to be twice as many crews as currently operating.

There are many different methods that can be used when cable logging. First, we commonly differentiate these by what skyline system is being used (i.e. none, standing, live, or running). Furthermore, we then classify which types of additional gear (i.e. ropes, carriages, and blocks) are used into a specific category called a

[1] *PhD Candidate, NZ School of Forestry, University of Canterbury, Christchurch, New Zealand. Email: hunter.harrill@pg.canterbury.ac.nz*
[2] *Associate Professor, NZ School of Forestry, University of Canterbury, Christchurch, New Zealand*

rigging configuration. There are a number of different rigging configurations which can be used, and some are more preferred than others in a given location (Studier and Binkley 1974; FITEC 2000). Deciding which rigging configuration to use can be challenging and is usually chosen based on the available equipment of the crew, the site conditions, among many other variables; but is often chosen based on the experience and comfort of the crew.

Survey work from Harrill and Visser (2011) found there were approximately 10 different rigging configurations commonly used in New Zealand, with the North Bend configuration being the most common, followed by Grabinsky (colloquially know as “scab”), shotgun, and highlead. However, in the last five years only 20% of crews had tried using any other configurations outside of the four most common. This is particularly interesting when considering the Fall Block rigging configurations (i.e. North Bend, South Bend, and Block in the Bight) of which North bend is most popular, but only different to the others based on the main line geometry; yet only few crews surveyed had tried South Bend, and the majority were not familiar with Block in the Bight.

Very few studies with the exception of Kellog (1987) have tried to compare various rigging configurations in the same operating conditions. There has been plenty of work over a period from the 1960’s to the 1980’s that described static tensions in logging cables and how to calculate them. Woodruff (1984) developed a computer program to analyse static tensions for the Fall Block configurations: North Bend, South Bend, and Modified North Bend. The industry uses a safety factor of three when calculating the payload potential for logging skylines (Studier and Binkley 1974).Safety factors provide room for dynamic forces, sometimes called shock loading that can often send temporary fluctuations in stored elastic energy through the system (Pyles and Womack 1994; Womack et al. 1994; Visser 1998). Dynamic forces can sometimes be greater than the payload itself, and if not accounted for through the safety factor, could lead to a skyline failure and potential injury to workers. Unfortunately, very little work has been completed in monitoring of dynamic forces in cable logging and none have aimed to compare these tensions between rigging configurations. This study aims to quantify and compare the observed skyline tensions using a model yarder, by simulating common situations that are known to cause shock loading.

Objectives

Quantify the skyline tensions due to dynamic (i.e. shock) loading for each of the Fall Block rigging configurations when:

1. The load suddenly drops into full suspension.
2. The load collides with a ground object.
3. Bridling to reach stems away from the skyline corridor.

Methods

Equipment

All simulated yarding tests were performed using the 1:15 scale University of Canterbury’s School of Forestry Model Yarder (Figure 1). The yarder was custom built, including a 2m adjustable spar, with electric variable speed motor, and a four drum winch set. The synthetic ropes originally manufactured for yachting, range in diameters from skyline (4mm) to main line and haulback (3mm) and tagline (2mm).

Skyline tensions were measured with the use of a PT Global PT1000 Single Point load cell and custom built mounting bracket along with a PT200M display unit (Figure 1). The display unit was connected to a laptop computer which recorded skyline tensions to the nearest gram continuously at 20 reading per second. The laptop computer also recorded video of operation and line tension simultaneously using Snagit video capturing software and the laptops built in camera. The video was later used for time study analysis.

Figure 1: UC Model yarder and PT Global load cell with custom built mounting bracket and display unit.

Operations Description

Three tests were performed to simulate common causes of shock loading during cable yarding operations (Figure 2). Each test was repeated 10 times for each of the three rigging configurations (e.g. North Bend, South Bend, and Block in the Bight); five of which used long choker lengths (55 mm) and the other five used short choker lengths (32 mm). The same 4.92 kg log was used for every yarding test, and it was positioned in the same starting spot each time. The span was 12m and the spar height and tail hold height were 2.32 and 2.05 m respectively. The haulback tail block was placed directly in line with the skyline at a height of 1.15 m from the ground except during the bridling test. The skyline was set at 10% mid-span loaded deflection for each test, measured using a laser level. The yarder’s motor was set to the desired speed level (approximately 0.3 m/sec) and audible signals were used to annotate operational procedures. The operator took special effort to control the drag as consistently as possible for each test, in an attempt to minimize variability due to operator.

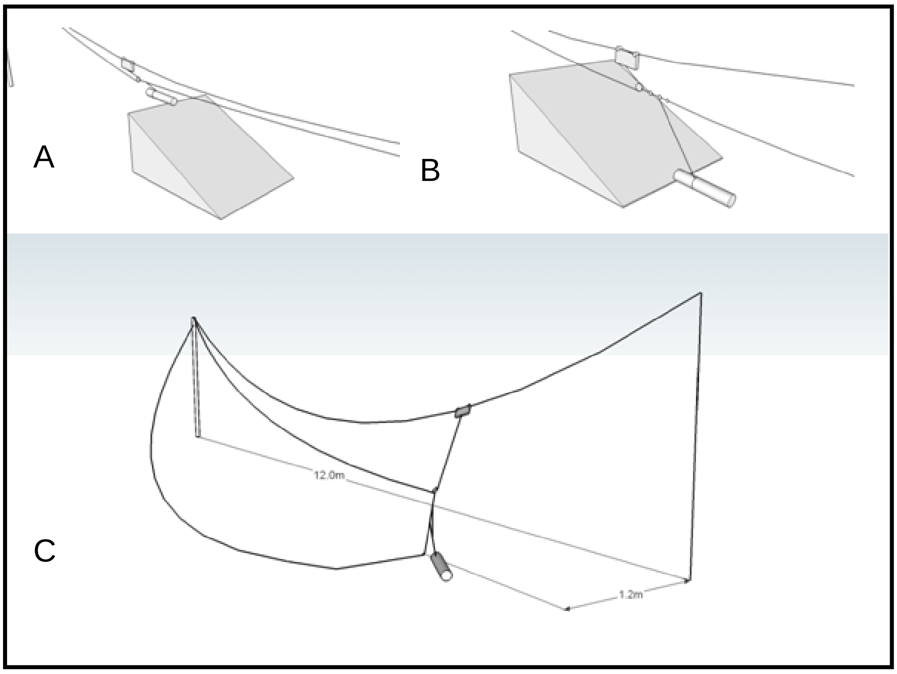


Figure 2: Diagram of the three tests performed (A) Drop, (B) Impact, and (C) Bridling.

Drop Test

The drop test (Figure 2A) started with the log at mid span (6m) resting on the ground. The main line was pulled in with brake applied to the haulback until slack was taken out of the line and the log began to move. Brake pressure was reduced to the haulback to allow the log to be yarded forward and up the ramp. The log was then pulled over the end of the ramp into full suspension generating a shock load, and then continued along the skyline corridor until it reached the tower, where it was lowered to the ground.

Impact Test

The impact test (Figure 2B) started in the same position as the drop test. The log was then yarded forward 45 cm until it collided with the bottom of the ramp where it initially stopped until slack was pulled out the ropes and enough force was generated to dislodge the log, generating a shock load. The log continued to be yarded to the tower and then lowered the same as in the drop test. The haulback and main ropes were operated in the same manner, only this time less brake pressure was applied to the haulback in order to maintain ground leading of the log to ensure a collision with the ramp edge.

Bridling Test

The bridling test (Figure 2C) started with the log resting on the ground at 10.35 m from the tower and offset to one side of the skyline by 1.20 m where it would normally be too far away to reach with either size of chokers, thus requiring the practice of bridling. The tail block was offset 1.20 m from the skyline and placed directly behind the log at ground level. The mainline was pulled in while applying pressure to the haulback brake until partial suspension was generated. Brake pressure was then decreased to allow the log to be yarded laterally back under the skyline corridor, and eventually along the corridor until mid span where it was lowered to the ground.

Data Analysis

Video recording along with the sound feed of audible signals was used to perform a time study on individual yarding cycles (Figure 3). Cycles were broken down into extraction cycle segments: breakout of the log, yarding or lateral yarding, yarding up ramp, full suspension, and lowering the load. The maximum tensions observed during those time segments were recorded into Microsoft Excel spreadsheets to generate graphs and summary statistics. The data was screened for normality and then used to perform a two-way analysis of variance (ANOVA) in Minitab[3]. A Tukey test was included for the purpose of making a comparison of maximum tensions between rigging configurations. In all test the null hypothesis was that there was no difference in maximum skyline tension between treatments.

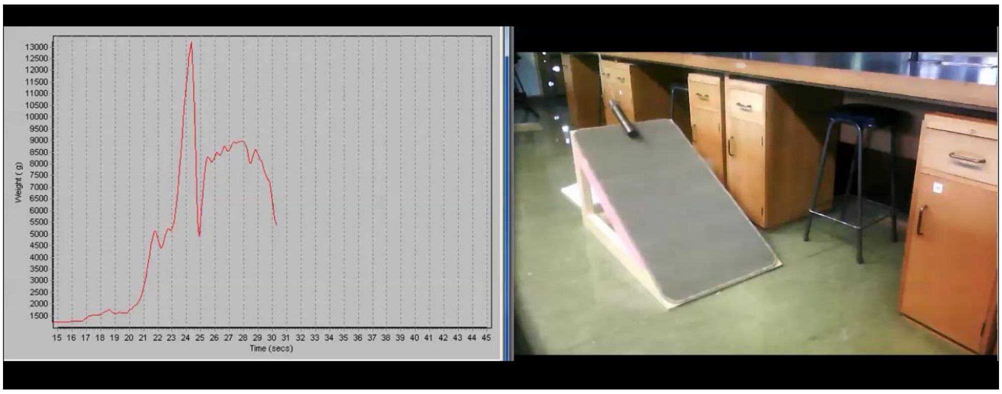


Figure 3: Simultaneous video recording of yarding cycle and skyline tension monitoring using Snagit software.

Results and Discussion

Drop Test

ANOVA for the drop test indicated that both the variable of choker length and rigging configuration were statistically significant but not the interaction between them, with P-value<0.01 and P-value<0.00; α = 0.05 respectively. Maximum tensions were consistent within treatments, with longer chokers generating higher tensions and showed that South Bend behaved quite similar to Block in the Bight (Figure 4). Higher tensions with longer chokers can be explained by the log having to fall further and therefore attain higher velocity. South Bend and Block in the Bight may perform similarly but the Tukey test found them to be significantly different from North Bend.

[3] Minitab Version 16.2. Minitab Inc., State College, PA, USA

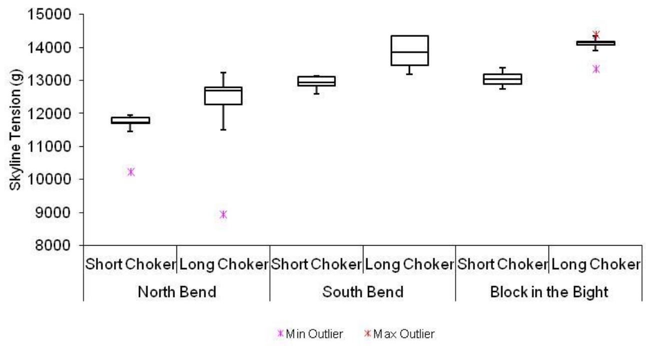


Figure 4: Maximum skyline tensions generated during drop test with log in full suspension.

Impact Test

ANOVA found no statistical significance in either rigging configuration or choker length for the impact test. What is interesting to note however, is how similar tensions were between the long and short chokers when the Block and the Bight rigging configuration was used as compared to others (Figure 5). South Bend with short chokers produced the lowest tensions, which can be attributed in part to the more upward lift generated by the geometry of the main rope and fall block used. It was also observed that this configuration performed very well at avoiding the ground object as several cycles were repeated since the log avoided collision altogether.

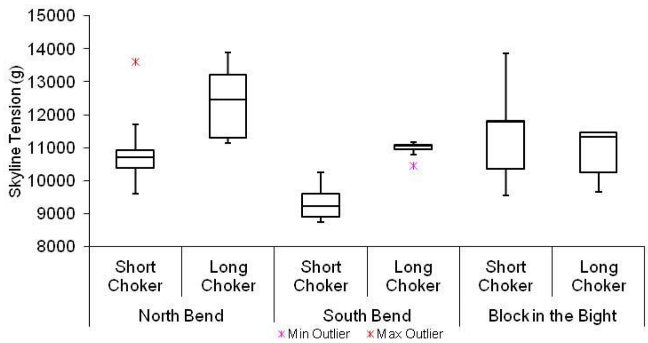


Figure 5: Maximum skyline tensions generated when log had collision with ground object.

Bridling Test

During bridling maximum tensions recorded during the initial breakout component of the yarding cycle were somewhat similar with exception of Block in the Bight using long chokers (Figure 6). The video footage shows the skyline in this setup deflecting into view of the camera lens, when other configurations did not. This can be somewhat explained by how the mainline had to pull more rope onto the drum than with short chokers, which put more tension on the mainline and haulback to attain the same amount of desired lift to the log, thus allowing the coefficient of friction to be reduced and allowing the log to move forward. The increased tension in mainline and haulback is partially transferred to the skyline and in this case is exaggerated by the geometry of the mainline and the purchase in the fall block; where the terminal end is connected to the skyline carriage. ANOVA results indicated that only choker length was statistically significant (p-value<0.00, α = 0.05).

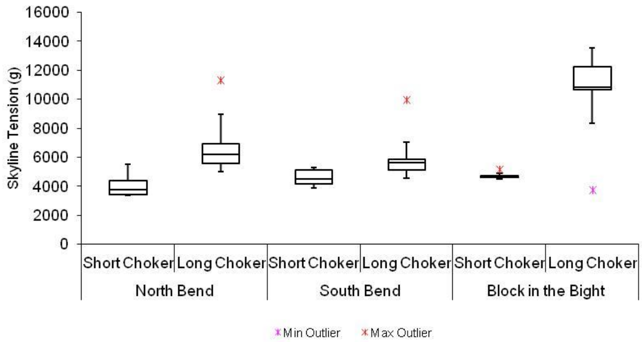


Figure 6: Maximum skyline tensions generated during initial breakout while bridling.

Once the log was moving during the component of lateral yarding the exacerbated effect of the long choker length on Block in the Bight was reduced. However, choker length was still the only variable to have statistical significance (p-value < 0.00, α = 0.05). The longer choker length also produced greater variability in maximum tension, but more so for the South Bend and Block in the Bight configurations (Figure 7). This again may be somewhat explained in the geometry of the main rope and fall block, where North Bend does a better job of equalizing the tensions when the fall block runs back and forth on the mainline rather than straight up and down with the double purchase of the others.

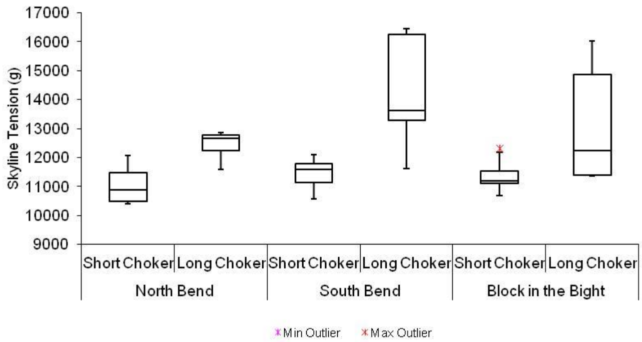


Figure 7: Maximum skyline tensions generated during lateral yarding when bridling.

Conclusion

The study results, using a model yarder, showed that there were differences in skyline tensions between rigging configurations and varying choker length for the same application. However, statistical analysis proved that in all tests with exception to the drop test that there was no significant difference in maximum skyline tensions generated based on which rigging configuration was used. There was no significant difference in skyline tension between any of the treatments when the log had a collision with a ground object, although South Bend yielded the smallest tension and performed best in avoiding collision. In both the initial breakout and lateral yarding components of a cycle during bridling, choker length was the only variable found to be statistically significant. Where longer chokers produced higher and more variable skyline tensions especially when using Block in the Bight during breakout, and while lateral yarding with South Bend or Block in the Bight.

Results suggest that in some cases one configuration might be more preferred than another based on potential skyline tension. However, there are other ropes involved in these configurations which are subject to shock loading like the haulback and especially the mainline, and in some occasions the mainline tension can limit the allowable payload. Monitoring tensions on these operating ropes requires a load cell that allows the moving ropes to pass through the device. Monitoring of the mainline and haulback were outside of the scope of this research but warrant further investigation. It is also important to note that tensions and shock loading in this study will differ due to scale issues, especially with respect to rope self weight. Where a common 28 mm skyline weighs approximately 3.12 kg/m and can account for a large portion of vertical forces, compared to 13.7 g/m used with the model yarder.

Acknowledgements

The authors would like to thank Future Forest Research (FFR) Rotorua, New Zealand for supporting the development of this research project. In particular we acknowledge Keith Raymond of FFR for his input into developing the research direction.

References

Harrill, H., R. Visser 2011. Rigging Configurations used in New Zealand Cable Logging. Future Forest Research. HTN-03-11. 6p.

FITEC, 2000. Best Practice Guidelines for Cable Logging. Forest Industry Training and Educational Council New Zealand.

Kellogg, L. 1987. A cable hauling trial with the Madill 071 – using three different rigging systems. LIRA Report, Vol. 12 No. 11.

Pyles, M. R., K. C. Womack. 1994. Dynamic Characteristics of a Small Skyline Logging System with a Guyed Tailspar. International Journal of Forest Engineering 6(1): 35-49.

Studier, D.D., V.W. Binkley. 1974. Cable logging systems. USDA For. Serv., Div. of Timber Management, Portland, Oregon. 205 p.

Visser, R 2013. 2012 New Zealand Yarder survey. Unpublished report, School of Forestry, University of Canterbury, Christchurch, New Zealand. 8p

Visser, R.J.M. 1998. Tensions monitoring of forestry cable systems, PhD Dissertation from the Forest Engineering Department, Bodenkultur University, Vienna, Austria. 183p.

Womack, K.C. 1994. Computer model for dynamic skyline behaviour. Journal of Forest Engineering. 5(2): 55-62.

Woodruff, W. C. 1984. Payload analysis for the North Bend, South Bend, and modified North Bend skyline logging systems. Masters Dissertation from School of Forest Engineering, Oregon State University, Corvallis, Oregon. 105p.

http://www.ffr.co.nz/publications. FFR. Four Corners June 2010. Downloaded on 20 Dec 2010.

http://www.maf.govt.nz/mafnet/publications/nefd/national-exotic-forest-2010. MAF. National Exotic Forest Description, downloaded on 20 Dec 2010.

http://www.maf.govt.nz/mafnet/publications/wood-availability/new-zealand. MAF. Wood Availability Forecasts, downloaded on 20 Dec 2010.

Modeling and Optimization of Woody Biomass Supply Chains in the Northeastern United States

Damon Hartley[1], Jingxin Wang[2]

Abstract

In the Northeastern United States, as in many places around the country, interest has developed in the increased use of renewable resources for the production of energy. While regions such as the Southwest and central have focused on the development of solar and wind technologies; these technologies have limitations on their effectiveness. In the Northeast, biomass derived from forests and short rotation woody crops (SRWC), may hold the key for renewable energy production in the region. While woody biomass is a potential feedstock for a diverse set of energy development options, little emphasis has been placed on developing supply chains to efficiently deliver the resource to the end user. Developing efficient supply chains is predicated on identifying configurations that will optimize the harvest, extraction, transport, storage and preprocessing of the woody biomass resources to provide the lowest possible delivered price. The characteristics of woody biomass, such as spatial distribution and low bulk density, tend to make collection and transport difficult as compared to traditional energy sources. These factors, as well as others, have an adverse effect on the cost of the feedstock. The objective of this research is to identify potential supply chain alternatives, through the use of mathematical modeling and computer simulations, that will potentially be able to provide sufficient quantities of biomass resources that can be utilized in the production of renewable energy at an economical price.

[1] Graduate Research Assistant, West Virginia University
[2] Professor, Division of Forestry and Natural Resources, West Virginia University

Assessment Of Feller-Buncher And Harvester Caused Stand Damage In Partial Harvests In Maine

Patrick Hiesl[1] and Jeffrey G. Benjamin[2]

Abstract

In the summer of 2012 a productivity study of whole-tree and cut-to-length systems in partial harvests in Maine was carried out. A residual stand damage assessment was conducted prior to skidding and forwarding to isolate the impact of harvesting equipment on post-harvest conditions. Damage was classified in three categories – low (bark scuff), medium (cambium broken but sapwood still intact), and high (cambium and sapwood broken). Wound size and distance to the bottom of each wound were measured to the nearest cm. Distance from trail center was measured perpendicular to the trail for each damaged tree. Results show that stand damage (medium and high) caused by feller-bunchers ranges from 7% to 25% of the residual trees, and for harvester from 19% to 40%. No significant difference could be found in the distance of damaged trees from trail center (p>0.508) or the height of first occurrence of damage (p>0.440) among the three damage classes for feller-buncher and harvester. The stand damage caused by feller-buncher and harvester is significantly different (p=0.007), with the harvester damaging the greater number of trees. Further stand damage measurements will be taken in the future to increase the sample size and to further investigate the damage caused by individual machines and harvesting systems.

Introduction

It is well documented that mechanical harvesting systems can cause significant damage to residual stems under a variety of site conditions and management objectives. Coup (2009) reviewed stand damage studies throughout the northeast region and found that 30% - 42% of the trees in a harvest block were injured to some degree. Benjamin et al. (2012) found that an experienced and conscientious cut-to-length (CTL) operator harvesting at 24.4 m trail spacing produced less than 10% stem damage in a thinning operation. Clearly operator experience, machine configurations, site conditions and harvest prescription play an important role in minimizing damage to residual stems. Post-harvest assessments of this nature typically measure stem damage with respect to a qualitative scale related to size, location and significance of individual wounds (Ostrofsky and Dirkman 1991; Ostrofsky et al. 1986) and several

[1] Patrick Hiesl (patrick.hiesl@maine.edu), Graduate Research Assistant, University of Maine, School of Forest Resources, 5755 Nutting Hall, Orono, ME 04469

[2] Jeffrey G. Benjamin (jeffrey.g.benjamin@maine.edu), Associate Professor in Forest Operations, University of Maine, School of Forest Resources, 243 Nutting Hall, `Orono, ME 04469

studies in this region have applied this technique (Benjamin et al. 2012; Coup 2009; Cline et al. 1991)summarized the effect of stand damage on tree growth from a number of studies conducted in Europe, Russia and the USA. The prescriptions ranged from pre-commercial thinnings to partial harvests and clear cuts in mostly Norway spruce (*Picea abies*) stands. Stand damage was caused in parts by tractors and mechanized harvesting systems. Vasiliauskas (2001) found that tree damage can decrease growth by 5% to 35%. Studies from Finnland and Sweden show the negative effect of 25% reduction in height growth due to root damage from mechanized harvesting (Wästerlund 1988; Isomäki and Kallio 1974) and a reduction of 35% in radial growth (Isomäki and Kallio 1974) in Norway spruce stands.

All of the previous studies focus on post-harvest stand damage caused by a harvesting system (e.g. feller-buncher / grapple skidder or harvester / forwarder). However, Bruhn (1986), published stand damage caused by three feller-bunchers (drive-to-tree and swing-to-tree with shearheads) in thinnings of pole-sized northern hardwood stands in Michigan. The reported damage ranges from 18% to 40% of the residual trees. Stand damage of 48% of the residual trees caused by feller-buncher was reported by Matzka and Kellogg (2003) who operated in noble fir (*Abies procera*) stands in Oregon. Stand damage information available in this region consists of the damage caused by a harvesting system and does not differentiate between felling and extraction machines. There is a need of stand damage information for harvesting machines to highlight the importance of operator training in order to further reduce stand damage.

Materials and Methods

In the summer of 2012 a harvesting equipment productivity study was carried out in Maine for whole-tree (feller-buncher / grapple skidder / stroke delimber) and cut-to-length (harvester / forwarder) systems. After the harvest the stand density was measured along horizontal line samples and the opportunity was given to take note of the feller-buncher and harvester caused stand damage before the skidding and forwarding. Due to the delay of the skidding and forwarding of the harvested wood of several days and weeks, and due to the limited time available for research, the stand damage after the skidding and forwarding process could not be measured.

Data were collected on seven whole-tree and three cut-to-length harvest sites. Initial stand densities ranged from 1000 trees/ha to over 2500 trees/ha, with basal area between 25 m^2/ha and 54 m^2/ha (Table 1). Horizontal line samples (Husch et al. 1982; Beers and Miller 1976; Strand 1958) using a prism with a basal area factor of approximately 4.7 m^2/ha (20 ft^2/acre) were taken before the harvest to establish the initial basal area, stand density and dbh distribution. Immediately after the harvest, basal area and stand density measurements were taken along the same line. In addition, tree damage was recorded for residual trees greater 5 cm in dbh. Damage was classified in three severity classes – low (bark scuff), medium (cambium broken but sapwood still intact), and high (cambium and sapwood broken) (Ostrofsky and Dirkman 1991; Ostrofsky et al. 1986). Wound size and distance to the bottom of each wound were measured to the nearest 2.5 cm (1 inch). Distance from trail center was measured perpendicular to the trail for each damaged tree.

Table 1: Site, stand and machine conditions for whole-tree and cut-to-length harvest sites studied.

Site #	System	Trail Spacing (m)	Initial Density (trees ha^{-1})	Initial Basal Area (m^2 ha^{-1})	Basal Area Removed	Slope
1	WT	18.3	1756	26.8	67%	3%
2	WT	30.5	1015	32.8	48%	11% - 14%
3	WT	19.8	2104	54.6	15%	5% - 7%
4	WT	24.4	1934	27.3	66%	7%
5	WT	18.3	1469	34.4	54%	2%
6	WT	24.4	1062	25	33%	7% - 12%
7	WT	24.4	2536	29.4	76%	3%
8	CTL	15.2	1403	37.3	57%	17% - 35%
9	CTL	18.3	2596	47.9	25%	1%
10	CTL	18.3	1630	27.4	45%	2%

Site #	Harvested dbh (cm)	Power (hp)	Work Hours	Operator Experience [a]	Productivity (m^3 PMH^{-1}) [b]	Stand Damage [c]
1	10 - 48	241	8800	7 years	42	29%
2	10 - 43	167	10000	13 years	22.8	7%
3	10 - 53	300	196	8 years	62.3	8%
4	10 - 63	284	11800	4 years	48.9	19%
5	10 - 58	241	9000	7 years	66.1	18%
6	10 - 58	228	10000	1 year	59.2	12%
7	10 - 38	241	8800	15 years	31.2	26%
8	10 - 56	300	2800	4 years	33.2	57%
9	10 - 38	215	14650	12 years	13.9	30%
10	10 - 30	228	5000	<1 year	10.5	25%

[a] Operator experience in feller-buncher/harvester.
[b] Productive Machine Hours including breaks less than 15 minutes.
[c] Stand damage of residual trees. Includes low, medium and high damage categories

Results

Residual stand damage across all three severity classes ranges from 7% to 29% and 25% to 57% for feller-buncher and harvester, respectively (Table 1). Stand damage caused by harvesters is higher than that caused by feller-bunchers with an average for each damage class of 16% to 20% and standard deviations of 10% to 17% (Figure 1). Results of a one-way ANOVA show that there is a significant difference ($p=0.007$) in stand damage between feller-buncher and harvester. These stand damage numbers include all three classes (low (n=16), medium (n=15), high (n=21)) of stand damage. However, the low stand damage class is only a bark scuff and will be excluded from further results. Residual stand damage of medium and high damage combined ranges from 7% to 25% and 19% to 40% for feller-buncher and harvester, respectively (Figure 2). The residual stand damage represents a basal area of 2% to 26% and 16% to 27% of the residual basal area for feller-buncher and harvester cut stands, respectively (Figure 2).

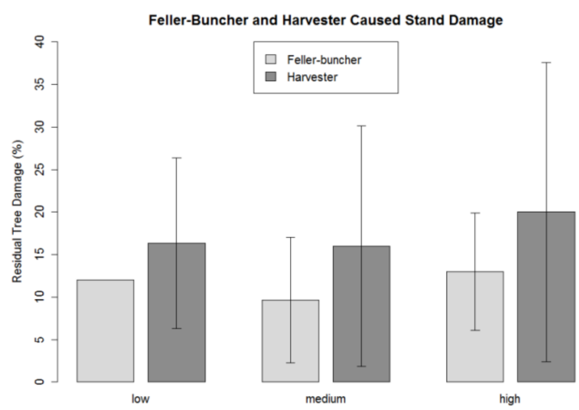


Figure 1: Average stand damage caused by feller-buncher and harvester including standard deviation error bars.

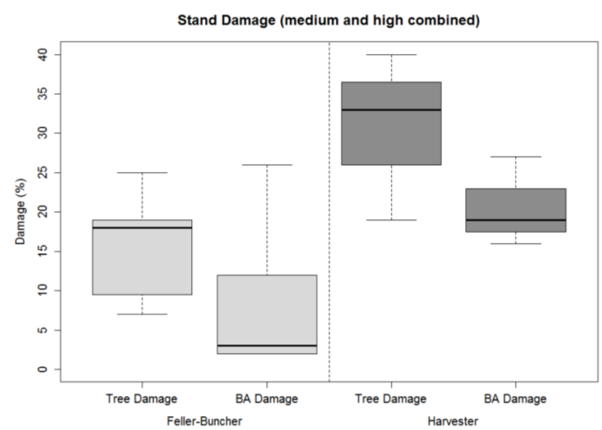


Figure 2: Residual tree damage and represented post-harvest basal area (BA) for medium and high damage combined for feller-buncher and harvester. Tree Damage is the percentage of damaged trees in a stand. BA Damage is the percentage of basal area that the damaged trees represent in a stand.

Damaged trees are situated between 1.2 m and over 10 m from trail center (Figure 3). A one-way ANOVA in combination with Tukey's HSD pairwise group comparison shows that there is no significant difference in distance to trail center ($p>0.508$), and height of damage ($p>0.440$) among the damage classes for feller-buncher and harvester caused damage. The height of the first occurrence of damage on a bole ranges from 0 m to over 7 m (Figure 3). No significant difference could be found in the distance from trail ($p=0.829$), and height of damage between feller-buncher and harvester ($p=0.574$). Four outliers had to be removed to adhere to ANOVA assumptions for the analysis of height of damage. Wound size for medium and high damage ranges from 20 cm^2 to over 900 cm^2 (Figure 4). Due to unequal variance and the lack of normality in the small sample size a Mann-Whitney U test (also known as Wilcoxon rank sum test) has been applied to the data. The results is that there is no significant difference (p=0.829) in the probability distribution of wound size between the two machines. The mean wound damage is 344 cm^2 and 145 cm^2 for feller-buncher and harvester caused damage, respectively.

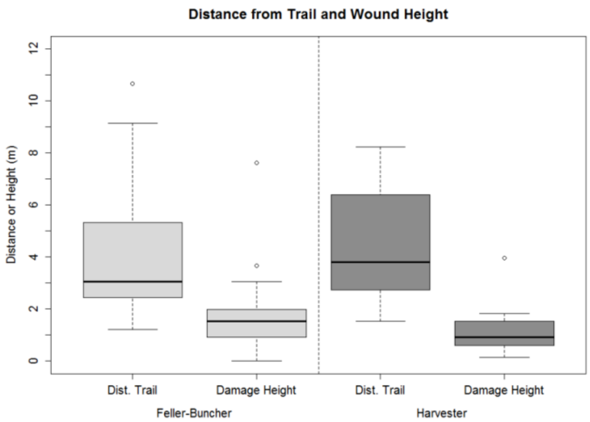


Figure 3: Distance from trail center, and height of first wound occurrence for medium and high damaged trees for feller-buncher and harvester caused damage.

Figure 4: Wound size caused by feller-buncher and harvester for medium and high damaged trees combined.

Discussion

The number of damaged trees within each site and between the two harvesting machines varies greatly. Damage caused by feller-bunchers has been reported previously between 14% and 40% of the residual trees or 5% to 13% of the residual basal area (Bruhn 1986). Three out of seven sites in the present study experienced stand damage of less than 14% and none of the sites experienced stand damage as high as 40%. A study by Matzka and Kellogg (2003) even shows a feller-buncher caused stand damage of 48% of the residual trees which is by far higher than the damage caused in the present study by any feller-buncher and operator combination.

Damage caused by harvester has been reported as between 15.2% and 45.2% (Sirén 2001) of the residual trees. This study was carried out in thinnings of Norway spruce in Finland. An even greater damage was reported by Han and Kellogg (2000) with 63.8% of the residual trees. This study was carried out in a Douglas-fir (*Pseudotsuga menziesii*) dominated stand in Oregon with a 18.3 m trail spacing. Most of the stand damages in the present study are within the range of Sirén (2001) with the exception of a 57% damage observation. This particular outlier, however, consists of a tracked harvester operation on a steep slope and cannot be easily compared to lower stand damage on flat ground with wheeled harvesters. During the harvest the machine was sliding on ledges which increased the residual stand damage. Neither of the stand damage observed in Maine is as high as the one reported by Han and Kellogg (2000).

It is difficult to compare the feller-buncher and harvester caused stand damage to other observations since most of the published information entails system level (e.g. feller-buncher / grapple skidder and harvester / forwarder) stand damage. According to Ostrofsky et al. (1986) stand damages of 20% - 40% (on system level) are generally acceptable. These values, however, include the stand damage caused by the harvesting machine and the extraction device (e.g. grapple skidder). Stand damage found by other studies range from 20% to 53% (Coup et al. 2008; Nichols et al. 1994; Ostrofsky 1988; Ostrofsky et al. 1986; Biltonen et al. 1976). Ostrofsky (1988) points out that even bark scuffs can have a high impact on log quality, depending on species. Considering the damage caused by feller-buncher, there is only a small margin for extraction devices to stay within acceptable stand damage levels. Stand damage for medium and high damage classes combined were reported as between 21% and 24% by Benjamin et al. (2012). Compared to these damage values some of the damage caused by feller-bunchers in the present study seems to be very high. Reason for that might be a combination of operator experience, trail spacing and stand density. Due to the small amount of samples it is difficult to make any concrete assumptions about the influential factors.

The height of damage from the ground on trees, caused by feller-buncher, has been published by Matzka and Kellogg (2003) as between 0 m and 13.7 m with an average of 2.7 m. The height of damage observed in the present study is mostly below 4 m and does not even reach 13.7 m for a maximum. No information could be found for harvester regarding the height of damage; however, the observed values are well within the previously mentioned range. The wound size caused by feller-buncher has been reported as between 93 cm^2 and 5,574 cm^2 with an average of 372 cm^2 (Matzka and Kellogg 2003). The observed damage in the present study averages 344 cm^2 and is in its range well below the 5,500 cm^2 mark. Wound size has also been reported for harvester caused damage by Han and Kellogg (2000) as 144 cm^2. This value seems to be perfectly concurring with the observed value of 145 cm^2 in the present study.

It is important to note that under the right conditions stand damage can be minimized. For example, Benjamin et al. (2012) found that an experienced and conscientious CTL operator harvesting at 24.4 m trail spacing produced less than 10% stem damage in a thinning operation. Observations of the researcher indicate that the forwarder operator inexperience and proficiency can add significant stand damage. Due to the small amount of sample for harvester it is difficult to say if the stand damage caused by this type of machine is generally higher than the damage caused by feller-buncher. The samples taken might not represent the average operator or stand damage caused by this type of machine. However, the previously mentioned studies indicate overall higher stand damage for harvester than feller-buncher. Further samples need to be taken to increase the comparability of the two machines and to strengthen the results of this study. Also due to the small amount of samples for feller-buncher and harvester, the results of non-significant differences in distance to trail, height of damage, and wound size among the damage classes and between the two machines might not be representative. Additional data needs to be collected to further investigate the relationship of damage class and other factors such as distance to trail.

Conclusion

The conclusion is that there are differences between feller-buncher and harvester caused damage. Harvester caused damage is significantly higher than feller-buncher caused damaged. However, all the reported damages in this study are lower than damage values reported in previously published articles. Feller-buncher damage levels are generally low enough to stay within acceptable damage levels after the skidding process. Harvester damage levels are fairly high, but still within the range of acceptable stand damage. Since forwarding usually does not introduce a large amount of stand damage, the overall damage will be within the range of 20% - 40% of the residual trees. With the small sample no differences could be found regarding the distance of damaged trees from trail center among the damage classes and between the two harvesting machines. The same is true for the height of damage on the bole and the wound size. Additional data needs to be collected in order to be able to draw more representative conclusion about stand damage in this region.

Acknowledgment

We would like to thank the Cooperative Forestry Research Unit (CFRU) in Maine for funding this project. Special thanks go to all the land managers, contractors and operators that participated in this study. We would also like to thank Dr. Robert Seymour and Dr. Aaron Weiskittel for their input and help during the study design and data analysis phases of this study. Our thanks go to Casey Elmer of the University of Maine for his help in the data collection phase during the summer of 2012.

References

Beers, T.W. and Miller, C.I. 1976. Research Bulleting No. 934. *Line sampling for forest inventory*. West Lafayette, IN: Department of Forestry and Natural Resources. Purdue University Agricultural Experiment Station

Benjamin, J.G., Meacham, E., Seymour, R.S. and Wilson, J.S. 2012. Early Commercial Thinning in Maine's Spruce-Fir Forests. In: *Proceedings of the 35th Council on Forest Engineering: Engineering New Solutions for Energy Supply and Demand*. New Bern, NC.

Biltonen, F.E., Hillstrom, W.A., Steinhilb, H.M. and Godman, R.M. 1976. Research Paper NC-137. *Mechanized Thinning of Northern Hardwood Pole Stands*. St. Paul, MN

Bruhn, J.N. 1986. General Technical Report NC-113. *Damage to the Residual Stand Resulting from Mechanized Thinning of Northern Hardwoods; in Procedings of a Symposium: Hardwood Thinning Opportunities in the Lake States*. Houghton, MI

Cline, M.L., Hoffman, B.F., Cyr, M. and Bragg, W. 1991. Stand Damage Following Whole-Tree Partial Cutting in Northern Forests. *Northern Journal of Applied Forestry* 8(2), pp. 72–76.

Coup, C.E. 2009. Master Thesis: A Case Study Approach For Assessing Operational And Silvicultural Performance Of Whole-Tree Biomass Harvesting In Maine. Orono, ME: University of Maine.

Coup, C.E., Benjamin, J.G. and Wagner, R.G. 2008. Harvesting Biomass to improve low-value beech dominated hardwood stands in Maine. In: Baker, S. A., Bolding, M. C., and Greene, W. D. eds. *Proceedings of the 31st Annual Meeting of the Council on Forest Engineering (COFE)*. Charleston, SC, pp. 1–6.

Han, H.-S. and Kellogg, L.D. 2000. Damage Characteristics in Young Douglas-fir Stands from Commercial Thinning with Four Timber Harvesting Systems. *Western Journal of Applied Forestry* 15(1), pp. 27–33.

Husch, B., Miller, C.I. and Beers, T.W. 1982. Inventory using sampling with varying probabilities. In: *Forest Mensuration*. 3rd Ed. Malabar, FL: Krieger Publishing Company, pp. 213–275.

Isomäki, A. and Kallio, T. 1974. Consequences of injury caused by timber harvesting machines on the growth and decay of spruce (Picea abies (L.) Karst.). *Acta Forestalia Fennica* 136, pp. 1–25.

Matzka, P.J. and Kellogg, L.D. 2003. Harvest system selection and design for damage reduction in noble fir stands: A case study on the warm springs Indian Reservation, Oregon. *Western Journal of Applied Forestry* 18(2), pp. 118–126.

Nichols, M.T., Lemin, Jr., R.C. and Ostrofsky, W.D. 1994. The impact of two harvesting systems on residual stems in a partially cut stand of northern hardwoods. *Canadian Journal of Forest Research* 24, pp. 350–357.

Ostrofsky, W.D. 1988. Miscellaneous Report 327. *Improving Tree Quality and Forest Health by Reducing Logging Injuries; in Proceedings of Maine's Hardwood Resource: Quantity Versus Quality*. Orono, ME

Ostrofsky, W.D. and Dirkman, J.A. 1991. CFRU Information Report 27. *A Survey of logging damage to residual timber stands harvested for wood biomass in sourthern Maine*. Orono, ME

Ostrofsky, W.D., Seymour, R.S. and Lemin, Jr., R.C. 1986. Damage to northern hardwoods from thinning using whole-tree harvesting technology. *Canadian Journal of Forest Research* 16, pp. 1238–1244.

Sirén, M. 2001. Tree Damage in Single-Grip Harvester Thinning Operations. *International Journal of Forest Engineering* 12(1), pp. 29–38.

Strand, L. 1958. Sampling for volume along a line. *Meddelelser fra Det Norske Skogsforsøksvesen (Reports of the Norwegian Forest Research Institute)* 15(3), pp. 326–331.

Vasiliauskas, R. 2001. Damage to trees due to forestry operations and its pathological significance in temperate forests: a literature review. *Forestry* 74(4), pp. 319–336.

Wästerlund, I. 1988. Damages and growth effects after selective mechanical cleaning. *Scandinavian Journal of Forest Research* 3, pp. 259–272.

Function modeling: improved raster analysis through delayed reading and function raster datasets

Hogland, John S.[1], Anderson, Nathaniel M.[1], Jones, J. Greg[1]

[1] US Forest Service, Rocky Mountain Research Station, Missoula, MT

Abstract

Raster modeling is an integral component of spatial analysis. However, conventional raster modeling techniques can require a substantial amount of processing time and storage space, often limiting the types of analyses that can be performed. To address this issue, we have developed Function Modeling.

Function Modeling is a new modeling framework that streamlines the raster modeling process by utilizing lazy reading methodologies. To assess the efficacy of Function Modeling, we compared the processing time and storage space required to execute six simulation using our newly developed methodology and conventional modeling techniques. Our findings indicate that Function Modeling substantially reduces both processing time and storage space when compared to conventional modeling. Outside of simulations, we have used Function Modeling to characterize the impacts of fuel treatments on soil erosion given fire disturbance, estimate basal area, trees, and tons of above ground biomass per acre, identify locations in need of forest management, calculate forest residuals given multiple management prescriptions, and integrate spatially explicit delivery cost models with forest residual estimates in a fraction of the time and storage space it would take to perform similar analysis using conventional modeling methodologies.

Overall, Function Modeling significantly improves how raster models are processed. To facilitate the use of Function Modeling, we built an object oriented .NET library called RMRS Raster Utility. RMRS Raster Utility is free, readily available, has an intuitive user interface, and directly plugs into Environmental Science Research Institute (ESRI)'s software as an ESRI add-in.

Introduction

Raster modeling is an integral component of spatial analysis and remote sensing. It has been used to address a broad array of questions in forest resources management, ranging from estimating forest carbon (Patenaude et al. 2005) to soft mass availability (Reynolds-Hogland et al. 2006). However, current model processing can require a substantial amount of time and storage space, often limiting the types of analyses that can be performed. As a compromise, some analysts re-sample data to perform analyses, which sacrifices data fidelity. While this can make the data more manageable, it can also blur the relationships between dependent and independent variables. In a recent project we were faced with this dilemma, forcing us to take a closer look at raster modeling and develop novel ways to address typical constraints.

After reviewing the conventional raster modeling techniques, it is clear that the way raster models process data can be improved. Specifically, raster models are composed of multiple spatial operations. Each operation reads data from a given raster dataset, transforms the data, and then creates a new raster dataset (Figure 1). While this process is intuitive, creating and reading new raster datasets at each step of a model comes at a high processing and storage price, prompting two questions: 1) Do we need to create intermediate outputs to get a final model output? 2) If we remove intermediate outputs from the modeling process, what improvements in processing and storage can we expect?

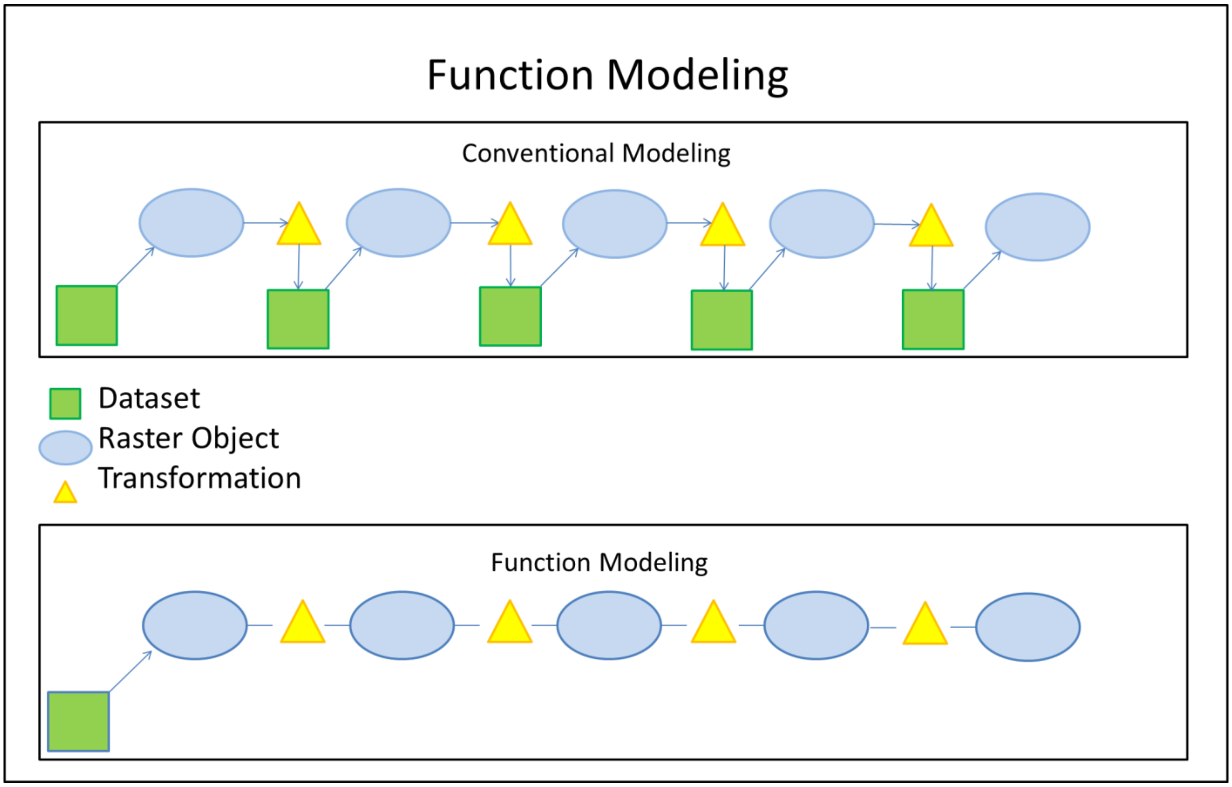


Figure 1. Conceptual idea behind Function Modeling. For each raster transformation (yellow triangles) within a conventional model, an intermediate raster dataset is created (green block). Intermediate raster datasets are then read into a raster object (blue ovals) and transformed to produce another intermediate raster dataset. Function Modeling does not create intermediate raster datasets and only stores the type of transformation occurring to source raster datasets. When raster data are read, this technique performs the transformations to the source datasets without creating intermediate raster datasets.

Methods

To address these questions we developed a modeling framework, called Function Modeling, that allows users to model functions as opposed to raster datasets using an object-oriented design, .NET framework, Environmental Systems Resource Institute (ESRI)'s ArcObjects, and function raster datasets (ESRI 2010). Next, we designed, ran, and recorded processing time and storage space associated with six simulations that varied the size of the raster datasets. Finally, to compare and contrast Function Modeling (FM) with conventional modeling (CM) techniques, we used linear regression. All conventional modeling techniques were directly coded against ESRI's ArcObject Spatial Analyst classes to minimize conventional modeling processing time.

Spatial modeling scenarios within each simulation ranged from one arithmetic operation to twelve operations that included arithmetic, logical, conditional, focal, and summary type analyses (Table 1). Each modeling scenario created a final raster output and was run against six raster datasets ranging in size from 1,000,000 to 121,000,000 total cells, incrementally increasing in size by 2000 columns and rows at each step. Cell numeric precision remained constant as floating type numbers across all scenarios and simulations.

Table 1. Spatial Operations used to compare and contrast Function Modeling and conventional raster modeling. Superscript values indicate the number of times an operation was used within a given model. Model number also indicates the total number of processes performed for a given model.

Model	Spatial Operation Types
1	Arithmetic (+)
2	Arithmetic (+) & Arithmetic (∗)
3	Arithmetic (+), Arithmetic (∗) & Logical (>=)
4	Arithmetic $(+)^2$, Arithmetic (∗) & Logical (>=)
5	Arithmetic $(+)^2$, Arithmetic (∗), Logical (>=) & Focal (Mean,7,7)
6	Arithmetic $(+)^2$, Arithmetic $(*)^2$, Logical (>=) & Focal (Mean,7,7)
7	Arithmetic $(+)^2$, Arithmetic $(*)^2$, Logical (>=), Focal (Mean,7,7), & Conditional
8	Arithmetic $(+)^3$, Arithmetic $(*)^2$, Logical (>=), Focal (Mean,7,7), & Conditional
9	Arithmetic $(+)^3$, Arithmetic $(*)^2$, Logical (>=), Focal (Mean,7,7), Conditional, & Convolution (Sum,5,5)
10	Arithmetic $(+)^3$, Arithmetic $(*)^3$, Logical (>=), Focal (Mean,7,7), Conditional, & Convolution(Sum,5,5)
11	Arithmetic $(+)^3$, Arithmetic $(*)^3$, Logical (>=), Focal (Mean,7,7), Conditional, Convolution(Sum,5,5), & Summary(∑)
12	Arithmetic $(+)^4$, Arithmetic $(*)^3$, Logical (>=), Focal (Mean,7,7), Conditional, Convolution(Sum,5,5), & Summary(∑)

Results

FM significantly reduced both processing time and storage space when compared to CM (Figures 2 and 3). To perform all six simulations FM took 26.13 minutes and a total of 13,299.09 megabytes while CM took 73.15 minutes and 85,098.27 megabytes. Theoretically, processing time and storage space associated with creating raster data for a given model, computer configuration, set of operations, and data type should be a linear function of the total number of cells within a rater dataset and the total number of operations within the model:

$$\text{Time}_i \text{ (seconds)} = \beta_i(\text{cells x operations})_i$$

$$\text{Space}_i \text{ (megabytes)} = \beta_i(\text{cells})_i$$

where i denotes the technique, either FM or CM in this case. Our empirically derived FM Time and Space models nicely fit the linear paradigm (R^2=0.96 and 0.99, respectively). However, for the CM techniques the model for Time (R^2=0.91) deviated slightly and the model for Space (R^2=0.10) deviated significantly from theoretical distributions, indicating that in addition to the modeling operations, extra operations occurred to facilitate raster processing and that some of those operations produced intermediate raster datasets.

FM and CM time equation coefficients indicate that, on average, FM reduced processing time by approximately 286%. Model fit for FM and CM space equations varied greatly between techniques and could not reliably be compared in the same manner. For the CM methodology, storage space appeared to vary depending on the types of operations within the model and often decreased well after the creation of the final dataset because of delayed removal of intermediate datasets. Overall though, FM reduced total storage space by 640% when compared to the CM.

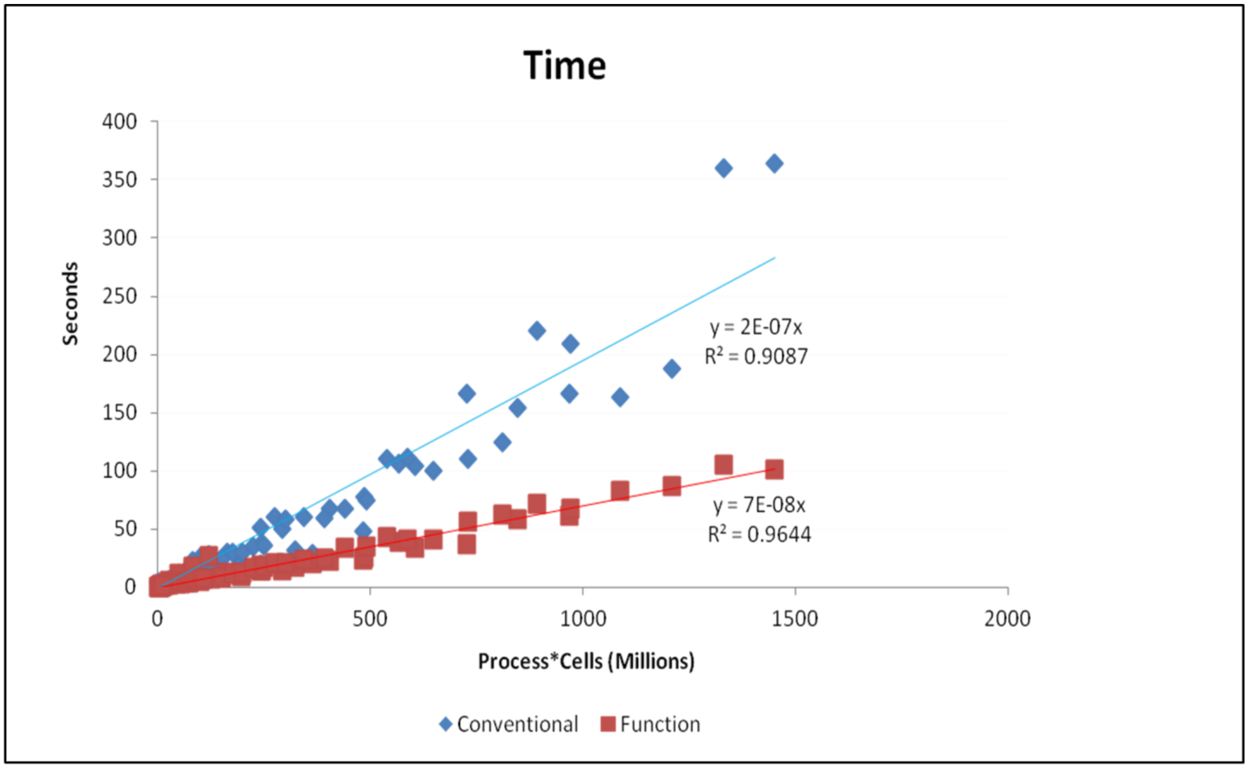


Figure 2. Function Modeling and conventional modeling regression results for processing time.

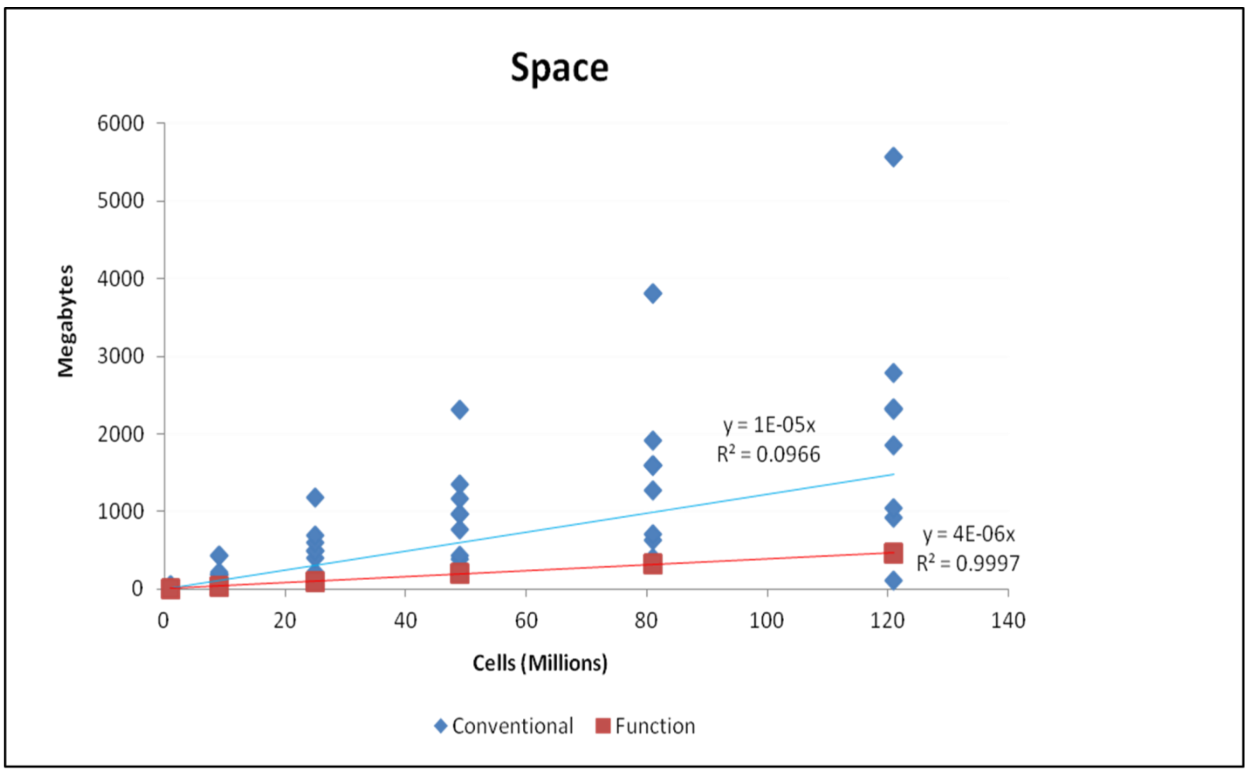


Figure 3. Function Modeling and conventional modeling regression results for storage space

Discussion

CM typically creates intermediate raster datasets. As a model becomes more complex, the number of intermediate datasets increases, which significantly increases the amount of processing time and storage space required to run a model. FM does not create intermediate datasets and significantly decreases model processing time and storage space. In this study we compared FM to CM methodologies by creating final raster outputs from multiple, incrementally complex models. However, FM does not need to create permanent raster datasets. Instead, all functions occurring to source raster datasets can be stored and used in a dynamic fashion to display, visualize, symbolize, retrieve, and manipulate function datasets at a small fraction of the time and space it takes to create a final raster output. For example, if we were to perform the same six simulations presented here but replace the requirement of creating a final output raster dataset with creating a function modeling dataset, FM would take less than 1 second and would require less than 50 kilobytes of storage to finish the simulations.

To facilitate the use of FM we created a user-friendly ESRI toolbar (Figure 4) that provides quick access to a wide array of spatial analyses, while allowing users to easily store and retrieve FM models (RMRS Raster Utility 2012). Moreover, FM models can be loaded into ArcMap as a function raster dataset that can be used interchangeably with all ESRI raster spatial operations. While function modeling is extremely efficient and uses almost no storage space, there may be circumstances when one might want to combine the idea of FM with creating intermediate raster datasets. For example, if the same FM model is used multiple times to create a new raster dataset and the associated time it takes to calculate each operation within that original FM model is greater than the combined read and write time of creating an intermediate raster datasets, then it would be advantageous to create an intermediate dataset. Nonetheless, results from this study demonstrate that raster modeling does not require the creation of intermediate datasets and FM substantially reduces processing time and digital storage. Though straightforward in concept, our work represents the first time the two methodologies have been empirically compared and our publicly available toolbar effectively operationalizes the concepts of FM.

Figure 4. RMRS Raster Utility toolbar is a free, public source, object oriented library packaged as an ESRI add-in that simplifies data acquisition, raster sampling, and statistical and spatial modeling while reducing the processing time and storage space associated with raster analysis. To find out more about the project please visit our website (http://www.fs.fed.us/rm/raster-utility/).

References

ESRI. 2010. ArcGIS Desktop Help 10.0 – Rasters with functions. Available online at http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#/Rasters_with_functions/009t0000000m000000; last accessed Sept. 4, 2012.

Patenaude, G., R. Milne, and T.P. Dawson. 2005. Synthesis of remote sensing approaches for forest carbon estimation Reporting to the Kyoto Protocol. *Environmental Science and Policy* 8(2): 161–178.

Reynolds-Hogland, M., M. Mitchell, R. Powell. 2006. Spatio-temporal availability of soft mast in clearcuts in the Southern Appalachians. *Forest Ecology and Management* 237(1–3): 103-114.

USFS. 2012. RMRS Raster Utility. Available online at http://www.fs.fed.us/rm/raster-utility; last accessed Sept. 4, 2012.

Long-Term Biomass Harvesting Effects on Forest Productivity under Three Silvicultural Systems in the Northern Rocky Mountains

Woongsoon Jang[1], Christopher. R. Keyes[1], Thomas E. Perry[1]

Abstract

Recent rising public concerns about climate change and increasing energy costs have led to the need to re-evaluate forest biomass as an alternative energy feedstock. Biomass harvesting could potentially impact ecosystems in various ways, including site productivity and forest stand dynamics. Since these issues influence decision-making, the effects of biomass utilization are primary issues not only for silviculturists but also forest engineers. Yet our understanding of long-term effects of biomass removal remains limited. Better understanding is needed of the effects of biomass utilization on forest composition, structure, and productivity. This study revisits a 1974 forest harvest and biomass utilization research program in mixed-conifer stands at Coram Experimental Forest in northwestern Montana. Four harvest utilization standards (combined with prescribed burning treatment) were established with two replications under three harvesting systems (shelterwood, clearcut and group selection) via a running skyline yarder. This study will examine the consequences of biomass utilization and harvesting system on 1) the physiological productivity of individual trees, 2) stand productivity, 3) vegetation structure and composition, and 4) regeneration dynamics. In combination with a related study of soil responses, this study will provide a comprehensive understanding of the effects of biomass utilization and harvesting treatments on above-ground and below-ground forest condition and productivity.

Introduction

Recent rising public concerns about climate change and increasing energy costs have spurred public attention to an alternative energy feedstock – using forest biomass (Guo et al. 2007; Janowiak and Webster 2010). Estimates suggest that forest biomass has the potential to supply up to 10% of America's current level of fossil fuel consumption (Perlack et al. 2005). For this reason, the US government seeks to boost the utilization of forest biomass (e.g. Energy Policy Act of 2005, Energy Independence and Security Act (EISA) of 2007).

According to EISA, biofuel production should be increased five times within the next 15 years, and 60% of biofuel should be derived from cellulosic feedstocks. There are many advantages to using forest biomass as an energy feedstock: 1) reduction of greenhouse gas emissions, 2) benefits for local economy, 3) reduction of energy costs,

[1] Applied Forest Management Program, University of Montana

4) reduction of emissions from burning treatments, 5) mitigation of dependency on energy feedstock imports, and 6) recycling of waste materials (Farr and Atkins 2010). With these advantages, it seems inevitable that future demands of forest biomass as a feedstock alternative will increase.

The responses of forest land management activities to meet future potential demands were summarized by Janowiak and Webster (2010) in three general ways. First, previously unmanaged, mismanaged, or underused stands (due to their low-market values) will be managed more aggressively. Second, on currently managed forest, biomass harvest intensity will be increased through increased residue removal. Lastly, more stands will be managed for the crops of short rotation. Among those alternatives, the second is most likely to be realized immediately due to its feasibility. Thus, future demands will likely lead to a more intensive utilization of forest residual materials.

Providing an alternative energy source must be balanced against maintaining ecosystem function and service. Forest residues are known to play an important role with crucial ecological functions forming structural features of forest ecosystem (Harmon et al. 2004). Many studies have addressed the importance of residues for various ecological functions, such as provision of soil organic matter, influence on nutrient cycling and hydrology, and wildlife habitat composition (Reijnders 2006; Patton-Mallory 2008). The long-term effect of intensive biomass removal on a forest ecosystem and its productivity should be a primary consideration among forest managers.

Impacts of biomass harvesting on soil/forest productivity

Biomass removal treatments affect ecosystems in various ways, with effects on microclimate, soil and forest productivity, hydrology, vegetation, biodiversity, and wildlife habitat (Reinhardt et al. 2010). Although some of these issues are beyond the scope of this study, these properties and processes are closely related and interact with each other.

Soil productivity – Timber harvesting and related management activities can enhance the soil microclimate. In Western Montana, Hungerford (1980) and Hungerford and Babbitt (1987) reported that exposed mineral soils or remnant substrates after management activities can increase the soil temperature, stimulating tree growth by enhancement of the root membranes' permeability (Burger 2002). In addition, reduced solar radiation on the forest floor due to the generation of forest residues can adjust the water balance favorably. Since management practice can enhance the balance between water and air to improve root respiration, water uptake, and nutrient uptake (Burger 2002), biomass utilization might induce positive effects on productivity.

However, negative effects of biomass harvest on forest productivity are relatively well documented. These can include: soil compaction, depletion of organic matter and nutrients, and obstruction of microbial functions.

Most negative impacts of harvesting practice on soil physical properties are likely caused by soil compaction, especially from ground-based equipment. The greater removal of biomass requires more machinery use in general, resulting in increased soil compaction (Janowiak and Webster 2010). Compaction reduces soil porosity, hindering the movement of air, water, and nutrients needed for microbial activity (Thibodeau et al. 2000). Decrease of microbial activity in soil can consequently reduce the tree growth (Page-Dumroese et al. 2010).

In addition, intensified biomass removal may remove a larger amount of soil carbon and forest floor organic matter (Janowiak and Webster 2010). Loss of organic matter can negatively impact soil moisture retention, cation exchange capacity, and, as a result, tree growth (Ballard and Will 1981). Therefore, a reduction of soil organic matter and change in soil physical properties could have even greater consequences for site productivity than simply the removal of soil nutrients (Page-Dumroese et al. 2010).

Many studies have demonstrated the potential negative impact of intensive biomass removal on soil nutrient contents (e.g. White 1974; Kimmins 1977). Compared to conventional harvesting, intensive biomass utilization involves removal of additional materials. The problem is that these materials – such as branches and foliage – have much higher nutrient concentrations. Many scientists have argued that intensive biomass removal increases the risk of soil nutrient depletion such as N (Johnson and Curtis 2001), P, K (White 1974) and Ca (Boyle et al. 1973; Mann et al. 1988).

Stand manipulation can control microbial functions (Larsen et al. 1980). Mahmood et al. (1999) argued that there was a strong biomass removal effect on the quantity and development of ectomycorrhizae in Norway spruce forest in Sweden. They detected a significant decrease in ectomycorrhizal roots and humus layer thickness resulting from residue harvesting. Since the development of ectomycorrhizal roots is critically related to forest productivity in western forests (Harvey et al. 1980; Perry et al. 1989), the impact of biomass removal on microbial activity is an important determinant of site productivity. Larsen et al. (1980), for example, argued that decaying residues could mitigate water stress by increasing the pore volume of the woody substrate in northern Rocky Mountain forests. In contrast, biomass removal from the forest floor could lower moisture levels, leading to a decline in nitrogen fixation by soil bacteria.

Forest productivity & vegetation dynamics – The negative effects of biomass removal on soil productivity have the potential to be manifested in reduced tree growth. Simulation modeling approaches have shown that intensive biomass utilization is capable of depleting the nutrient budget to the extent that long-term productivity decline results (e.g. Boyle et al. 1973; Paré et al. 2002). Empirical evidence has also been found suggesting that nutrition deficiency induced by intensive biomass utilization leads to reduced tree growth. In Europe, whole-tree harvest resulted in tree growth reduction for Scots pine (Egnell and Leijon 1999; Egnell and Valinger 2003) and Sitka spruce (Walmsley et al. 2009; Proe et al. 1996).

However, increased biomass utilization does not always cause a reduction of above-ground biomass increment. There was no effect of biomass removal on Scot pine growth in 22 yrs after whole-tree harvest in eastern Finland (Saarsalmi et al. 2010). Power et al. (2005) failed to find any significant relationship among biomass utilization treatments, soil nutrient contents, and above-ground biomass in a summary of 26 experimental sites across North America after 10 years harvest. Thus, the controversy over above ground productivity is still in progress.

Biomass utilization treatments can influence understory vegetation dynamics. In Sweden, Bråkenhielm and Liu (1998) found differences in understory vegetation species composition, dominance, species richness, and diversity when logging residues were retained versus removed. Schmidt (1980) and Fahey et al. (1991) reported differences in shrub recovery associated with combinations of biomass utilization level in the northern Rocky Mountains and in Wales, respectively.

Regeneration can be affected by the biomass utilization level as well as the harvesting system. In Washington, the height and diameter growth of 2-year-old Douglas-fir decreased with increasing biomass utilization levels, especially at low productivity sites (Bigger and Cole 1983). In the northern Rocky Mountains, Shearer and Schmidt (1999) observed the least natural regeneration at the intermediate biomass utilization level treatment (combined with no-burn treatment) 15-20 yrs following harvest. In the southern United States, 5-yr-old loblolly pine seedlings showed an 18 percent reduction in volume growth in a whole-tree harvest treatment (Scott et al. 2004).

Our understanding of the long-term effects of biomass removal remains limited. Many studies (e.g. nutrient budget analysis, modeling approach) on this topic have yielded uncertainty thus far (Mann et al. 1988; Egnell and Valinger 2003), since biotic and abiotic factors change and interact intricately after harvest. Instead, studies have demonstrated the necessity of long-term field experiments (Egnell and Leijon 1999; Egnell and Valinger 2003). Long-term assessment is critical in order to thoroughly understand complex changes in ecosystem function and structure (Likens 2004), but conducting and maintaining such experiments is often infeasible, expensive, and impractically time- and resource-consuming (Reinhardt et al. 2010). Although the subject is tangentially addressed by several long-term research networks – such as the North American Long-Term Soil Productivity (LTSP; for detail see Powers 2006; Page-Dumroese et al. 2006) and Long Term Ecological Research (LTER) – studies specifically focusing on biomass harvesting are insufficient, or are too young to draw long-term inferences.

1974 Forest Residues Utilization Research and Development Program

In the 1970s, there was plenty of interest in increasing biomass utilization from forests. This interest arose from increasing demands for wood material and from concerns over undesirable impacts on ecosystems (Benson and Schlieter, 1980). In the forest manager's point of view, two conflicting needs emerged: 1) improvement of recovery and utilization of wood resources under the minimum residual materials, and 2) reduction of unfavorable esthetic and environmental consequences of management activities (Barger 1980).

To address these concerns, a comprehensive and multidisciplinary research effort, the Forest Residues Utilization Research and Development Program, was established in 1974 at Coram Experimental Forest. Managed by researchers at the US Forest Service's Intermountain Forest and Range Experiment Station, the program was initiated to investigate timber harvesting alternatives and pursue the improved intensity and environmental compatibility of timber utilization.

The regeneration harvests of three silvicultural systems (shelterwood, clearcut, and group selection) were performed, and four utilization treatments ranging from conventional saw log utilization to near-complete utilization were allocated to each harvesting unit. A running skyline yarder was used for harvesting to reduce understory disturbance. Prescribed broadcast burning treatment was included as part of four utilization treatments.

Today, this experimental installation provides a unique and timely opportunity to document the long-term effects of biomass utilization on productivity and regeneration dynamics. In spite of achievements of historical research program, the study's value has not been fully exploited. The publications and reports spawned by the program contain only short-term responses or interim results, and the long-term impacts of biomass utilization level and harvest on ecosystems remain unclear. Since it has been nearly 40 years since treatments were put in place, the site now allows an opportunity to explore the long-term impacts of biomass utilization and harvest on ecosystems. Every block and treatment unit is easily accessed via a well-maintained forest road, and the integrity of treatment units remains largely intact. Coram Experimental Forest's conditions suitably represent upland mixed conifer forests throughout the northern Rocky Mountains (Shearer and Kempf, 1999), thus the inferential value of research based at this site is great.

Research objectives and questions

The primary objective of the present study is to investigate the effects of biomass harvest levels (varying utilization standards combined with post-harvest prescribed burning treatment), when coupled with each of three common silvicultural systems (regeneration harvest methods), on northern Rocky Mountain forest vegetation and productivity. The study spans scales varying from individual tree (Objective 1) to stand (Objective 2), including understory vegetation (Objective 3). Additionally, this study will evaluate whether impacts of biomass utilization can be partially ameliorated (or exacerbated) by the use of artificial regeneration (Objective 4). Each research question and hypothesis is summarized in Table 1.

Table 1. Research questions and hypotheses.

Research Question	Research hypothesis
Do biomass utilization treatments impact the physiological productivity of individual trees?	If biomass utilization treatments influence the physiological productivity of individual (regenerated) trees, then the growth efficiency of individual trees will be different by biomass utilization treatments. If biomass utilization treatments impact the physiological productivity of residual trees in the shelterwood harvesting units, then the growth efficiency (or radial growth) of residual trees will differ by biomass utilization treatments.
Do biomass utilization treatments impact the productivity of the stand?	If there is a relation between biomass utilization treatments and stand productivity, then the total above-ground biomass of the stand following harvest differs by biomass utilization treatment treatments. If the impacts of biomass utilization treatments on productivity vary with stand strata (shrub, seedling, sapling and pole size-tree, and residual tree layer), then the amount of above-ground biomass for each stratum will be different by biomass utilization treatment treatments. If there is an interaction between biomass utilization effects and regeneration harvest method (silvicultural system), then the magnitude of effect on productivity will differ by regeneration harvest method.
Do biomass utilization treatments impact vegetation composition and structure?	If the biomass utilization levels are related to the resulting vegetation composition, then species composition of tree and shrub community will vary with biomass utilization treatments. If biomass utilization levels affect structural complexity of the stand, then structural complexity will differ by biomass utilization treatments.
Can biomass utilization treatment impacts be ameliorated by artificial regeneration?	If planting seedlings can alleviate the negative effect of biomass utilization treatments on regeneration, then planted Douglas-fir trees will exhibit greater biomass accumulation than naturally-regenerated Douglas-fir trees. If planting seedling can alleviate the negative effect of biomass utilization treatments on regeneration, then planted Douglas-fir trees will exhibit greater growth efficiency than naturally regenerated Douglas-fir trees.

Conclusion

Depending upon the specifics of the treatment, intensive biomass utilization appears capable of resulting in a more severe alteration of forest ecosystem function and structure than conventional timber harvesting. If so, then these alterations should be carefully assessed to clearly articulate the tradeoffs between biomass utilization and undesirable effects on forest and soil productivity. However, the current extent of our knowledge is insufficient to predict these effects and their magnitude, if any. The results of this study should provide meaningful information to fill these knowledge gaps and better inform biomass harvesting strategies.

References

Ballard, R., and G.M. Will. 1981. Removal of Logging Waste, Thinning Debris, and Litter From a Pinus radiata Pumice Soil Site. New Zealand journal of forestry science 11(2):152-163.

Barger, R.L. 1980. The forest residues utilization program in brief. P. 7-24 in Environmental consequences of timber harvesting in Rocky Mountain coniferous forests: Symposium proceedings; 1979 September 11-13; Missoula, MT, Gen. Tech. Rep. INT-90. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT.

Benson, R.E., and J.A. Schlieter. 1980. Logging residues in principal forest types of the northern Rocky Mountains. Intermountain Forest and Range Experiment Station. Ogden, Utah. 14 p.

Bigger, C.M., and D.W. Cole. 1983. Effects of harvesting intensity on nutrient losses and future productivity in high and low productivity red alder and Douglas-fir stands. 167-178.

Boyle, J.R., J.J. Phillips, and A.R. Ek. 1973. " Whole tree" harvesting: nutrient budget evaluation. Journal of Forestry 71(12):760-762.

Bråkenhielm, S., and Q. Liu. 1998. Long-term effects of clear-felling on vegetation dynamics and species diversity in a boreal pine forest. Biodiversity and Conservation 7(2):207-220.

Burgur, J.A. 2002. Soil and long-term site productiivty values. P. 165-189 in Bioenergy from Sustainable Forestry: Guiding Principles and Practice, Richardson, J., R. Björheden, P. Hakkila, A.T. Lowe, and C.T. Smith (eds.). Kluwer Academic Publishers, Dordrecht.

Egnell, G., and B. Leijon. 1999. Survival and Growth of Planted Seedlings of Pinus sylvestris and Picea abies After Different Levels of Biomass Removal in Clear-felling. Scandinavian Journal of Forest Research 14(4):303-311.

Egnell, G., and E. Valinger. 2003. Survival, growth, and growth allocation of planted Scots pine trees after different levels of biomass removal in clear-felling. Forest Ecology and Management 177(1):65-74.

Fahey, T., M. Hill, P. Stevens, M. Hornung, and P. Rowland. 1991. Nutrient accumulation in vegetation following conventional and whole-tree harvest of Sitka spruce plantations in North Wales. Forestry 64(3):271-288.

Farr, A.K., and D. Atkins. 2010. Fuel Supply Planning for Small-Scale Biomass Heating Systems. Western Journal of Applied Forestry 25(1):18-21.

Guo, Z., C. Sun, and D. Grebner. 2007. Utilization of forest derived biomass for energy production in the USA: status, challenges, and public policies. International Forestry Review 9(3):748-758.

Harmon, M.E., J.F. Franklin, F.J. Swanson, P. Sollins, S.V. Gregory, J.D. Lattin, N.H. Anderson, S.P. Cline, N.G. Aumen, J.R. Sedell, G.W. Lienkaemper, K. Cromack Jr, and K.W. Cummins. 2004. Ecology of Coarse Woody Debris in Temperate Ecosystems. P. 59-234 in Advances in Ecological Research, Caswell, H. (ed.). Academic Press.

Harvey, A.E., M.F. Jurgensen, and M.J. Larsen. 1980. Clearcut harvesting and ectomycorrhizae: survival of activity on residual roots and influence on a bordering forest stand in Western Montana. Canadian Journal of Forest Research 10(3):300-303.

Hungerford, R.D. 1980. Microenvironmental response to harvesting and residue management. P. 37-73 in USDA Forest Service. Environmental consequences of timber harvesting in Rocky Mountain coniferous forests: Symposium proceedings; 1979 September 11-13; Missoula, MT. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT.

Hungerford, R.D., and R.E. Babbitt. 1987. Overstory removal and residue treatments affect soil surface, air, and soil temperature: implications for seedling survival. Res. Pap. INT-377. U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 19 p.

Janowiak, M.K., and C.R. Webster. 2010. Promoting Ecological Sustainability in Woody Biomass Harvesting. Journal of Forestry 108(1):16-23.

Johnson, D.W., and P.S. Curtis. 2001. Effects of forest management on soil C and N storage: meta analysis. Forest Ecology and Management 140(2):227-238.

Kelliher, F.M., D. Whitehead, K.J. McAneney, and M.J. Judd. 1990. Partitioning evapotranspiration into tree and understorey components in two young pinus radiata D. Don stands. Agricultural and Forest Meteorology 50(3):211-227.

Kimmins, J.P. 1977. Evaluation of the consequences for future tree productivity of the loss of nutrients in whole-tree harvesting. Forest Ecology and Management 1(0):169-183.

Larsen, M.J., A.E. Harvey, and M.F. Jurgensen. 1980. Residue decay processes and associated environmental functions in northern Rocky Mountain forests. P. 157-174 in USDA Forest Service. Environmental consequences of timber harvesting in Rocky Mountain coniferous forests: Symposium proceedings; 1979 September 11-13; Missoula, MT. Gen. Tech. Rep. INT-90. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT.

Likens, G.E. 2004. Some perspectives on long-term biogeochemical research from the hubbard brook ecosystem study. Ecology 85(9):2355-2362.

Mahmood, S., R.D. Finlay, and S. Erland. 1999. Effects of repeated harvesting of forest residues on the ectomycorrhizal community in a Swedish spruce forest. New Phytologist 142(3):577-585.

Mann, L., D. Johnson, D. West, D. Cole, J. Hornbeck, C. Martin, H. Riekerk, C. Smith, W. Swank, and L. Tritton. 1988. Effects of whole-tree and stem-only clearcutting on postharvest hydrologic losses, nutrient capital, and regrowth. Forest Science 34(2):412-428.

Page-Dumroese, D.S., M. Jurgensen, and T. Terry. 2010. Maintaining soil productivity during forest or biomass-to-energy thinning harvests in the western United States. Western Journal of Applied Forestry 25(1):5-11.

Page-Dumroese, D.S., M.F. Jurgensen, A.E. Tiarks, J. Ponder, Felix, F.G. Sanchez, R.L. Fleming, J.M. Kranabetter, R.F. Powers, D.M. Stone, and J.D. Elioff. 2006. Soil physical property changes at the North American Long-Term Soil Productivity study sites: 1 and 5 years after compaction. Canadian Journal of Forest Research 36(3):551-564.

Paré, D., P. Rochon, and S. Brais. 2002. Assessing the geochemical balance of managed boreal forests. Ecological Indicators 1(4):293-311.

Patton-Mallory, M., ed,. 2008. Forest Service, U.S. Department of Agriculture woody biomass utilization strategy. Washington, DC: U.S. Department of Agriculture, Forest Service. 17 p.

Perlack, R.D., L.L. Wright, A.F. Turhollow, R.L. Graham, B.J. Stokes, and D.C. Erbach. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. Oak Ridge National Lab. 72 p.

Perry, D., H. Margolis, C. Choquette, R. Molina, and J. Trappe. 1989. Ectomycorrhizal mediation of competition between coniferous tree species. New Phytologist:501-511.

Powers, R.F., D. Andrew Scott, F.G. Sanchez, R.A. Voldseth, D. Page-Dumroese, J.D. Elioff, and D.M. Stone. 2005. The North American long-term soil productivity experiment: findings from the first decade of research. Forest Ecology and Management 220(1):31-50.

Proe, M., A. Cameron, J. Dutch, and X. Christodoulou. 1996. The effect of whole-tree harvesting on the growth of second rotation Sitka spruce. Forestry 69(4):389-401.

Reijnders, L. 2006. Conditions for the sustainability of biomass based fuel use. Energy policy 34(7):863-876.

Reinhardt, E.D., L. Holsinger, and R. Keane. 2010. Effects of biomass removal treatments on stand-level fire characteristics in major forest types of the northern Rocky Mountains. Western Journal of Applied Forestry 25(1):34-41.

Saarsalmi, A., P. Tamminen, M. Kukkola, and R. Hautajärvi. 2010. Whole-tree harvesting at clear-felling: Impact on soil chemistry, needle nutrient concentrations and growth of Scots pine. Scandinavian Journal of Forest Research 25(2):148-156.

Schmidt, W.C. 1980. Undersotry vegetation response to harvesting and residue management in a larch/fir forest. P. 221-248 in Environmental consequences of timber harvesting in rocky mountain coniferous forests. USDA Forest Service Gen. Tech. Rep. INT-90. Intermountain Forest and Range Experiment Station.

Scott, D.A., A.E. Tiarks, F.G. Sanchez, M. Elliott-Smith, and R. Stagg. 2004. Forest soil productivity on the southern long-term soil productivity sites at age 5. in Proceedings of the 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–71. Asheville, NC: US Department of Agriculture, Forest Service, Southern Research Station.

Shearer, R.C., and M.M. Kempf. 1999. Coram Experimental Forest: 50 years of research in a western larch forest. United States Department of Agriculture, Forest Service, Rocky Mountain Research Station. 66 p.

Shearer, R.C., and J.A. Schmidt. 1999. Natural regeneration after harvest and residue treatment in a mixed conifer forest of northwestern Montana. Canadian Journal of Forest Research 29(2):274-279.

Thibodeau, L., P. Raymond, C. Camiré, and A.D. Munson. 2000. Impact of precommercial thinning in balsam fir stands on soil nitrogen dynamics, microbial biomass, decomposition, and foliar nutrition. Canadian Journal of Forest Research 30(2):229-238.

Walmsley, J.D., D.L. Jones, B. Reynolds, M.H. Price, and J.R. Healey. 2009. Whole tree harvesting can reduce second rotation forest productivity. Forest Ecology and Management 257(3):1104-1111.

White, E.H. 1974. Whole-tree harvesting depletes soil nutrients. Canadian Journal of Forest Research 4(4):530-535.

Application of carriage-mounted agricultural cameras to improve safety in cable logging operations

Robert Keefe[1] and Jan Eitel[2]

Abstract

A large number of logging safety accidents in cable operations occur as a result of poor visibility between yarder operators and individuals in the brush. Industrial safety campaigns, such as Weyerhaeuser Corporation's 'in-the-clear' messaging, help to improve safety. However, reliance on audio communication with audio signals as the primary method for communications to ensure safety when the yarding of logs commences has some safety shortcomings that could potentially be improved upon. For example, if the yarder operator receives a signal to commence yarding when a choker setter has not yet moved fully into the clear, there is no back-up safety system to confirm the audio command.

Recently, carriage-mounted agricultural cameras have been used to guide the acquisition of sawlogs by remote grapple carriages, such as the Eagle Yoder Claw Grapple and Eagle Mega Claw Line. A small agricultural camera is mounted on these carriage models. The grapple is operated remotely from the cab by the operator, who has a bird's eye view of the area below the carriage on a 9 inch screen that is mounted in the cab. In this study, we are evaluating the potential use of inexpensive agricultural cameras and screens as a back-up, secondary safety measure in cable logging communications. We affixed an agricultural camera to a carriage on a Koller 300 series yarder used on the University of Idaho Experimental Forest, and also on a small, trailer-mounted mini-yarder. A designed experiment was conducted to evaluate the effects of image filtering methods, harvest type, and camera field of view on image contrast and visibility. Our objective was to determine whether a combination of remote sensing image filtering techniques could be used to clearly identify choker setters with very high contrast under a range of light and background conditions. Results of the preliminary experiment are reported and a larger operational pilot study is described.

Introduction

[1] Assistant Professor of Forest Operations, Dept. of Forest, Rangeland, and Fire Sciences, University of Idaho, Moscow, ID, 83844-1133

[2] Research Assistant Professor, Dept. of Forest, Rangeland, and Fire Sciences, University of Idaho, Moscow, ID, 83844-1133

A number of inexpensive video cameras marketed alternatively as agricultural, security, trailer, and vehicle backup cameras have recently become available. These cameras are popular in various agricultural applications because of the high quality video they provide at limited cost (typically <$400). Increasingly, agricultural cameras are also showing up on logging equipment, where they provide increased visibility in blindspots for loaders, feller-bunchers, and other equipment. Depending on the desired application, inexpensive video cameras are available in closed circuit and wireless models. Some models exist that transmit directly to a screen, requiring a separate battery connection both for the camera and screen. Various, small battery-powered video cameras with field mounts designed for extreme sports (e.g. GoPro, Contour) are also readily available, and several of these have the capacity to transmit via cell signal when cellular coverage is available.

At least two models of grapple carriages, the Eagle Yoder Claw Grapple and Eagle Mega Claw Line, now make use of agricultural cameras for operation. With these carriages, a yoder operator is able to watch a screen in an enclosed cab that feeds directly from a camera mounted vertically below the carriage. This perspective facilitates rotating and positioning the grapple correctly to collect logs down the hillside, independently of whether the operator has a direct line of site.

Many cable yarding injuries and fatalities occur in the brush, when choker setters are struck by rolling are swinging logs during yarding. The Washington FACE program reported seven fatalities associated with loggers being struck by logs over the five year period between 1998 and 2003 (Washington FACE, 2004). Technological advancements such as use of remote-controlled chokers, synthetic rope (Pilkerton et al. 2001) and increased safety campaigns have the potential to reduce cable logging accidents. However, the use of agricultural cameras coupled with carriages as a supplemental safety precaution has not previously been investigated.

In this preliminary study, which will guide a larger field trial in 2013-2014, I conducted a preliminary experiment to evaluate methods for creating high contrast imagery of the area below the skyline carriage. My hope was to develop a method by which a high level of contrast could be created on an onboard screen, in order to increase visibility of a ground worker below the skyline being viewed through a carriage-mounted video camera.

Methods

Several factors potentially affect the ability of agricultural cameras to provide clear, high contrast images for yarder operators to utilize for safety purposes. To begin the process of determining the relative importance of these factors prior to an operational study with full size yarders, a factorial experiment was conducted with small machines to evaluate the relative importance of image filtering methods, stand density, and worker position on visibility and detection in video capture images.

For the preliminary study, two small yarders were used to collect carriage videography. The first was a Koller 300 series yarder mounted on the 3 Point Hitch of a 70 HP Valtra 700 farm tractor modified for woods use. The second was a small, 8 HP custom built trailer-mounted mini-yarder used primarily for research and teaching purposes. The skyline for the Koller was extended approximately 900 feet across a stream and secondary forest road on the University of Idaho Blodgett Outdoor Classroom. The mini-yarder skyline was extended 600 feet across a draw on the West Hatter Creek Unit of the University of Idaho Experimental Forest. Average slope was 43%. Height of the skyline at the measurement point for the Koller 300 was 35 ft. Height for the mini-yarder was 20 feet.

The factor treatment levels for the experiment were as follows:

Worker position	**Image filter**	**Harvest type**
Below skyline	Red band only	Partial
25 % from center	Red, green, blue	Clearcut w/ reserves

All images were captured using digital video as a camera passed over a worker stationed either directly beneath the skyline corridor centerline or at a 25% angle from the center, measured from the camera in a horizontal direction perpendicular (lateral) to the corridor. Three separate video passes, treated as replicates, were recorded for each treatment combination. Image contrast was quantified using the histogram spread (HS) metric proposed by Tripathi et al. (2011):

$$HS = \frac{Interquartile\ range\ (IQR)}{Potential\ range}$$

Where the interquartile range is based on the actual image histogram pixel values observed (75 % - 25 %), and the potential range is the minimum minus the maximum values that any pixel can take on. Image filtering was carried out with Multispec software. Histogram measurements were conducted with the Gnu Image Manipulation Program.

Results

In preliminary image processing, filtering images to show only the red color band appeared to create a high level of contrast for conventional high-visibility orange safety vests used commonly in forest operations (Figure 1).

Figure 1: High visibility safety vest with no filtering (left), and with a red band filter applied (right).

However, in the replicated field experiment, the amount of vegetation present (harvest type) also affected contrast, in addition to filtering method. Imagery collected in partial harvests had higher contrast than imagery collected in clearcut with reserve treatments. Both factors significantly affected image contrast (Table 1).

	DF	SS	MS	F	Pr(>F)
Treatment	1	0.0076	0.0076	6.2472	0.0213
Angle	1	0.0005	0.0005	0.4422	0.5136
Filter	1	0.0073	0.0073	6.0201	0.0234
Residuals	20	0.0244	0.0012		

Table 1: ANOVA table indicating the factors affecting image contrast.

In all analysis, field of view had no significant effect on the level of image contrast observed; contrast was equal when the worker was directly below the center of the skyline corridor, or positioned laterally at 25% of cable height.

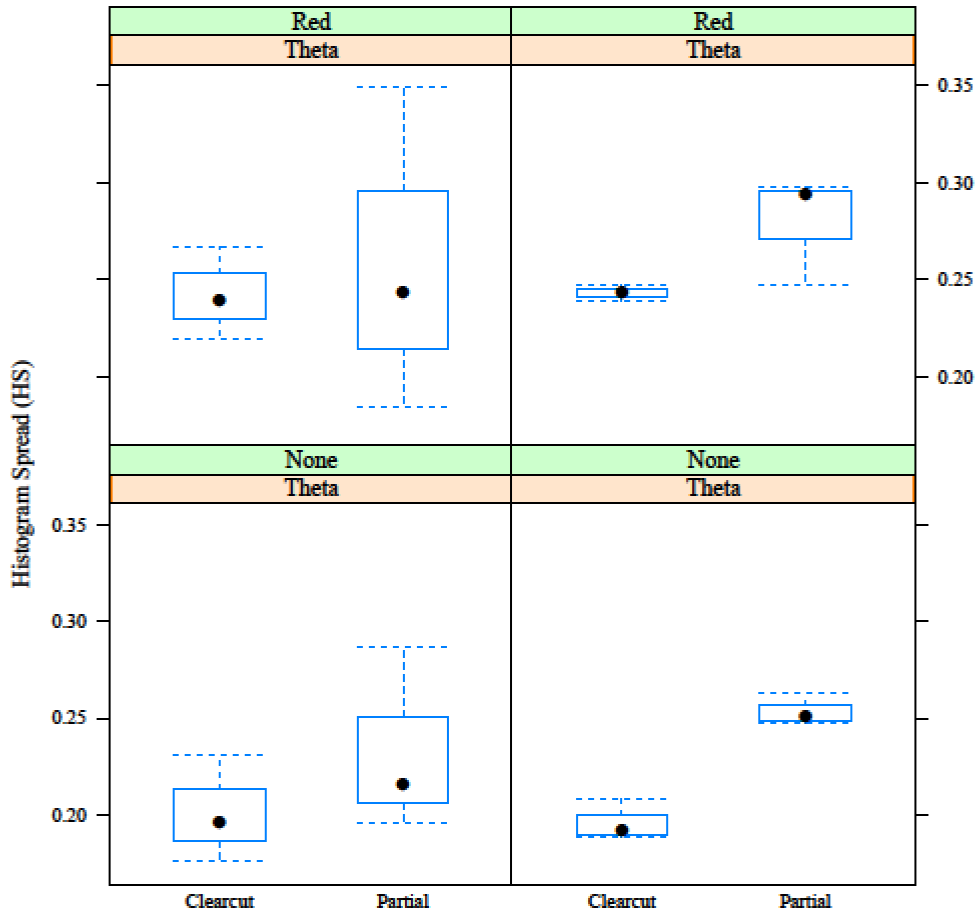


Figure 2: Level of image contrast, measured as histogram spread (HS) for all treatment combinations.

Discussion

Our assumption in designing this preliminary study was that deploying methods to maximize image contrast, quantitatively, would produce the most highly visible screen viewing environment for detection of individuals working unsafely below the skyline. However, practical analysis of the imagery collected showed that non-filtered imagery including all R,G,B bands was more useful than red band filter imagery in partial harvests. Although filtering only the red band produced greater image contrast based on histogram spread, the resulting whitening of orange safety vests made it difficult to distinguish the worker from residual overstory vegetation. In partial harvests, full color imagery showing the hi-visibility orange safety vests and yellow safety hard hat worn in the trials made it easier to quickly identify workers within the field of view of the carriage.

Further research to evaluate the potential use of agricultural cameras to improve safety in cable operations is needed before any operational use should be considered. In 2013-2014, a field study is being conducted that will evaluate use of wireless cameras mounted on carriages in active operations, including collecting perceptions from loggers. This preliminary image analysis study suggests that factors to be considered in the larger, operational study should focus primarily on high visibility safety helmets and vests coupled with color cameras and viewing screens, rather than partial color image filtering to increase contrast.

References

Gnu Image Manipulation Program Documentation Team (2009). GIMP User Manual: GNU Image Manipulation Program Photo Retouching, Image Composition and Image Authoring. Create Space, Paramount, CA. 656 p.

Pilkerton, S. J., Garland, J.J., Sessions, J., and B. Stringham (2001). Prospects for Using Synthetic Rope in Logging: First Look and Future Research. p. 37-47.The International Mountain Logging and 11th Pacific Northwest Skyline Symposium.

Tripathi, A. K., Mukhopadhyay, S., and Dhara, A. K. (2011). Performance metrics for image contrast. IEEE 2011 International Conference on Image Information Processing (ICIIP 2011). 4 pp.

Washington Fatality Assessment and Control Evaluation (FACE) Program (2004). Logging-Related Fatalities, 1998-2003

WorkSafeBC. (2006). Cable Yarding Systems Handbook. ISSN 1712-5871. Workers Compensation Board of British Columbia. 204 pp.

Impact assessment of tree spacing on crown fire spread distance for Korean pine stands using a fire simulator

Dong-Wook Kim[1], Woodam Chung[1], Russell A. Parsons[2], and Byungdoo Lee[3]

Abstract

There is a recognized need to apply fuel reduction thinning to the existing young growth pine stands in Korea to reduce catastrophic forest fires. However, thinning guidelines, such as the intensity of thinning treatments or optimal stand density, have not been well established for individual forest stands. In an attempt to identify effective thinning guidelines, we evaluated the effects of different tree spacing on crown fire propagation by simulating fire spread across individual trees using the Wildland-urban interface Fire Dynamics Simulator (WFDS), a physics-based fire spread and behavior model. The results indicate that tree spacing significantly affects the size and intensity of crown fires when all other factors are held constant. Tree spacing that is large enough to remove crown overlaps between neighboring trees appears to be highly effective in reducing crown fire propagation in our simulation.

Introduction

Forest fire is known as one of the most destructive natural disturbances for forest ecosystems, as well as a threat to the lives and property of people living in the forest interface (Conard and A. Ivanova 1997). There is a recognized need to apply fuel treatments, such as fuel reduction thinning, to alter fire behavior and thus reduce catastrophic forest fires (Pollet and Omi 2002, Agee and Skinner 2005, Prichard et al 2010). However, thinning guidelines, such as the intensity of thinning treatments or optimal stand density, have not been well established. Science-based, yet field applicable thinning guidelines would be necessary to maximize the effects of thinning treatments on reducing fire risks. It would be a worthy attempt to evaluate different thinning intensities for their effects on changing fire behavior for the purpose of identifying general thinning guidelines under diverse fuels, ground, and weather conditions.

Over 25% of the total land area in Korea is covered by coniferous forest; about half of which are pine-dominant stands (Korea Forest Service 2011). Pine trees (*Pinus Densiflora*) in Korea are well-known as highly flammable tree species due to their physical and chemical properties (Kim et al. 2011). Their needles contain terpene, a flammable chemical, and their crown shapes and structure make it easy to initiate and propagate crown fires (Ormeño et al 2009). Most pine stands in Korea are currently between 30 and 50 years old with relatively high tree density due to lack of thinning since planted; the average stand density is over 1,000 trees per hectare. Large historic fires occurred in pine stands include the notorious Yangyang fire in 2005 which burned

[1] Department of Forest Management, The University of Montana, 32 Campus Drive, Missoula, MT 59812, USA.
[2] US Forest Service, Fire Sciences Laboratory, 5775 US Hwy 10 W, Missoula, MT 59808, USA.
[3] Korea Forest Research Institute, 57, Hoegiro, dongdaemun-gu, Seoul, 130-712, Korea.

a historic temple site (Korea forest service 2011). Reducing fire risks through proper thinning operations particularly in pine stands has become a priority in forest management in Korea.

In this study, the Wildland-urban interface Fire Dynamics Simulator (WFDS) is used to simulate crown fire propagation between individual trees across a forest stand. WFDS is an extension to Fire Dynamics Simulator (FDS) developed by the National Institute of Standards and Technology (NIST). WFDS is a physics-based model that was designed based on fluid dynamics, combustion, and heat transfer; thus, it is able to predict more detailed fire behavior in a fine scale considering interactions among fire, fuel, and atmosphere (Mell et al 2005). Since WFDS is a three-dimensional model, the predicted fire behavior can be realistically depicted by the *Smokeview* program also developed by NIST to visualize the simulated results of WFDS (McGrattan et al 2008). One of the known limitations of using WFDS is the large amount of data and computation time required to represent fine scale fire behavior (Mell et al 2007).

As the importance of stand density in fire management, especially in reducing crown fire risks, has been widely recognized (Roloff et al 2005, Alvarez et al 2012, Contreras et al 2012), we consider tree spacing representing stand density as an important thinning guideline in this study. The objective of this study, therefore, is to evaluate the effects of thinning treatments at different tree spacing on crown fire propagation by simulating crown fire propagation across individual trees using WFDS.

Input Data

Fire simulation at an individual tree-level using WFDS requires individual tree characteristics including physical properties and crown fuels (Table 1), surface fuels (Table 2), simulation domain (i.e., imaginary forest stands) (Figure 1), ignition locations (Table 4), and weather conditions (Table 5).

In order to examine the effects of tree spacing on fire spread across individual trees, we used six different tree spacings while holding the other factors constant. The simulation domain was built as a cube of 125 m length × 110 m width × 160 m height (Figure 1). The imaginary forest stands were assumed to have a 50% ground slope, the average slope of pine stands in Korea. The flat area of 5 m × 110 m in the domain front was used for surface fire ignitions. For the WFDS fire simulation, line-fires were used as fire ignitions and placed in the left edge of the simulation domain (Table 1). April is known as the highest risk month for forest fires in Korea, and thus the weather data of April 2012 were used for the WFDS simulation (Table 5). To consider wind speed reduction within forest stands, an average value of the maximum wind speeds of April 2012 was adjusted by a reduction factor of 0.3 (Rothermel 1983). Since this study was designed to examine crown fire propagations, extremely flammable surface fuels were used to initiate crown fires as quickly as possible (Table 2). Our fire simulations using WFDS were analyzed to quantify the effect of tree spacing on crown fire behavior and propagation in terms of crown fire spread distance.

Table 1. Physical tree attributes and characteristics of crown fuels used in the WFDS fire simulation.

Characteristics of individual trees	
Physical properties	
Height	11 m
Crown base height	6 m
Crown width (bottom)	6 m
Crown width (top)	1 m
Diameter at breast height (DBH)	0.2 m
Crown fuels	
Foliar moisture content	100%
Material density	520 kg m^{-3}
Bulk density	0.252 kg m^{-3}
Surface to volume ratio	4000 m^{-1}
Char fraction	0.25
Drag coefficient	0.375
Max. burning rate	0.4 kg m^{-3} s^{-1}
Max. dehydration rate	0.4 kg m^{-3} s^{-1}
Initial temperature	18.7 ˚C

Table 2. Characteristics of surface fuels used in the WFDS fire simulation.

Surface Fuels	
Foliar moisture content	10%
Material density	514 kg m^{-3}
Bulk density	0.626 kg m^{-3}
Surface to volume ratio	12240 m^{-1}
Char fraction	0.2
Drag coefficient	0.375
Max. Burning Rate	0.4 kg m^{-3} s^{-1}
Max. Dehydration Rate	0.4 kg m^{-3} s^{-1}
Initial temperature	18.7 ˚C

Table 3. #of tree per tree spacing.

Tree spacing (m)	# of tree per imaginary forest stands
3	1,320
4	750
5	500
6	357
7	270
8	208

Table 4. Description of ignition line-fires.

Ignition line-fires	
HRRPUA	148.82 kW/m^2
Residence time	10 s
Ignition area	4 m long × 100 m wide

Table 5. Description of weather conditions used in WFDS fire simulations.

Weather conditions	
Max. ambient temperature	18.7 ˚C
Min. relative humidity	34%
Wind speed	3 m/s

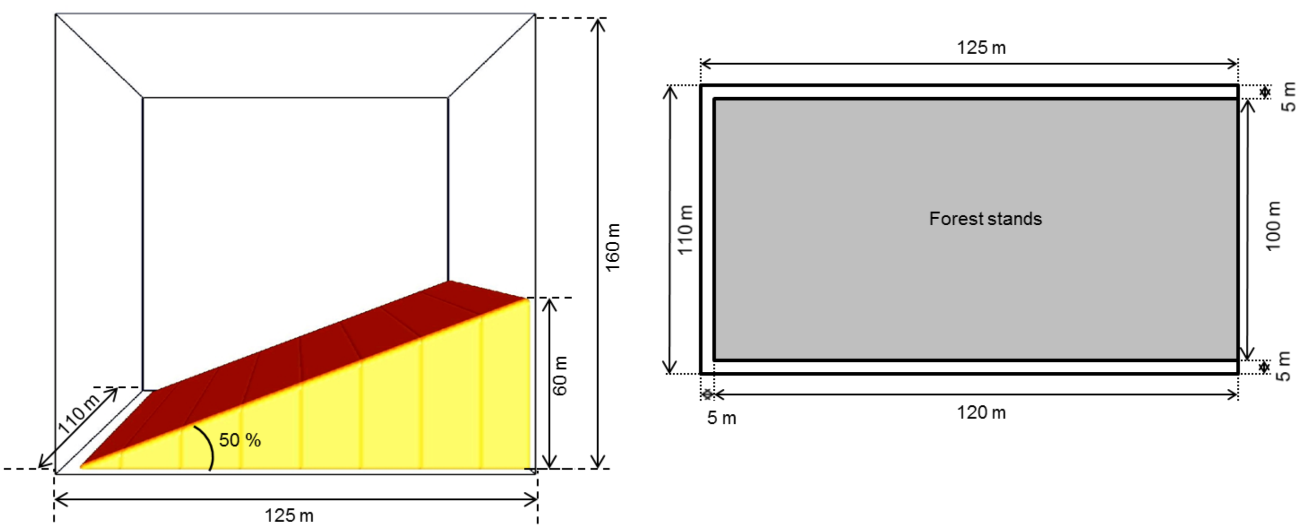


Figure 1. Simulation domain developed for the WFDS fire simulation.

Results

The fire simulations using WFDS indicate that tree spacing significantly affects the size and intensity of crown fires when all other factors are held constant (Figure 2). Crown fire spread distance from the ignition locations appears to widely vary with tree spacing (Table 6). The spread distance decreases as tree spacing increases. To limit the spread distance within 100m, it was required tree spacing of 6m or larger. The results indicate that tree spacing large enough to remove crown overlaps between neighboring trees would reduce crown fire risks under the given vegetation, ground and weather conditions.

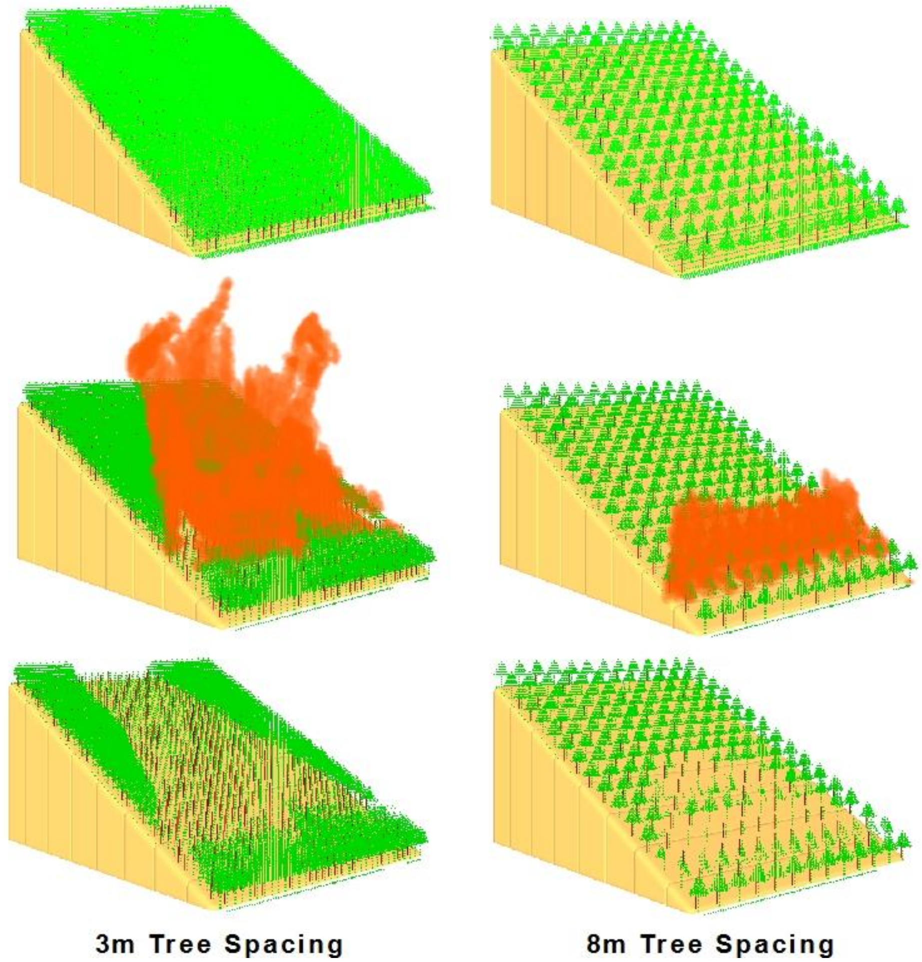


Figure 2. Screen shots of Smokeview displaying the imaginary forest stands with 3m and 8m tree spacing: initial condition (top), when the crown fires are most active (middle), and after fire simulation is completed (bottom).

Table 6. Results of crown fire spread distance varying with tree spacing.

Tree spacing (m)	Crown fire propagation distance (m)
3	>100
4	>100
5	>100
6	66
7	56
8	56

Concluding Remark

Based upon our results, it is thought that the average pine stands in Korea with over 1,000 trees per hectare are at high risk of large crown fires, and thus need to be actively thinned. Our limited fire simulation experiments indicate that reducing crown overlaps between neighboring trees is a key to reduce crown fire risks effectively. Tree spacing of 6m would be a good starting point for thinning guideline for 40 years pine stands in Korea. However, the results of this study should be used with caution because the fire simulations performed in this study were only for limited vegetation, fuels, ground, and weather conditions. Future studies should investigate how tree spacing would interact with various conditions of vegetation, crown fuels, topography, and weather in changing crown fire behavior.

Literature Cited

Agee, J.K. and C.N. Skinner. 2005. Basic principles of forest fuel reduction treatments. For. Ecol. Manage. 211(1–2):83-96.

Alvarez, A., M. Gracia and J. Retana. 2012. Fuel types and crown fire potential in Pinus halepensis forests. European Journal of Forest Research. 131(2):463-474.

Conard, S.G. and G. A. Ivanova. 1997. Wildfire in Russian Boreal Forests—Potential Impacts of Fire Regime Characteristics on Emissions and Global Carbon Balance Estimates. Environmental Pollution. 98(3):305-313.

Contreras, M.A., R.A. Parsons and W. Chung. 2012. Modeling tree-level fuel connectivity to evaluate the effectiveness of thinning treatments for reducing crown fire potential. For. Ecol. Manage. 264:134-149.

Kim, S., B. Lee, Y. Seo and Y. Lee. 2011. Crown fuel characteristics and allometric equations of pinus densiflora stands in Youngju region. Jour. Korean For. Soc. 100:266-272.

Korea Forest Service. 2011. Statistical yearbook of forestry.

McGrattan, K.B., S. Hostikka, J. Floyd, H. Baum and R. Rehm. 2008. Fire dynamics simulator (version 5), technical reference guide. NIST special publication. 1018:5.

Mell, W., J.J. Charney, M.A. Jenkins, P. Cheney and J. Gould. 2005. Numerical simulations of grassland fire behavior from the LANL-FIRETEC and NIST-WFDS models. P. 11-13 in EastFIRE Conference, Anonymous .

Mell, W., M.A. Jenkins, J. Gould and P. Cheney. 2007. A physics-based approach to modelling grassland fires. Int. J. Wildland Fire. 16(1):1-22.

Ormeño, E., B. Céspedes, I.A. Sánchez, A. Velasco-García, J.M. Moreno, C. Fernandez and V. Baldy. 2009. The relationship between terpenes and flammability of leaf litter. For. Ecol. Manage. 257(2):471-482.

Pollet, J. and P.N. Omi. 2002. Effect of thinning and prescribed burning on crown fire severity in ponderosa pine forests. Int. J. Wildland Fire. 11(1):1-10.

Prichard, S.J., D.L. Peterson and K. Jacobson. 2010. Fuel treatments reduce the severity of wildfire effects in dry mixed conifer forest, Washington, USA. Canadian Journal of Forest Research. 40(8):1615-1626.

Roloff, G.J., S.P. Mealey, C. Clay, J. Barry, C. Yanish and L. Neuenschwander. 2005. A process for modeling short- and long-term risk in the southern Oregon Cascades. For. Ecol. Manage. 211(1–2):166-190.

Rothermel, R.C. 1983. How to predict the spread and intensity of forest and range fires. US Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station Ogden, UT, USA.

Geospatial Analysis: Determining transportation cost zones for woody biomass feedstock allocation

Anil Raj Kizhakkepurakkal[1], A. Hohl, H-S. Han[2] and J. A. Bisson[3]

Abstract

Transportation of comminuted residual woody biomass from the site of production to the utilization point poses as one of the most cost consuming operation within any woody biomass energy project. The purpose of this study was to determine the area from which a small scale woody biomass power plant located in Humboldt County, CA, could potentially draw its feedstock and classify these regions into different zones based on the transportation cost. A network analysis was conducted utilizing the forest ownership and road data obtained from the county and TIGER census database. The forest ownership data was broadly divided as National Forest, Tribal Lands, Timber Production Zone (TPZ), Grazing/Timber and Other lands. Various other factors like rate of travel over different road types, time impedance, distance of travel, etc. were also determined from a literature survey and existing data in order to be incorporated into the network model. The network model was developed to meet the limitations of the chip trucks hauling the biomass and of the available forest road network.

Our results showed within 10 $/BDT travel cost zone, the facility could extract wood biomass from more than 170,000 acres of forest and the biomass would be with in a distance of 20 miles from the power plant. Among this, the highest amount of land fell under timber production zones (168,898 acres). The 4 travel cost zones were developed upto 40 $/BDT, with $10 increments, after which the project would not be economically feasible.

[1] Research Associate, Department of Forestry and Wildland Resources, Humboldt State University, Arcata, California, U.S.A

[2] Professor, Department of Forestry and Wildland Resources, Humboldt State University, Arcata, California, U.S.A

[3] Lecturer, Department of Environmental Sciences and Management, Humboldt State University, Arcata, California, U.S.A

Performance of a Tracked Feller-Buncher with a Shear Head Operating in Small-Diameter Pine

John Klepac[1]

Abstract: A Tigercat[2] 845D tracked feller-buncher equipped with a shear head was evaluated while performing a clearcut in a 15-year old Loblolly pine (*Pinus taeda*) plantation and a 18-year old natural stand. Mean density of the plantation was 573 TPA (Trees per Acre) while the natural stand averaged 328 TPA, with a slightly higher density of 390 TPA in the study area. Total cycle time was not significantly different between the two stands and averaged 66.8 seconds. The feller-buncher harvested an average of 6.3 trees per min and 7.1 trees per accumulation. Productivity of the feller-buncher in the plantation averaged 77.9 green tons per PMH (Productive Machine Hour) with a mean tree size of 0.19 green tons. In the natural stand productivity averaged 118.7 green tons per PMH with a mean tree size of 0.49 green tons.

Keywords: biomass, feller-buncher, time-study, productivity, pine.

Introduction

Reducing US imports of petroleum products and utilizing the nation's available sources of energy from forest and agricultural lands is a desirable, yet challenging, goal of both policymakers and the nation as a whole. In 2009, the United States imported about 51 percent of the petroleum consumed. This usage translates into a yearly total of 4.34 billion barrels imported (U.S. Energy Information Administration, 2011). The Energy Independence and Security Act of 2007 requires that 36 billion gallons of bio-fuels be produced annually by 2022 (EISA). To help meet these demands efficient and sustainable utilization of our nation's forest products will be necessary and will have to be implemented thru vital forest operations to get material from the woods to feedstock conversion facilities for bio-fuel production.

With the potential for increased demand for woody biomass in the future to help supplement current energy sources, high production, low cost harvesting methods will be essential for delivering a cost effective product. Merchantable trees are gathered and transported from stump to mill for processing into usable products thru the harvesting phase of forest operations. This consists of felling, skidding, loading and/or chipping and transport of trees. In-woods clean chipping removes bark, limbs, and tops from trees that are processed thru the chipper, which creates large amounts of residue

[1] Author is John Klepac (jklepac@fs.fed.us), General Engineer, USDA Forest Service, Southern Research Station, Auburn, Alabama.

material. Total logging residue and other removals in the United States currently amount to nearly 93 million dry tons annually—68 million dry tons of logging residue and 25 million dry tons of other removal residue (Smith et al., 2009). Most of this residue is left onsite because its small piece size makes it unsuitable and uneconomical for the manufacturing of forest products (U.S. Dept. of Energy, 2011). However, as markets for bioenergy feedstocks develop, a significant fraction of this residue could become economically feasible to remove, most likely in conjunction with conventional harvest operations where the costs of extraction (i.e., felling and skidding) are borne by the conventional forest product (U.S. Dept. of Energy, 2011).

Dedicated southern pine energy plantations could provide significant feedstocks for U.S. bio-fuel and bio-power demands. Southern pine plantations of 1.5 million acres could produce an estimated 105 million dry tons per year (Taylor and Rummer, 2011). The stands proposed for the energy plantations would predominately be composed of loblolly pine (*Pinus taeda*) planted at a density between 1000 and 1200 trees per acre (TPA) and would be grown for 10-15 years where they would be harvested by the clearcut method (Jernigan et.al, 2012). Harvesting these smaller trees cost effectively is difficult to accomplish using current conventional logging systems. In the southeastern US, where the majority of the terrain is flat to gentle slopes, drive-to-tree rubber-tired feller-bunchers equipped with a circular saw head are the most common machines used.

One system that is currently being investigated for potential biomass harvesting is a recently developed tracked feller-buncher equipped with a shear head coupled with a large capacity rubber-tired skidder. This paper discusses the performance of the tracked feller-buncher operating in a plantation stand and a natural stand in south Alabama.

Operation

This study was part of a larger project funded by the Department of Energy to evaluate new technologies for harvesting small-diameter trees for biomass. Data were collected on the harvest operation at two sites: a plantation stand and a natural stand. A clearcut prescription was implemented at both sites where trees were felled with a Tigercat 845D tracked feller-buncher equipped with a shear head and powered by a Tier 4 260-hp engine. A Tigercat 630D grapple skidder powered by a 260-hp engine transported tree bundles to a landing.

In the plantation trees were felled and bunched and left on the ground for about six weeks to dry. After the drying period trees were skidded to a landing and clean chipped. The purpose of chipping dried material was to evaluate actual payload of larger volume chip vans hauling dried chips. For the natural stand trees were felled and skidded to a landing where they were processed thru a Chambers Delimbinator and loaded onto trucks as longwood. Harvesting was accomplished during the last week of May 2012 for the plantation and October into November 2012 for the natural stand.

Methods

Study Sites

The plantation consisted of 15-year old loblolly pine located in Covington County, Alabama. It had not been thinned and included a total area of 37 acres. The natural stand was approximately 18 years old and was located in Butler County, Alabama. This stand was predominately pine with a small component of hardwoods, mainly sweetgum, and contained a harvest area of 36 acres.

To characterize each stand a line-plot cruise was completed for each stand using 0.1-acre fixed radius plots. Within each plot, trees measuring over 1.5 inches Dbh (Diameter at Breast Height) were tallied. Total tree heights were measured on every fifth pine tree using a vertex hypsometer. A Trimble Ranger equipped with TCruise (Matney 1998) was used to record plot data. A PC version of TCruise was used to generate a cruise summary of each tract.

Felling

The Tigercat 845D (Table 1) was observed while cutting trees which were marked with a number for identification and measured for Dbh. The same operator was observed on both sites. In the plantation the operator felled trees in a five row swath, centered on a row and felling two rows on each side. The machine was recorded on digital video while felling trees in the study area and each tree was identified as it was being cut.

The digital video file was reviewed using the software program Timer Pro (Timer Pro Professional), which is a program designed for time-and-motion study analysis. Machine elements that were evaluated and made a complete cycle included move to 1st tree, accumulate, move between trees, move to dump, and dump.

Move to 1st tree occurred when the machine traveled to cut the first tree in a cycle. The element began at the end of the dump element when the tracks started rolling. The element ended when track movement stopped.

Accumulate included both reaching to a tree and shearing for all trees in the cycle. The element began when track movement to the first tree stopped and extension of the boom started. The element ended when the last tree for the cycle was sheared. If the machine did not move to the first tree after dumping the head then accumulating time began after all trees were dumped and movement of the boom began.

Move between trees occurred when the machine traveled during the accumulating element in order to reach additional trees to shear. The element began after a tree was sheared and the tracks started rolling. The element ended when track movement stopped.

Move to dump occurred after all trees in the cycle were sheared and the machine traveled to a location to place the accumulated trees. The element started when the tracks began rolling after the last tree was sheared and ended when the tracks stopped rolling.

Dump included placing trees accumulated in the head either on the ground or in a bundle of previous placed trees. The element began when the tracks stopped rolling at the end of move to dump and ended when all trees were out of the head. If the machine did not move to dump then dump time started after the last tree was sheared.

Cycle volumes were determined by calculating individual tree weights using a regression equation developed from data collected from each site in addition to other sites in Butler, Covington, and Crenshaw Counties in Alabama (Klepac 2013). Some trees in the natural stand encountered by the feller-buncher were fairly large and outside the range of weight data collected for the site. These weights were estimated using published equations (Clark and Saucier, 1990).

Table 1. Specifications of the Tigercat 845D feller-buncher (Tigercat 2013).

	Cummins 260 hp Tier 4
	26 ft 5 in
	28 in
Total width	129 in
Total length w/o boom	193 in
	57,100 lb

Results

Study Sites

Cruise data from each site are summarized in Table 2 and reflect trees per acre and whole-tree green tons per acre for loblolly pine. The plantation stand had a very small component of sweetgum and oak in the 4 and 5-inch diameter classes that totaled only 3 trees per acre. The natural stand had a larger component of hardwood which totaled 28 trees per acre in the 4 to 9-inch diameter classes. Quadratic mean diameter for pine trees in the 4-inch and larger diameter classes was 6.0 inches for the plantation stand and 8.7 inches for the natural stand.

Fifty percent of the trees in the plantation stand were in the 5 and 6-inch Dbh classes. The largest Dbh class represented in the plantation was the 10-inch class which contained less than one percent of the total trees per acre. As a comparison, 25 percent of the total trees per acre in the natural stand were in the 5 and 6-inch Dbh classes while almost 9 percent were in 13 to 19-inch Dbh classes.

Table 2. Stand table for the plantation and natural stands.

Dbh class	Trees/acre		Green tons/acre	
(in)	Planted	Natural	Planted	Natural
4	93	29	7.3	2.3
5	125	46	15.2	5.7
6	162	37	27.3	6.5
7	125	43	27.7	10.7
8	50	38	14.4	12.5
9	14	32	5.1	13.3
10	4	30	1.9	15.5
11		25		15.9
12		19		14.0
>12		29		60.4
Total	**573**	**328**	**98.9**	**156.8**

Felling

The Tigercat 845D feller-buncher was observed while felling 712 trees (348 trees in the plantation and 364 trees in the natural stand). Of the 364 trees felled in the natural stand only 6.3 percent were hardwoods. Trees felled in the plantation ranged in Dbh from 2.6 inches to 10.0 inches, while trees felled in the natural stand ranged from 2.3 inches to 19.2 inches in Dbh.

Total cycle time was modeled using a General Linear Models Procedure in SAS (Statistical Analysis Software, 2011). The number of trees felled per cycle ($p<.00001$) and mean Dbh of trees felled per cycle ($p=0.0003$) were both significant independent variables for predicting total cycle time. Stand type (natural or plantation) was also tested but was not significant ($p=0.8766$), therefore, observations from both sites were combined.

An ANOVA (Analysis of Variance) for total cycle time is summarized in Table 3. The model had a sample size of 93, an $R^2 = 0.79$ and a coefficient of variation of 13.85. The equation for predicting total cycle time for the feller-buncher is listed below and is shown in Figure 1 along with a plot of measured time study data.

*Total cycle time (sec) = 7.883603*Trees + 1.713463*MDbh – 1.181092*

where: Trees = number of tree cut per cycle
MDBH = mean Dbh of trees cut per cycle

Table 3. Analysis of Variance for total cycle time.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	29419.43896	14709.71948	172.05	<.0001
Error	90	7694.91911	85.49910		
Corrected Total	92	37114.35806			

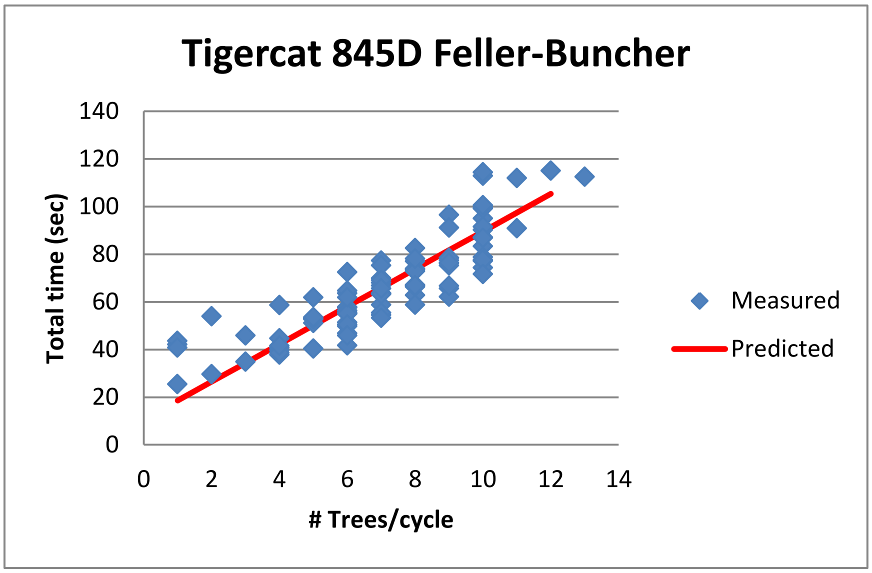


Figure 1. Plot of time study data and regression equation for the feller-buncher.

At the beginning of a cycle, which started after trees were dumped from the head, the feller-buncher was able to reach the first tree of a cycle 52 percent of the time without moving. In addition, the feller-buncher was required to move an average of 1.5 times during a cycle to reach additional trees to shear, with 41 percent of cycles with no moves between trees. The feller-buncher was required to move to dump only two percent of the time. A summary of time study data for the feller-buncher is shown in Table 4.

Table 4. Performance summary of the Tigercat 845D feller-buncher.

Variable	N	Mean	SD	Min	Max
Move to 1st tree (sec)	45	8.4	4.77	3.0	29.1
Accumulate (sec)	93	52.2	16.65	13.3	92.0
Move between trees (sec)	56	8.2	6.85	2.0	42.5
Move to dump (sec)	2	8.5	6.86	3.6	13.3
Dump (sec)	93	8.2	2.35	4.1	16.2
Total time (sec)	93	66.8	20.08	25.3	115.0
Trees/cycle	93	7.1	2.60	1.0	13.0
Trees/min	93	6.3	1.45	1.4	8.7
Moves/cycle	93	1.5	1.36	0.0	7.0

Although total cycle time was not significantly different between the plantation and natural stands, there was a difference in mean tree size which resulted in a higher productivity in the natural stand. Mean tree size for the plantation was 0.19 tons per tree, which resulted in a mean of 1.51 green tons per cycle and a mean productivity of 77.9 green tons per PMH. The natural stand averaged 0.49 tons per tree, which resulted in a mean of 1.88 green tons per cycle and a mean productivity of 118.7 green tons per PMH. Figure 2 shows the distribution of the number of trees felled in each 2-inch Dbh class for both stand types.

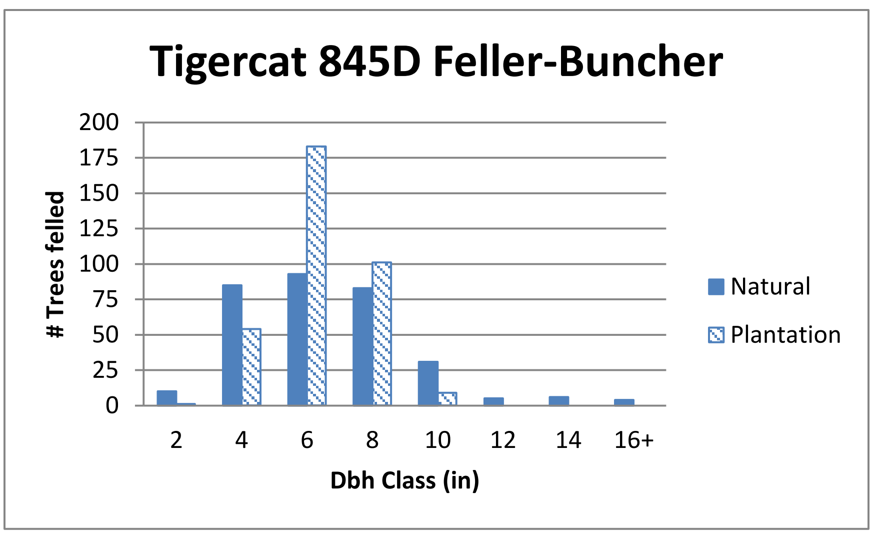


Figure 2. Number of trees felled by diameter class for the feller-buncher.

Fuel consumption was monitored using the machine's electronic fuel monitoring system while operating in the plantation study area. During this time the 260-hp feller-buncher consumed fuel at a rate of 6.5 gal per hour (0.025 gal per hp-hr). On a per unit basis the feller-buncher consumed 0.0972 gal per green ton felled, which resulted in a total of 10.29 green tons produced per gallon of fuel used.

Conclusions

The Tigercat 845D tracked feller-buncher averaged 66.8 seconds per cycle with a mean accumulation size per cycle of 7.1 trees. The number of trees and the mean Dbh of trees felled per cycle were both significant independent variables for predicting total cycle time. Production rates reached 77.9 green tons per PMH in the plantation for a mean tree size of 0.19 green tons and 118.7 green tons per PMH in the natural stand for a mean tree size of 0.49 green tons.

The feller-buncher was evaluated in stands which consisted of larger trees and lower densities as compared to the proposed energy plantation stands (1000 to 1200 TPA). Mean Dbh of accumulated trees in the plantation was 6.2 inches. Assuming a higher density stand with a mean Dbh of 5 inches and 12 trees per accumulation would result in a predicted total cycle time of 102 seconds. From tree weight data collected in the area a 5-inch Dbh plantation tree would weigh around 208 lbs., resulting in a productivity of 44 green tons per PMH. At this production rate a system could potentially require at least two feller-bunchers to provide enough wood for sufficient utilization of the large capacity Tigercat 630D grapple skidder.

This study demonstrated that the feller-buncher is capable of operating productively in different stand types over a range of tree sizes. With the tracked machine less frequent travel within stands was required which resulted in less ground disturbance. Evaluation of machine performance in higher density stands with a smaller tree size would be beneficial since this would be more representative of the type of stands the feller-buncher would operate in for biomass harvesting.

Acknowledgements

This work was partially funded by the Department of Energy under grant DE-EE0001036. The author would also like to thank Corley Land Services, Auburn University's Department of Biosystems Engineering, and the Auburn University Center for Bioenergy and Bioproducts for their cooperation with this project.

References

Clark III, A. and Saucier, J.R. 1990. Tables for Estimating Total-Tree Weights, Stem Weights, and Volumes of Planted and Natural Southern Pines in the Southeast. Res. Pap. SE-79. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 23 p.

Jernigan, P., Gallagher, T., Smidt, M., Teeter, L., and Mitchell, D. 2012. High Tonnage Harvesting and Skidding for Loblolly Pine Energy Plantations. Council on Forest Engineering Annual Meeting. New Bern, North Carolina.

Klepac, J. 2013. Tree weights of plantation and natural loblolly pine trees in south Alabama. Unpublished.

Matney, T.G. 1998. Timber Cruise Program version 6.01. Heuristic Solutions.

Rummer, B. and Taylor, S. 2011. Presentation.

SAS version 9.3 for Windows, SAS Institute Inc., 2011, Cary, NC.

Smith W.B., Miles P.D., Perry C.H., Pugh S.A. 2009. Forest Resources of the United States, 2007. Gen. Tech. Rep. WO-78. U.S. Department of Agriculture, Forest Service, Washington, DC. 336 pp

Tigercat website. Http://www.tigercat.com. [Date accessed: May 10, 2013].

Timer Pro Professional. 2000-2011. Applied Computer Services, Inc.

U.S. Department of Energy. 2011. U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry. R.D. Perlack and B.J. Stokes (Leads), ORNL/TM-2011/224. Oak Ridge National Laboratory, Oak Ridge, TN. 227p.

U.S. Energy Information Administration. Independent Statistics and Analysis for petroleum and other liquids. http://www.eia.doe.gov/dnav/pet/pet.move.wkly.dc.NUS-Z00.mbblpd.w.htm. [Date accessed: May 3, 2013].

Towards Collaborative Business Models for Wood-Supply Operations in Public Forests

Luc Lebel[1], Riadh Azouzi[2]

Abstract

Balancing the ever-shifting suite of economic, environmental and social expectations associated with public forests is a complex undertaking. State organizations are looking for better ways to make integrated forest resource management more effective. For their parts, forest products companies and their suppliers are seeking new models of cross-organizations collaboration. The project reported in this paper is part of an 'action research' program looking at developing collaborative business models for several actors in the public forest value chain in the province of Quebec, Canada. The program contains two phases: strategy elaboration and business models development. Accordingly, the paper first presents the strategy that resulted from a previous project that has been drawn as a case study, and then it reports on progress made with pilot-projects for the development and experimentation of collaborative business models in selected operational contexts.

Introduction

In many countries, a large proportion of productive forested land is within the public domain. Public forests belong to society and the government is responsible for their management in an integrated fashion; the government must balance ecologic objectives with social development through a range of sporting, leisure, tourist and economic activities. Balancing the ever-shifting suite of economic, environmental and social expectations associated with public forests is complex. Governments are looking for ways to make integrated resource management more effective. In contrast to monodisciplinary management approaches such as sustained yield, integrated resource management demands a multidisciplinary approach that engages diverse perspectives and skill sets. Thus, governments and all the actors in the forest value chain, including the forest products companies (FPCs) and their suppliers or upstream actors (general entrepreneurs, forest workers cooperatives, forest management groups, silviculture workers or logistical services providers, as shown in Figure 1), need find ways to conduct activities in the forest more collaboratively and effectively. One approach consists in establishing new models of cross-organizations collaboration. Here, collaboration, both horizontally between competitors, and vertically among actors in charge of different activities for a same organization, is considered. The challenge in such cross-organizations collaborations is related to the division of work in daily collaborations with various partners and the coordination of day-to-day activities for creating value to customers. Different actors are thus interlinked, forming networks of business actors which are drawing on each other's specific resources and coordination activities (Hakansson et al. 2009).

[1] Faculté de foresterie, géographie et géomatique, Université Laval, QC G1V 0A6, Canada
[2] Faculté des sciences et génie, Université Laval, Québec, QC G1V 0A6, Canada

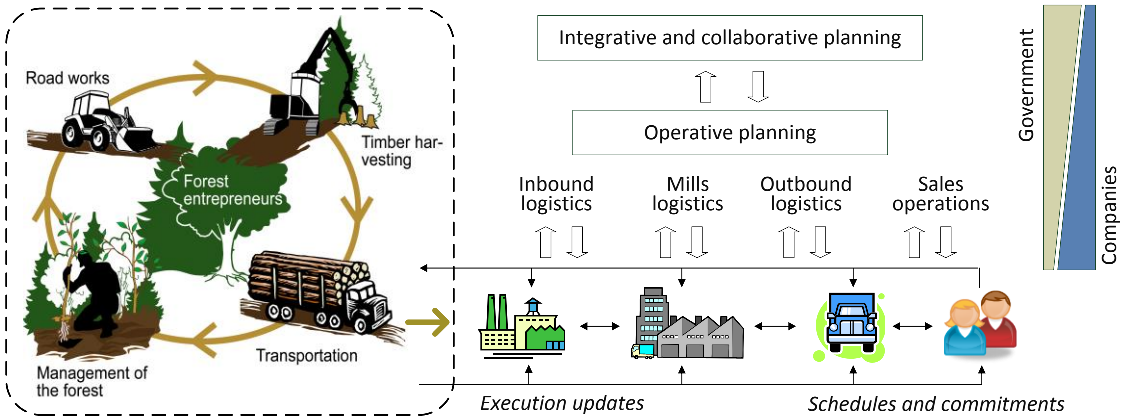


Figure 1: Wood supply chain within the forest value network

Organizations exploring collaborative business field aim at creating a fruitful environment for joint innovation and fostering strategic discussions about new business challenges and emerging business models (Konnertz et al. 2011). Strategic innovation requires the migration from an existing business model to a newer one. We adopt the definition offered by Shafer et al. (2005) for the term "business model" that is, "a representation of a firm's underlying core logic and strategic choices for creating and capturing value within a value network". The business model and the strategy of the enterprise are closely linked. In fact, the business model can be used to help analyze and communicate strategic choices. Thus, in this research, the concept of business model becomes the unit of analysis. On the other hand, as emphasized by Eppler et al. (2011), the collaboration perspective relies essentially on including others (competitors and other actors working at different levels of the value chain) in the process of developing ideas. Therefore, to engender successful cross-organizations collaborations in the forest value chain, it is important that different organizations (or value chain actors) participate in the development of the business models. The organizations might differ in type (industry, public research and non-profit), their position in the value chain and even in industry. This is referred to as collaborative business modeling (Rohrbeck et al. 2013).

Accordingly, the project reported in this paper is part of an 'action research' program looking at developing collaborative business models for several actors in the public forest value chain in the province of Quebec, Canada. One key objective is to streamline the planning and execution of forest activities. The project coincides with the implementation of a new forest law which aims at fostering integrated resource management implementation. The program contains two phases: 1) strategy elaboration phase and 2) business models development phase. Accordingly, the paper introduces the research program, and then presents the strategy that resulted from a preliminary strategy development phase drawn as a case study. It finally reports on progress made with pilot-projects for the development and experimentation of collaborative business models in selected regional contexts.

Research program

The project reported here was part of an 'action research' program involving several actors in the public forest value chain in the province of Quebec, Canada. These actors have demonstrated interest in developing collaborative business models so that they can streamline the planning and execution of their activities and provide a comprehensive support for the implementation of a new forest law which fosters integrated resource management implementation in the province. As emphasized by Gilmore et al. (1986), “there is a dual commitment in action research to study a system and concurrently to collaborate with members of the system in changing it in what is together regarded as a desirable direction”. Thus, it would be possible for us as researchers to study the actions that the stakeholders would do to change or develop collaboratively their business models while concurrently collaborating with them in these actions and, more specifically, in establishing the way they should do this. The research action approach used to define a strategic vision is outlined in Figure 2.

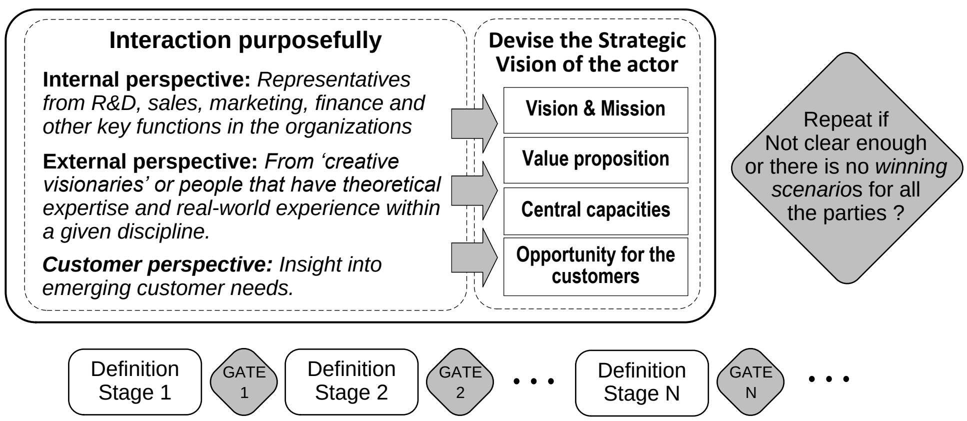


Figure 2: Strategic vision elaboration framework

In the first phase, the actors need to think about how they redefine themselves as an economic actor in the context of an integrated forest resources management regime. According to Verstraete and Jouison (2007), organizations elaborating a new strategy do this on the basis of the revision of their positioning in the value chain, of the configuration of their organizations, of their business network, of their performance requirements, and of their competencies or the new competencies they can develop. The information gathered at this phase can take the form of a detailed strategic vision for the organization, including its value proposition, its required competencies, the targeted customers, and the opportunities it creates for its customers and partners. In order to trigger cross-organizations collaborations, we propose a framework in which the perspectives of people from different organizations, including potential business partners and the government, are incorporated through purposeful interaction within the context of a sequence of definition stages (see Figure 2). As such, the structured process can take the form of an iterative series of focus group interviews. From one iteration to the other, the formulation of the strategic vision is refined and enriched, and discussions take place to see if ‘win-win’ outcomes can be identified for all the organizations and their partners. Then, the decision whether to conduct another stage is taken.

In the second phase, the business models are developed with the involvement of several other actors (including customers and competitors) in the value chain. Business model development and design is a challenging task. Based on the objectives of this project, and the complexity at hand, we considered it appropriate to use the case study methodology. We assume the strategy resulting from the first phase as the conceptual framework to the research process taking place in the case study. In a qualitative research project, the conceptual framework guides the initial stages of the research process (Cepeda and Martin 2005). Here, the strategy guides the development of information for each of the elements contained by the business model as depicted in Figure 3. These elements integrate the knowledge that is obtained about the stakeholder's system dynamics and the congruence between strategy and the environment. For a detailed description of each of these elements, the reader is referred to (Marrs and Mundt 2001). During the development of the information for each of the business model elements, data is collected through interviews, document study or observation. The analysis of the data should provide an assessment of the economic, social and environmental impact of the new business model.

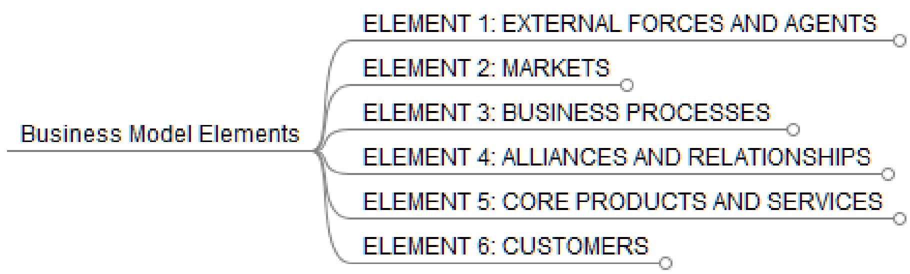


Figure 3: Business model elements

The next two sections provide details regarding the implementation of the of each the two phases presented above.

Phase 1 – Strategy elaboration

Quebec's new forest regime took effect in April 2013. It is now the government that has the primary responsibility for producing the tactical and operational land and resource management plans. Previously, it was the forest companies with timber licenses that had this responsibility. The tactical plan covers a three-year period and contains, among other things, the annual allowable cut (AAC) assigned to the unit, and the forest management strategies adopted to ensure that AAC is respected. On the other hand, the operational plan basically sets out the forest operations zones in which timber harvesting or other forest development activities are planned under the tactical plan. It also contains the measures to harmonize various interests and values at stake (such as measures for ensuring compatibility with the activities of other land users or for mitigating the visual impact of cuts). The government remains responsible for allocation of timber volume to mills through timber licenses (TL). Notice that a TL specifies the general areas from which wood for the mill can be procured and maximum procurement volume for one or more tree species.

Many actors in the value chain have already started thinking about how the new act would affect their businesses and how they should reposition themselves in the value chain to mitigate the impact of the new measures on their productivity. They noticed that, while the new forest regime contains provisions for improving integration at the tactical level to a certain extent, it overlooked real and effective integration at the operational and execution levels. For instance, the government agents preparing the resource management plans can hardly have the necessary knowledge and information that are critical for reconciling all the inconsistencies that result from the aggregation and dis-aggregation of information among the plans made at the tactical, operational or execution levels (this has been demonstrated also by the work of Beaudoin et al. 2008 and, more recently Paradis et al. (2013). Another concern expressed is the lack of integration of data provided by different actors when there are tradeoffs to be made between economics and environmental goals. Such tradeoffs could be related to the positioning of the harvest bock separators, the allocation of the cutting blocks, the use of the existing infrastructure (roads, bridges, firebreaks, etc.) or new infrastructure needed, or the assessment of the cumulative effects. The latter are impacts caused by an action in combination with other past, present and future actions (Carlson and Stelfox 2009). In brief, when it comes to the planning and execution of the day-to-day activities, the upstream actors claim that they can play a critical role in ensuring operations efficiency; leading to better delivery performance and lower procurements costs for the mills and other users of the forest resources.

To remediate such weaknesses, certain stakeholders decided to focus on defining a generic concept of Integrator-Supplier (IS). Basically, an IS is an intermediary that should support collaboration between them and act as a catalyst for reconciling their plans and for optimizing the performance of their activities related to land uses and forestry operations. There might be several actors in the value chain that can adapt their business models in order to fulfill the role of an IS. The other actors are customers and/or suppliers for the IS. They too will have to adjust their business models in order to establish new relations with all others in their environment so that the whole value chain is optimized. Thus, the IS sets out the strategic path or the key reference for the different actors in a forest region to revise their business models. Hence, it was decided to apply the framework of Figure 2 in order to define the IS.

As depicted in Figure 4, in all, seven stages were conducted to define the IS. Participants include forestry researchers and supply chain specialists; cooperatives professionals; FPCs professionals; and government representatives. For all the participants, it was clear that the IS should act as a catalyst for the optimization of the planning and execution of the forest operations and for achieving the objectives of all its customers and partners fairly. Its vision and mission were articulated around its role in the achievement of the interests of all the stakeholders by reconciling the plans and by optimizing the performance of the activities related to land use and forestry operations.

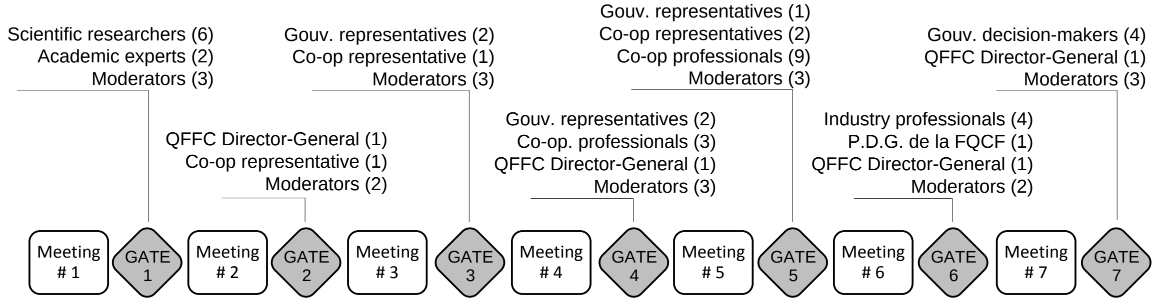


Figure 4: Definition stages conducted to define the IS

Figure 5 shows how the IS was positioned within the FVC. The IS here links several land users (including several companies consuming wood or TL holders, recreation organizations and First Nations communities), the government and the regional authorities to a comprehensive network of suppliers. This network, that we call "IS network", consists of forest workers cooperatives, entrepreneurs, independent carriers, etc. For all these actors, the IS creates a true collaborative planning environment, enabling them to integrate and reconcile their plans. It brings a comprehensive mix of competencies, the most important probably being the ability to effectively manage the inconsistencies that result from the aggregation and disaggregation of information among the plans made at the tactical, operational or execution levels, or from the integration of data provided by different actors. This cross-chain coordination would generate significant economies of scale. Detailed information on the value propositions and competencies of the IS can be found in (Azouzi et al. 2012).

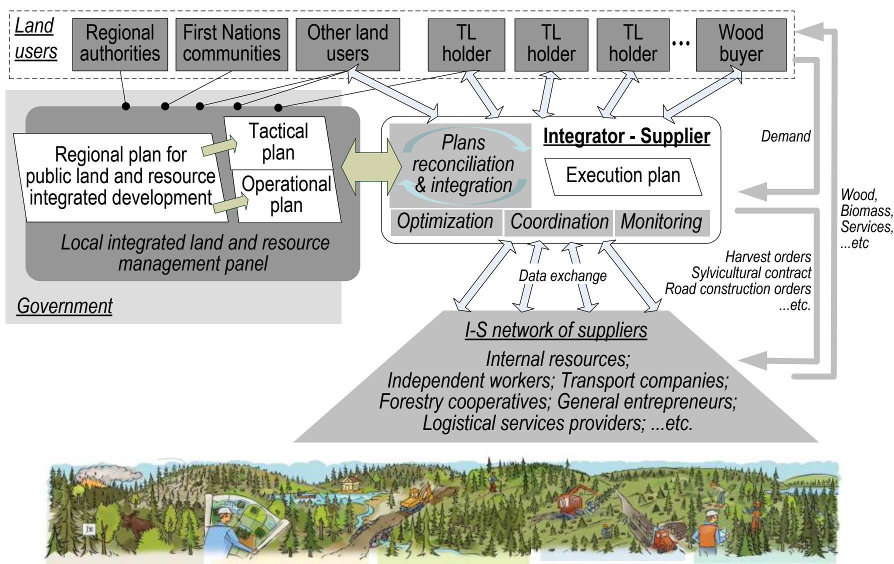


Figure 5: Positioning of the IS in the forest value chain

PHASE 2 – Business models development

The strategic path set out by the IS may be pursued differently by different actors, taking into account the local context. From one forestry region to another, the number of existing players, their sizes, and the nature of their role in the value chain might vary significantly. Some actors might not be ready to act as integrators but would rather prefer doing business with other actors operating as integrators-suppliers. The process illustrated in Figure 6 was applied in order to determine the different business models scenarios that might unfold. First, we needed to conduct several consultation meetings with several actors in order to determine how the concept of IS would be applied in their region. Different IS scenarios might emerge in different regional contexts. Then, we needed to identify among the actors those who had the potential to becoming IS, and thus, were interested to embark on a pilot project for business model development.

To date, six actors from different forest regions in Quebec have been consulted and four of them, three forest workers cooperatives and a FPC, have expressed interest in participating in pilot projects. These actors started to communicate with their network of suppliers, contractors, customers and other stakeholders in their value chain in order to receive their support.

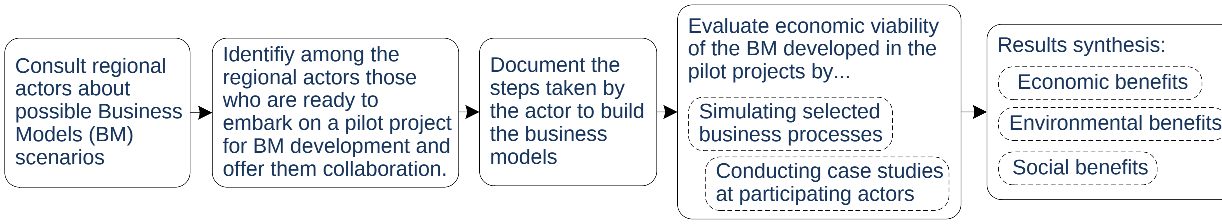


Figure 6: Business model development process

As researchers, we need to gain a complete understanding of the business process and produce a process flow diagram, which could be verified with the participants. Also, we need to document the existing context and the transformations that the business models of the different actors undergo so that we can capture the impact of these transformations on the structure of the entire value chain. Our plan consists in following each participant—through on-site visits, interviews with managers and employees and the analysis of available documents—and in documenting the rationale for decision he makes. Concurrently, we intend to rely on the strategic vision developed in phase 1 to collaborate the participant in changing their system in what is together regarded as a desirable direction. The strategic vision will be helpful in structuring the data collection process. As such, we intend to act as active agents in the data collection process. With the development of a set of case studies, frequent and extensive interactions should take place and an experience-sharing 'learning network' will be established.

Discussion & Conclusion

The research program presented in this paper combines research and action in an ongoing process of value chain restructuration that involves action planning, action taking and evaluation. It is an ambitious program at the end of which actors in selected value chains would have developed and experimented new collaborative business model. From a research perspective, the program encompasses case studies and business processes simulation. The case studies enable us to investigate the business models development. Simulations, for their part, are used to project the effects of the processes improvement scenarios and thus can provide direction for the business models developments. In particular, we are interested in assessing the economic, environmental and social impacts of the projected improvements. Participants' willingness to take action directly impacts the effectiveness of the case studies. Consequently, close cooperation with researchers in making a simplified representation of relationships between business processes changes and economic, social and environmental concerns greatly impact the reliability of the assessments made through simulation.

This research project deals with local and large scale issues and involves a large number of participants. Thus, it is critical that the research approach be fundamentally a collaborative learning approach, with open dialogue among stakeholders and researchers working as full partners in the project. Finally it is noted that the project lays the ground for the implementation of an organizational structure which could act in support of advanced supply chain optimization models. It connects with contribution in the fields of interoperability and collaborative planning and operations.

References

Azouzi R., Lebel L. and D'Amours S. (2012). Defining the Integrator Supplier concept for the forest supply chain. 4th International Conference on Information Systems, Logistics and Supply Chain (ILS). Québec , Canada, Août 26-29.

Beaudoin, D., Frayret, J.-M., and Lebel, L. (2008). Hierarchical forest management with anticipation: an application to tactical-operation planning integration. Can. J. For. Res. 38(8): 2198-2211.

Carlson, M. and Stelfox, B. (2009). Integrated resource management and planning. In Animal and Plant Productivity, [Ed. Robert J.Hudson], in Encyclopedia of Life Support Systems (EOLSS), Developed under the Auspices of the UNESCO, Eolss Publishers,Oxford,UK, [http://www.eolss.net] [Retrieved April 26, 2013].

Cepeda, G., and Martin, D. (2005). A review of case studies publishing in Management Decision: Guides and criteria for achieving quality in qualitative research. Management Decision, 43(6).

Eppler, M. J., Hoffmann, F., and Bresciani, S. (2011). New Business Models Through Collaborative Idea Generation. International Journal of Innovation Management, 15(06): 1323–1341. doi:10.1142/S1363919611003751

Håkansson, H., Ford, D., Gadde, L.-E., Snehota, I. and Waluszewski, A. (2009). Business in Networks. Wiley, UK, 308 pp.

Konnertz, L., Rohrbeck, R. and Knab, S. (2011). How collaborative business modeling can be used to jointly explore sustainability innovations. ISPIM Annual Conference. 12-15 June, Hamburg, Germany.

Marrs, F.O., and Mundt, B.M. (2001). Enterprise Concept: Business Modeling Analysis and Design. Handbook of industrial engineering technology and operations management, Salvendy G. (ed), John Wiley & Sons.

Paradis, G., LeBel, L., D'Amours, S., and Bouchard, M. (2013). On Risk of Systematic Drift Under Incoherent Hierarchical Forest Management Planning. Canadian Journal of Forest Research 43(5): 480-492.

Ramírez, R., Gilmore, T. and Krantz, J. (1986). Action-based modes of inquiry and the host-researcher relationship. Consultation, 5(3). 160-176.

Rohrbeck, R., Konnertz, L. and Knab, S. (2013). Collaborative Business Modelling for Systemic and Sustainability Innovations. International Journal of Technology Management, Forthcoming. Available at SSRN: http://ssrn.com/abstract=2197724

Shafer, S. M., Smith, H. J., and Linder, J. C. (2005). The power of business models. Business Horizons, 48(3) : 199–207. doi:10.1016/j.bushor.2004.10.014.

Verstraete, T., Jouison, E. (2007), Trois théories pour conceptualiser la notion de Business Model en contexte de création d'entreprise. Conférence Internationale de Management Stratégique – AIMS (16ème édition), Montréal, Québec.

Applying ant colony optimization to solve constrained forest transportation planning problems

Pengpeng Lin[1], Marco Contreras[2], Jun Zhang[3], Woodam Chung[4]

[1]Graduate Research Assistant, Department of Computer Science, University of Kentucky
[2]Assistant Professor of Forest Management, Department of Forestry, University of Kentucky
[3]Professor of Computer Science, Department of Computer Science, University of Kentucky
[4]Associate Professor of Forest Operations, Department of Forest Management, University of Montana

Abstract

Problems related to the transport of timber products from harvesting sites to conversion facilities have traditionally involved finding routes that minimize timber hauling and road construction costs. However, increasing environmental concerns have introduced negative impacts (i.e. soil erosion and water quality) into forest transportation planning problems (FTPP) making them larger and more complex. In this paper, we present an algorithm based on the ant colony optimization (ACO) framework, which has been shown to efficiently solve large-scale and complex multi-objective and constrained optimization problems. We used the algorithm to solve FTPP with fixed and variable costs as well as side constraints. Sediment yields expected to erode from road surfaces due to the heavy traffic of log trucks represented the negative environmental impact of timber transport and were considered as a side constraint. Our ACO algorithm used a two-stage process to find the least-cost set of routes from each timber sale location to selected mills resulting in a total sediment yield below a maximum allowable amount. During Stage I, the algorithm uses only sediment yield information on each road segment to quickly find feasible solutions. During Stage II, sediment and cost information per road segment are considered to select feasible solutions resulting in least-cost routes. After a solution is built, a 1-opt local refinement procedure was implemented to improve solution quality. First, we applied our ACO algorithm to a medium scale, grid-shaped hypothetical FTPP with 500 road segments (where traffic is allowed on both directions), 25 timber sale locations, and a single mill destination. Four cases with increasing levels of sediment constraints were considered, and an exhaustive parameter search process was conducted to select the best parameter combination for each case. To test the robustness of the ACO-algorithm, we created 10 different FTPP instances with different timber sale locations and destination nodes for the same hypothetical problem. Solutions were then compared with those obtained from comparable mixed-integer programming formulations solved by CPLEX.

I. INTRODUCTION

Traditionally, forest transportation planning problems (FTPPs) have focused on finding routes that minimize log hauling and road construction costs from harvesting sites to conversion facilities (Contreras et al., 2008). FTPPs that contain both variable (log hauling) and fixed costs (road construction) are a special case of the fixed charge transportation problem (FCTP), which is known as a NP-hard combinatorial optimization problem (Steinberg, 1970). Mixed-integer programming (MIP) has been commonly used to optimally solve FCTP (Adlakha and Kowalski, 2003); however, its application has been limited to small- and medium-scale problems because solution time grows exponentially with problem size (Kowalski, 2005). Several heuristic approaches have been developed to solve large-scale problems in a reasonable time. Although these approximation techniques do not guarantee optimality, they can efficiently provide high-quality solutions for large and complex problems (Jones et al. 1991; Martell et al. 1998; Sessions et al., 2003; Olsson and Lohmander, 2005). Examples of approximation approaches used to solve large-scale FTPP with fixed and variable costs include MINCOST (Schnelle, 1977), NETCOST (Weintraub and Dreyfus, 1985), NETWORK II (Sessions, 1985), and NETWORK 2000 (Chung and Sessions, 2003). Although these approaches have been widely used, their formulations are only set to minimize total transportation costs and cannot consider side constraints based on additional attributes of road segments. Increasing environmental concerns related to the transport of timber products have introduced negative impacts such as erosion and water quality into FTPPs (Grace and Clinton, 2007). These environmental considerations and requirements introduce side constraints making FTPPs more complex than the traditional cost minimization problems. A few studies have incorporated environmental impacts into the route selection process by assigning an environmental cost to sediment yields expected to erode from forest roads (Rackely and Chung, 2008; Efta and Chung, 2009). However, it is difficult and arbitrary to assign an economic value to a negative environmental impact. On the other hand, Contreras et al. (2008) developed an algorithm based on the ant colony optimization (ACO) metaheuristic to solve FTPPs considering sediment yields expected to erode from road surfaces due to the heavy traffic of log trucks (representing the negative environmental impact of timber transport) as a side constraint. They applied the ACO algorithm to solve three hypothetical FTPPs containing 100, 300, and 500 edges and compared ACO solution quality with MIP solutions. While the ACO algorithm achieved near-optimal solutions, optimality levels decreased as problem sized increased, and the MIP solver was not able to find an optimal solution for two out of four instances for the largest problem.

In this study we developed a new ACO algorithm to improve solution quality and increase the ability to solve large-scale problem, and update benchmarking solution quality with an improved MIP solver, CPLEX. Our ACO algorithm uses a two-stage process to find the least-cost set of routes from each timber sale location to selected mills with a total sediment yield below a maximum allowable amount. During Stage I, the algorithm only sediment yield information on each road segment to quickly find feasible solutions. During Stage II, sediment and cost information per road segment considered to select feasible solutions resulting in least-cost routes. After a solution built, a 1-opt local refinement procedure was implemented to improve solution quality. We applied our ACO algorithm to largest hypothetical FTPP presented in Contreras at al. (2008), which is medium scale, grid-shaped hypothetical FTPP with 500 road segments (where traffic is allowed on both directions), 25 timber sale locations, and a single mill destination. Four cases with increasing levels of sediment constraints were considered, and an exhaustive parameter search process was conducted to select the best parameter combination for each case. To test the robustness of the ACO-algorithm, we created 10 different FTPP instances with different location of timber sales and destination nodes on the same hypothetical problem.

II. MIP MODEL FORMULATION

We formulated the problem of finding transportation routes from multiple timber sale locations to selected mill destinations that minimize total fixed and variable costs subject to a sediment constraint for a single period as follows:

$$\text{Minimize } Z = \sum_{ij\in E} VC_{ij} \times Vol_{ij} + FC_{ij} \times E_{ij} \qquad [1]$$

Subject to:

$$\sum_{ij\in E} (Sed_{ij} \times E_{ij}) \le SedRct \qquad [2]$$

$$VolS_j + \sum_{ij\in L} Vol_{ij} - \sum_{ij\in L} Vol_{ij} = 0 \qquad \forall j \in S \qquad [3]$$

$$\sum_{ij\in L} Vol_{ij} - \sum_{ij\in L} Vol_{ij} = 0 \qquad \forall j \in T \qquad [4]$$

$$\sum_{ij\in L} Vol_{ij} - \sum_{j\in S} VolS_j = 0 \qquad j = D \qquad [5]$$

$$M \times E_{ij} - (Vol_{ij} + Vol_{ji}) \ge 0 \qquad \forall ij \in E \qquad [6]$$

$$Vol_{ij}, Vol_{ji} \ge 0 \qquad \forall ij \in E \qquad [7]$$

$$E_{ij} \in \{0,1\} \qquad \forall ij \in E \qquad [8]$$

Equation 1 represents the objective function where VC_{ij} is the variable cost (\$/m^3) over the edge *ij*, Vol_{ij} is the volume (m^3) transported over the edge, FC_{ij} is the fixed cost (\$) for edge *ij*, E_{ij} is the binary variable representing weather volume traffic exist over edge *ij*, and E is the total number of edges forming the transportation network. Equation 2 represents a single sediment constraint to limit the total amount of sediment (tons) expected from the entire road network by accounting for sediment yield on each edge (Sed_{ij}) if traffic exists over the edge. Conservation of flow constraints [3-5] ensure that the all volume entering the network can be routed to selected mill location. Equations 3, 4, and 5 apply to nodes representing timber sale locations (S), intermediate nodes (T), and the destination node (D) respectively, where $VolS_j$ represent the volume entering timber sale *j*, and L is the set of edges having node *j* as a from-or-to node. Equations 6 are road trigger constraints that ensure that if traffic exists over edge *ij*, fixed cost and sediment yield are accounted, where M is a constant larger than the total volume entering the network. Equations 7 and 8 are non-negativity constraints and binary value constraints.

III. ACO ALGORITHM

A. Ant Travelling Mechanism

In our ACO algorithm, one ant is placed in each entry node (timber sale location). Ants move sequentially through adjacent nodes until the destination node (mill) is reached. After all ants have found the best routes connecting each timber sale to the selected destination node, one iteration is completed. An ant selects what node to visit next based on a random number and a transition probability calculated for each adjacent edge as follows:

$$\rho_{ij}(c) = \frac{(\tau_{ij})^{\alpha} \times (\eta_{ij})^{\beta}}{\sum_{ik \in N_i} (\tau_{ik})^{\alpha} \times (\eta_{ik})^{\beta}} \quad [9]$$

where $\rho_{ij}(c)$ is the transition probability with which an ant select edge ij during iteration c, $N_i$is the set of edges having node i as a from-node, α and β are parameters that control the relative importance of the pheromone trail intensity (τ_{ij}) and the visibility values (η_{ij}) on the edge ij. Trail intensity refers to the amount of pheromone in the edge and indicates how often the edge has been selected in previous iterations. Visibility is usually calculated as a value representing the a priori quality of selecting an edge. In our ACO algorithm, visibility values are calculated differently in stages I and II. During Stage I, ants are set to rapidly find feasible solutions without consideration of transportation costs. Thus visibility values on each edge are calculated as the reciprocal of the associated sediment yields. After a feasible solution has been found, Stage II starts and visibility values on each edge are calculated based on the reciprocal of sediment amount, fixed cost, and variable cost. Equations 10 and 11 show the resulting functions to calculate transition probability values on each edge during Stages I and II, respectively.

$$\rho_{ij}(c) = \frac{(\tau_{ij})^{\alpha} \times (Sed_{ij}^{-1})^{\beta}}{\sum_{ik \in N_i} (\tau_{ik})^{\alpha} \times (Sed_{ik}^{-1})^{\beta}} \quad [10]$$

$$\rho_{ij}(c) = \frac{(\tau_{ij})^{\alpha} \times [\lambda\left(\frac{FC_{ij}}{\sum_s Vol_s} + VC_{ij}\right) + (1-\lambda)(Sed_{ij}^{-1})]^{\beta}}{\sum_{ik \in N_i} (\tau_{ik})^{\alpha} \times [\lambda\left(\frac{FC_{ik}}{\sum_s Vol_s} + VC_{ik}\right) + (1-\lambda)(Sed_{ik}^{-1})]^{\beta}} \quad [11]$$

where; λ and (1- λ) indicate weights given to costs and sediment yield values.

As aforementioned, ants move through adjacent nodes via edges, sequentially from each timber sale to the destination node. Starting at the first timber sale, an ant finds a route to the destination node. Then another ant starts from the next timber sale, and so on. During the route finding process, if an ant visits a node that is part of a previously found route, the ant stops the route finding process and the remaining route to the destination node is attached to the current route. An example is shown in figure 1a where the sequence of timber sales (number next to green circles) is n_1, n_5, n_4, n_3, n_2. Here, the selected route from the first timber sale to the destination ($n_1 \rightarrow n_7 \rightarrow \ldots \rightarrow n_{38} \rightarrow n_{40}$) is shown as a black path. Then, while building a route from the second timber sale, a node part of a previous route if found (n_{31}), the ant stops moving through adjacent nodes, and the remainder of the route to the destination node is attached to the current route resulting in the following route: $n_5 \rightarrow n_3 \rightarrow \ldots \rightarrow n_{31} \rightarrow n_{34}$ $n_{38} \rightarrow n_{40}$. As the third and fourth timber sales in the sequence (n_4 and n_3 respectively) are already part of a previously found route, ants are not required to find a new route. Thus the routes for the third and fourth timber sales are: $n_4 \rightarrow n_9 \rightarrow n_3 \rightarrow \ldots \rightarrow n_{38} \rightarrow n_{40}$ and $n_3 \rightarrow n_8 \rightarrow \ldots \rightarrow n_{38} \rightarrow n_{40}$. Lastly, the ant finding a route from the fifth timber sale to the makes only one move until a node part of a previous route is found. The resulting route is $n_2 \rightarrow n_3 \rightarrow \ldots \rightarrow n_{38} \rightarrow n_{40}$. This ant travel searching mechanism is designed specifically for the FTPP with fixed and variable costs, where sharing edges by multiple timber sales often reduces fixed costs.

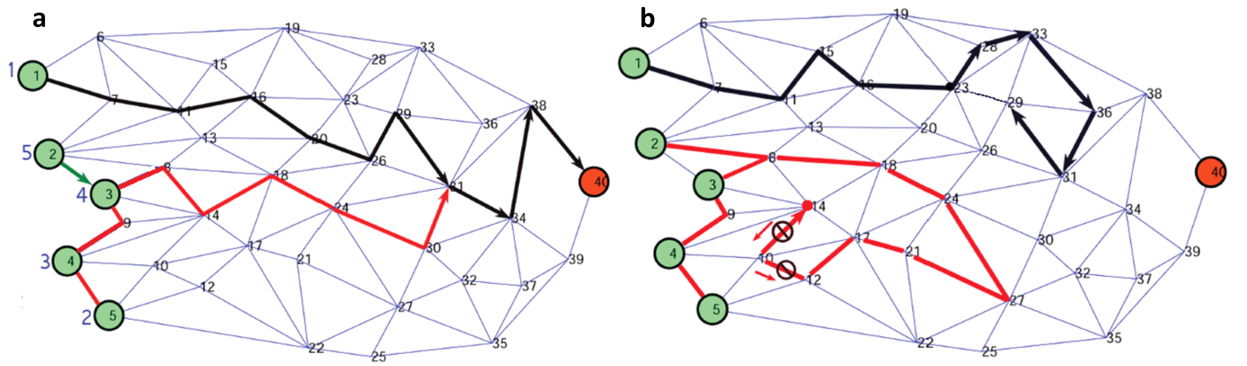


Figure 1: Ant travelling mechanism implemented into the ACO algorithm showing a) route searching process and b) back-track procedure.

When an ant is finding a given route, it is set to ignore previously visited nodes along the current route to avoid forming circles. If there is no available nodes to be selected because all adjacent nodes are already part of the current route, the ant will move back through one edge to the previous node and mark the node as unavailable. The back-tracking process continues until nodes become available. Figure 2b shows the case where an ant, after traveling to n_{29}, has only one node available (n_{26}) to visit next to avoid building a circle, and after traveling to n_{14} it has to back-track twice to n_{10} and then to n_{12} to have available nodes to visit next.

B. Local Search Refinement

Local refinement procedures have shown to improve solution quality for different ACO based algorithm (Stützle, 1999; Gambardela and Dorigo, 2000; Lopez-Ibañez and Stützle, 2012). In our application, a local search in the form of a 1-opt routine was implemented into our algorithm. Similar to the calculation of transition probabilities (Eqs. 10-11), the local search is based on sediment yield (Sed_{ij}^{-1}) only during Stage I and based on all three edge attributes during Stage II ($\left(\frac{FC_{ij}}{\sum_s Vol_s} + VC_{ij}\right) + (Sed_{ij}^{-1})$). After an iteration is completed, the local search procedure consists of looking at each node along the routes forming the solution and its adjacent nodes also forming the solutions. For a given node n_i forming a route s ($n_S \rightarrow \ldots \rightarrow n_i \rightarrow \ldots \rightarrow n_n$), the local search procedure looks at adjacent nodes of n_i other than n_{i-1} and n_{i+1} along the route and evaluates the edges to these nodes to determine if there is a shortcut that eliminates either n_{i-1} or n_{i+1} from the route. Figure 2 show an example of a selected route (red path fig. 2a) on which the local search refinement procedure is applied and resulting in the elimination n_7 and n_{11} from the route.

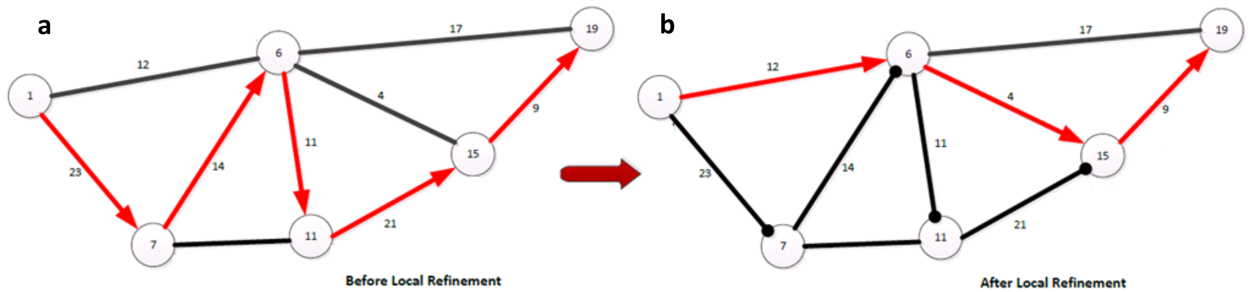


Figure 2: Diagram illustrating the 1-opt local search refinement procedure implemented into our ACO algorithm.

When routes from each timber sale location to the destination have been found at the end of an iteration and the local search procedure has been performed on all routes, all edges forming the solution are identified, the objective function is computed, and solution feasibility is evaluated. If the current solution is not better than the best found so far or is infeasible, the solution is ignored, the pheromone trail intensities remain the same, and another iteration begins. However, if the current solution is better than the best solution found so far, the current solution becomes the new best solution, and the pheromone trail intensity of the edges forming the solution is updated. At the same time, pheromone intensity on all edges decreases (evaporates) to avoid unlimited accumulation of pheromone.

C. Pheromone Update

Pheromone evaporation is a common procedure implemented in ACO algorithms to avoid a rapid convergence towards a suboptimal solution, allowing the exploration of other areas of the solution space. In our ACO algorithm, pheromone trail intensity is updated using the following equation:

$$\tau_{ij}(c+1) = \tau_{ij}(c) \times \rho + \Delta\tau_{ij} \qquad [12]$$

which considers two components. The first component is the current pheromone trail intensity on edge ij at iteration c ($\tau_{ij}(c)$), which is multiplied by $0 \leq \rho \leq 1$, where (1- ρ) represents the pheromone evaporation between iterations c and $c+1$. The second component is the newly added pheromone amount to the edge ij and is calculated differently in Stages I and II. Consistent with the purpose of obtaining feasible solutions, $\Delta\tau_{ij}$ is calculated based on sediment yield (Eq. 13). On the other hand, during Stage II, $\Delta\tau_{ij}$ is calculated based on all three edge attributes (Eq. 14), similar to the transition probability functions (Eq. 11)

$$Stage\ I \rightarrow \Delta\tau_{ij} = \begin{cases} \dfrac{Q}{Sed_{ij}}, & if\ edge\ ij\ is\ part\ of\ the\ solution \\ 0\,, & otherwise \end{cases} \qquad [13]$$

$$Stage\ II \rightarrow \Delta\tau_{ij} = \begin{cases} \dfrac{Q}{\left[\lambda\left(\dfrac{FC_{ik}}{\sum_s Vol_s} + VC_{ik}\right) + (1-\lambda)(Sed_{ik}^{-1})\right]}, & if\ edge\ ij\ is\ part\ of\ the\ solution \\ 0\,, & otherwise \end{cases} \qquad [14]$$

where Q is a constant with a value set to ensure that the amount of pheromone added to the edge ij slightly increases the selection probability of the edge during the next iteration. In our ACO algorithm Q was 0.00001.

Three stopping criterion are implemented into our ACO algorithm to address solution quality stagnation and solving time efficiency. During the Stage I the algorithm tracks the number of iterations evaluated, and if a user-defined maximum number of iterations (It_{sed}) is exceeded without finding a feasible solution, the algorithm stops and reports “no feasible solution found”. During Stage II, the algorithm tracks the number of consecutive infeasible iterations, and if it exceeds a user-defined maximum number (It_{infeas}), then the algorithm stops and reports the best feasible solution found. Each time a feasible solution is found, the algorithm resets the associated counter to zero. Also during Stage II the algorithm tracks the number of consecutive feasible solutions found of inferior quality than the best found so far, and if it exceeds a user-defined maximum number (It_{feas}), the algorithm stops and the best feasible solution found so far is reported. In our ACO; It_{sed}, It_{infeas}, and It_{feas} were all set to 10,000.

ACO parameters have been shown to have a significant effect on solution quality. Thus we conducted an exhaustive parameter search for the four parameters in our ACO algorithm. Table 1 shows the range of values considered when searching for appropriate parameter values.

IV. HYPOTHETICAL FTPP AND EXPERIMENTAL RESULTS

Our ACO algorithm was applied to a 500-edge FTPP presented in Contreras at el. (2008) (Figure 3). This hypothetical problem allows traffic in both directions (thus 1000 edges); it considers 25 timber sale locations with a total volume of 36,500 m^3 to be delivered to one mill destination in a single period. Variable cost, fixed cost, and sediment yield per edge ranged from \$0.01/m^3 to \$10/m^3, from \$0.1 to \$ 23,000 for road construction and maintenance, and from 0.4 to 200 tons, respectively. We also considered four cases with increasing level of sediment constrain, as presented in Contreras et al. (2008). Case I is a cost minimization problem without a sediment constraint, cases II and III were cost-minimization problems subject to increasing levels of upper-bound sediment constraints, 2,000 and 1,500 tons respectively, and case IV was a sediment-minimization problem without a cost constraint.

ACO parameters have been shown to have a significant effect on solution quality. Thus we conducted an exhaustive parameter search to find the best value for the four parameters in our ACO algorithm namely; $\alpha, \beta, \rho,$and λ. Table 1 shows the range of values considered when searching for the best parameter values, totaling 80,000 parameter combinations (Table 1). Each parameter combination was applied ten times and the combination providing the best solution on average was selected as the best parameter combination. This exhaustive parameter search was conducted for all four cases and resulted in a different best parameter combination for each case. Although pheromone importance (α) was relatively similar for all cases, the importance of the edge attributes (β), sediment yield and costs, increased as sediment constraint level became more limiting. Pheromone persistence (ρ) increased with increasing level of sediment constraint with the exception of case IV. As expected the importance the sediment yield ($1-\lambda$) increased as the sediment restriction level increased.

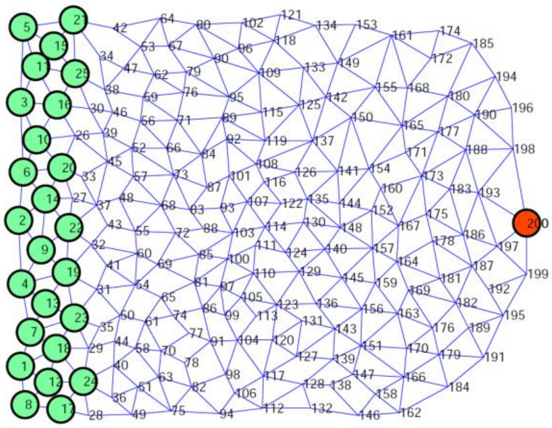


Figure 3. Hypothetical FTPP considered in this study, from Contreras et al. (2008)

Table 1. Range of parameter values considered in this study

Parameter	Interval	Pace
α	[0,1]	0.05
β	[0,1]	0.05
ρ	[0,1]	0.05
λ	[0,1]	0.1

Table 2. Best parameter combination found for each case

Case	α	β	ρ	λ
I	0.5	0.4	0.55	1
II	0.5	0.9	0.6	0.7
III	0.5	0.7	0.65	0.7
IV	0.45	1	0.15	0

The four cases of the hypothetical FTPP were solved to optimality by the MIP solver, providing an updated benchmark for cases III and IV for which optimal solutions were not found in Contreras et al. (2008). Our ACO algorithm was able to find the optimal solution for cases I and IV improving the solution quality when compared to approximately 98% reported in Contreras et al. (2008). We used these two unconstrained FTPP (cases I and IV) as a reference to obtain a meaningful sediment constraint range and set two increasing levels for the constrained cases. As the ACO algorithm presented in this study was designed to address constrained FTPP, it was able to reach high quality solutions for all cases and instances. The best found ACO solutions for cases II and III, achieved optimality levels of 96.7% and 96.1%, respectively, which are comparable to those reported by Contreras et al. (2008) (94.8% and 97.6%).

Table 3. Objective function comparisons between MIP and ACO solutions for the Hypothetical FTPP.

Case	ACO (Objective value)	Sediment constraint value (tons)	MIP (Objective value)	Percent difference
I	1,496,562	N/A	1,496,562	0.00%
II	1,637,860	2,000	1,585,393	3.31%
III	2,086,280	1,500	2,008,344	3.88%
IV	948.6	N/A	948.6	0.00%

To test the overall robustness of the ACO algorithm and to test its ability to consistently find high quality solutions on different FTPP of similar size using the same parameter values found for the original HTPP, we created a set of 10 different problem instances on the same transportation network (Figure 3). These ten problem instances were created by randomly assigning timber sale locations and the mill destination to different nodes (Figure 4). Timber volume at each sale location as well as the three edge attributes (fixed and variable transportation costs and sediment yield) on each edge remained the same for all problem instances. As with the original FTPP, we also considered the four problem cases with increasing level of sediment constraint. In order to compare ACO solution quality, we used the MIP solver to obtain optimal solutions. The total sediment amount associated with the optimal solution for case I (cost minimization) and the objective function of the optimal solution for case IV (sediment minimization) were used as the upper and lower limits of the sediment constraint in cases II and III. For all ten instances, one third and two thirds of the difference between the upper and lower limits were subtracted from the upper limit to determine the sediment constraint values for cases II and III, respectively.

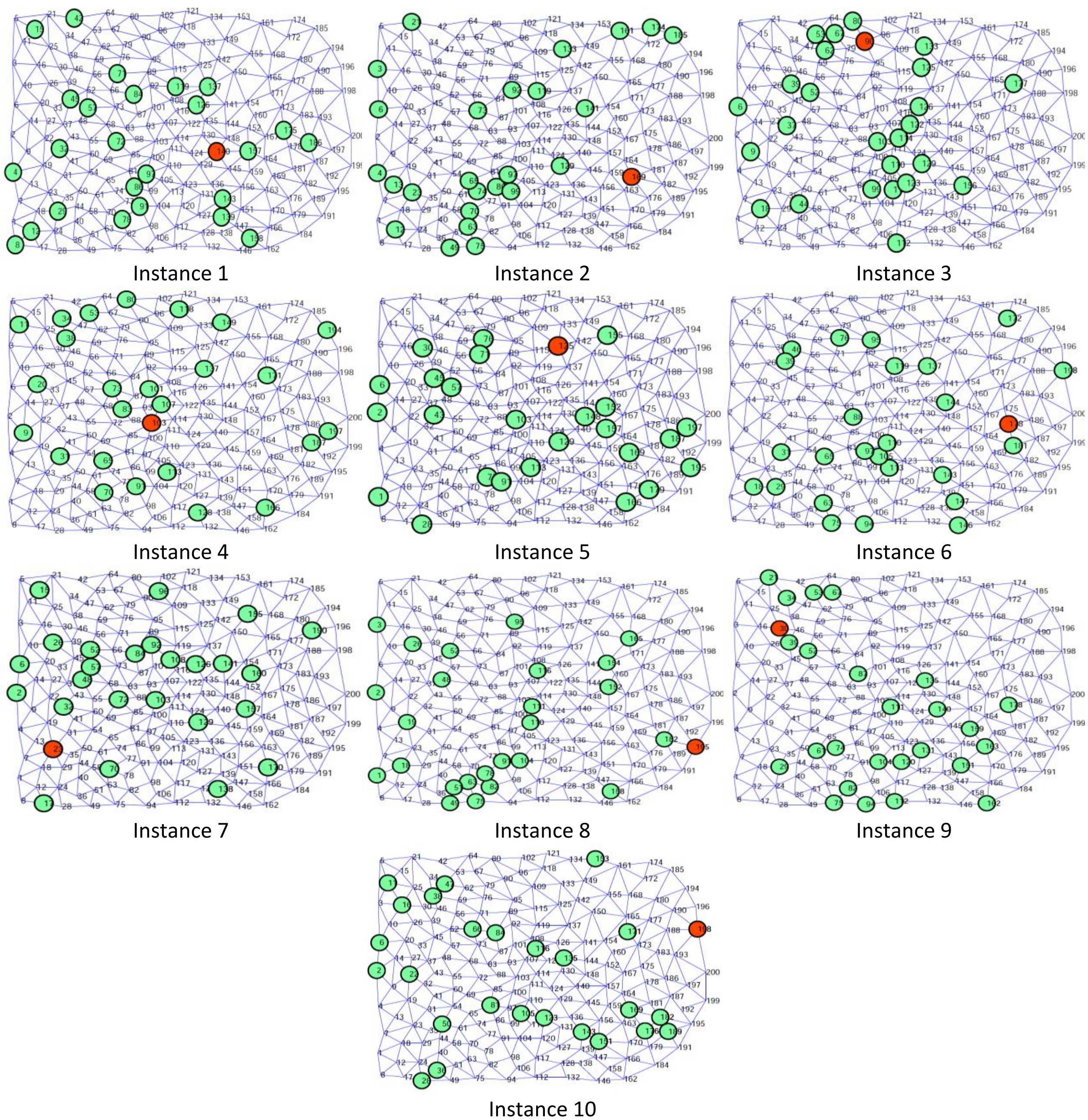


Figure 4. Ten problem instances created on the hypothetical FTPP considered in this study.

The ACO algorithm was able to successfully solve all FTPP, four cases for each of the ten instances, obtaining high quality solutions and in many cases matching optimal solutions. For case I, the ACO algorithm was able to find optimal solutions for seven of the ten instances, and on average for all ten instances ACO solutions were 99.8% optimal. For case IV, the ACO algorithm found optimal solutions for all problem instances but number five, which solutions quality was 99.6%. ACO solutions for the constrained FTPP (cases II and III), for which the ACO algorithm was designed, also provided near-optimal solutions. For case II, ACO solution quality ranged from 97.7% to 99.9% with an average solution quality of 98.9%. As problem complexity increased in case III due to the more strict constraint, ACO solution quality averaged 97.8% with a range between 95.3% and 100%. Consistently for all problem instances, solution quality for case II was slightly better than for case III, mainly because of the fewer feasible solutions evaluated per unit of time.

Table 4. Objective function comparisons between MIP and ACO solutions for cases II and II of the ten different problem instances.

Instance	Case	ACO (Objective value - $)	Sediment constraint (tons)	MIP (Objective value - $)	Percent Difference
1	II	887,719	2,159	878,749	1.02
	III	1,027,550	1,727	981,203	4.72
2	II	1,416,090	2,490	1,415,960	0.01
	III	1,619,740	1,860	1,563,669	3.59
3	II	1,055,330	2,254	1,048,768	0.63
	III	1,174,630	1,746	1,170,956	0.31
4	II	914,972	2,449	910,152	0.53
	III	1,043,763	1,778	1,043,763	0.00
5	II	1,203,500	2,445	1,181,284	1.88
	III	1,301,920	1,945	1,260,541	3.28
6	II	1,212,620	2,354	1,208,610	0.33
	III	1,398,950	1,760	1,355,860	3.18
7	II	1,089,140	2,672	1,066,148	2.16
	III	1,164,660	1,978	1,164,368	0.03
8	II	1,241,760	2,660	1,229,392	1.01
	III	1,418,220	1,971	1,361,841	4.14
9	II	1,410,850	2,262	1,378,432	2.35
	III	1,679,540	1,734	1,636,147	2.65
10	II	1,403,150	2,342	1,394,355	0.63
	III	1,634,760	1,750	1,628,223	0.40

In general, the ACO algorithm was able to produce near-optimal solutions for all constrained FTPP. Although MIP was able to find optimal solution, the ACO algorithm only required a fraction of time (Table 5). On average, the best solution found by the ACO algorithm required about 25% (18 vs. 79 sec) and 1% (24 vs. 1678 sec) of the computing time required by the MIP solver to find the optimal solution for cases I and IV. For case II, the ACO was relatively similar taking between 190 and 960 sec with an average of 544 sec. On the other hand, computing time required by the MIP solver was about 18 times larger (9,949 sec). Due to the complexity of the problem, ACO and MIP solution times for case III were on average much larger and variable than those for case II. ACO solution times varied from 360 to 29,000 sec with an average of 5,370 sec, which is only about 7.3% of the average time required by the MIP solver.

Table 5. Comparison of computing times (sec) for a single run required by the ACO algorithm and the MIP solver for the four cases of each ten instances.

Instance	ACO				MIP			
	Case I	Case II	Case III	Case IV	Case I	Case II	Case III	Case IV
1	17	434	363	23	41	3,254	31,722	2,790
2	14	263	2,732	25	134	62,314	90,973	500
3	16	790	428	25	65	3,532	21,893	2,147
4	21	708	396	23	95	4,732	36,385	1,275
5	18	190	29,051	19	64	3,110	149,585	54
6	21	304	8,885	24	69	4,344	97,582	2,922
7	21	905	371	28	76	1,333	31,540	2,933
8	20	371	10,722	31	68	8,458	55,516	1,786
9	14	509	332	20	84	1,182	152,629	1,157
10	20	962	419	26	98	7,225	59,597	1,212
Average	18	544	5,370	24	79	9,949	72,742	1,678

V. CONCLUSIONS AND FUTURE WORK

We developed a customized ACO algorithm to solve FTPP considering fixed and variable costs as well as a sediment constraint representing the negative environmental impact of timber transport. The ACO metaheuristic, as most approximation algorithms, is highly dependent on problem specific fine tuning of parameters to ensure high quality solutions. Consequently, after conducting an exhaustive parameter search process on the hypothetical FTPP considered in this study, the ACO algorithm was able to find optimal and near-optimal solutions. The best parameter combination found for each case of the original hypothetical FTPP was applied to ten different problem instances. Resulting ACO solutions for the constrained problem (cases II and III) were on average 98.4% optimal, which indicated consistent results and overall robustness of the algorithm.

The algorithm developed in this study has a great application potential to ensure the economic efficiency of timber transport operations, which is the largest cost component of timber harvesting. However, the ACO algorithm needs improvement to ensure solution quality and time efficiency for larger and more complex, real-world FTPP. Future work should focus on time efficient technique to fine tune parameter values without the need to conduct an exhaustive parameter search. The current version of the algorithm coded in a sequential fashion, thus incorporating parallelization is likely to reduce solution time and allow addressing large-scale problems.

VI. REFERENCES

Adlakha, V., K. Kowalski. 2003. A simple heuristic for solving small fixed-charge transportation problems. OMEGA Int. J. Manage. Sci. 31:205-211.

Bettinger, P., K. Boston, J. Sessions. 1999. Intensifying a heuristic forest harvest scheduling search procedure with 2-opt decision choices. Can. J. For. Res. 29:1784-1792.

Chung, W., and Sessions, J. 2003. NETWORK 2000: a program for optimizing large fixed and variable cost transportation problems. In Proceedings of the 8th Symposium on Systems

Analysis in Forest Resources, 27–30 September 2000, Snowmass Village, Colorado. G.J. Arthaud and T.M. Barrett (Eds). Kluwer Academic Publishers, the Netherlands. pp. 109-120.

Contreras, M., W. Chung, G. Jones. 2008. Applying ant colony optimization metaheuristic to solve forest transportation planning problems with side constraints. Can. J. For. Res. 38: 2896-2910.

Efta, A. and W. Chung, 2009. A Methodology for Implementing Best Management Practices using WEPP:Road Erosion Modeling and a Simulated Annealing Algorithm. In Proceedings of the 2009 Council on Forest Engineering, June 15-18, Kings Beach, CA. 12pp.

Grace III, J.M, B.D. Clinton. 2007. Protecting soil and water in forest road management. Transactions of the ASABE 50:1579-1584.

Jones, G., A. Weintraub, M. Meacham, A. Megendzo. 1991. A heuristic process for solving mixed-integer land management and transportation problems planning models. USDA For. Serv. Intermountain Res. Stn. Res. Pap. INT-447.

Li, R., P. Bettinger, K. Boston. 2010. Informed development of meta heuristics for spatial planning problems. The Open Operational Research Journal 4:1-11.

Kowalski, K. 2005. On the structure of the fixed charge transportation problem. Int. J. Math. Educ. Sci. Technol. 36:879-888.

Martell, D., Gunn, E., and Weintraub, A. 1998. Forest management challenges for operational researchers. Eur. J. Oper. Res. 104: 1–17.

Olsson, L., and Lohmander, P. 2005. Optimal forest transportation with respect to road investments. For. Policy Econ. 7: 369–379.

Rackely, J. and Chung, W. 2008. Incorporating forest road erosion into forest resource transportation planning; a case study in the Mica Creek Watershed in Northern Idaho, U.S.A. Transactions of ASABE 51:115-127.

Schnelle, W.F. 1977. A brief guide to ‘‘MINCOST’’ (CSSG*RILIB. MINCST2). USDA For. Serv., Northern Region Engineering, Missoula, Mont.

Sessions, J. 1985. A heuristic algorithm for the solution of the fixed and variable cost transportation problems. In Proceedings of the 1985 Symposium on Systems Analysis in Forest Resources, 9–11 December 1985, Athens, Georgia. Edited by P.E. Dress and R.C. Field. University of Georgia, Athens, Ga. pp. 324–336.

Sessions, J., Chung, W., and Heinimann, H. 2003. New algorithms for solving large-scale transportation planning problems. In Workshop Proceedings: New Trends in Wood Harvesting with Cable Systems for Sustainable Forest Management in the Mountains, 18–24 June 2001, Ossiach, Austria. Edited by U. Arzberger and M. Grimoldi. pp. 253–258.

Weintraub, A., and Dreyfus, S. 1985. Modifications and extensions of heuristics for solving resource transportation problems. Cooperation Agreement Final Report. University of California, Berkeley, Calif.

Steinberg, D.I. 1970. The fixed charge problem. Naval Research Logistics Quarterly 17:217-235.

Performance of a Prototype 'ELoad Sheet' for Monitoring Timber Hauling Operations

Timothy McDonald[1], Frank Corley[2], Nick Hindman[2]

Abstract

Contract loggers can spend many hours each week accounting for transported wood. The accounting is necessary to resolve payments to contract haulers and landowners, to invoice consuming mills for delivered products, and to document pay and compliance with legal restrictions for drivers. The standard method used to track wood movements generated from a contractor has been something known as a `load sheet', typically kept at the logging deck and listing a unique load number, the tract from which the wood was cut, and a time. Load sheets are most often filled out by the loader operator. In addition to load sheets, drivers sometimes keep individual track of their time spent during the day, recording loads, delivery points, scale ticket numbers, fuel consumed, and many other items. Together these data are used to manage the hauling operation and their upkeep represents a great deal of administrative overhead cost to the contractor.

Mobile technology has the potential to replace all the paper record keeping used currently with a simple, cost effective device to automatically track data necessary for accounting, plus provide additional data for improved management of trucking systems. This study will be an effort to develop data collection systems deployable in log trucks that can, with minimal interaction with the driver, provide all necessary information related to timber hauling. It is anticipated the technology will also provide information not currently available, particularly a location for events such as setting out a trailer or off-route excursions by drivers. We anticipate providing details on the development of the software, an overview of its operation, and metrics concerning its performance relative to traditional accounting systems.

[1] Associate Professor, Biosystems Engineering, Auburn University
[2] Corley Land Services

Montana Logging Costs 2013-An Engineering Approach

Josh Meek[1], Steve Hayes[2], Beth Dodson

Abstract

Montana's forest products industry has changed significantly in the past decade. Decreased timber harvest, decreased employment in all forestry-related sectors, increased focus on ecosystem management and concerns of climate change, and an increased supply of smaller diameter timber have all led to important changes within the industry. Consequently, there is a need to update harvest-related costs across the board to reflect this shift in operations and to provide an easy to use resource for those interested in sustainable forest operations. The Bureau of Business and Economic Research (BBER) puts out logging cost data every two years; this data is based on expert opinion surveys sent to loggers in Montana and Idaho. Costs are calculated by identifying several timber harvest scenarios where loggers give their best estimate to what it would cost them to complete these scenarios. There has been a need identified to validate these responses by means of collecting fixed and variable costs for everything from total machine costs (including insurance, maintenance, depreciation values, etc…) to labor and other operating costs. While this information does already exist in several venues, it does not formally exist in a setting specific to Montana. To accomplish this, equipment dealers, insurance agencies, labor bureaus, county tax authorities, and loggers in western Montana were interviewed during the late winter/early spring of 2013. Costs were assembled in a spreadsheet and will serve as a means to validate survey responses for the upcoming round of production-level logging cost estimates developed by the BBER.

Introduction:

The field of forestry has long been one of Montana's foremost industries and our state has historically had a significant role in the Northwest's important forest industry. The industry has, of course, changed significantly from its early days, and is much different now than it was even twenty years ago. Harvest volumes have decreased by 64% since 1993 and consequently, so too have employment numbers (11,895 workers in 1993 to 6650 in 2012) and sales revenue from finished product (71% decrease) (Morgan et al. 2013). These factors combined with new ideas on how best to manage the nation's forests have significantly altered the nature of Montana's forest industry. To remain competitive and in touch with contemporary forestry issues, the industry in

[1] Bureau of Business and Economic Research-Research Assistant
[2] Bureau of Business and Economic Research-Research Forester
[3]College of Forestry and Conservation-Associate Professor

Montana must maintain and update its knowledge and data regarding logging cost and subsequent continued feasibility.

Over the past century, the industry has seen many ups and downs. Technological advances have greatly improved logging equipment efficiency, but have also led to increased costs across the board. In a sense, a "teeter totter" is a relevant symbol to illustrate swing in costs and revenue. That is, as logging costs increase, returned revenue decreases (generally) (Mathews 1942). The initial investment in a piece of new logging equipment has increased, as have fuel, oil, and maintenance costs. The cost of labor has followed a similar trend as have worker's compensation rates and general benefits to employees (Morgan et al 2013). At the same time, this modern equipment is faster and more efficient allowing for increased production, decreased fuel usage and emissions, and decreased need for human labor. These advances allowed by technology have been further stifled by the economic situation that Montana's timber industry faces. While advanced technology does exist that has the capacity to potentially improve harvest efficiency, whether or not this modern machinery is worth the investment is a concern of considerable measure for today's logger. Consequently, loggers and forest managers need to be aware of the costs associated with logging to be able to better handle their own future situation.

Justification:

The BBER has produced logging cost data for roughly 15 years, filling a gap left by the US Forest Service (USFS). To construct these cost estimates, the BBER surveys logging professionals in Montana and Idaho on a two year rotating basis. These surveys identify several scenarios among different harvest systems, a silvicultural prescription is given, and the logger is asked to prepare a cost estimate or bid based on these scenarios. This data is returned to the BBER where costs are then analyzed and reported.

There are several needs relevant to maintaining this logging cost data provided by the BBER. First is the need to both enhance and update knowledge on daily and hourly equipment and labor costs to act as a validation tool for the survey data returned by loggers. Second is a need to compile this data to be able to offer to loggers, forest managers, and private landowners a tool to estimate these costs "across the board". It is generally accepted that logging costs are inherently variable due to the many factors affecting the overall process. However, being able to offer at least a baseline of average costs could be a useful tool for estimation, as well as comparison between types of equipment.

Equipment and labor cost estimates have been produced in a variety of formats across the U.S. (SRS calculator, Charge-Out, various "homemade" costing spreadsheets, etc…) (USDA n.d., Bilek 2008, Brinker et al 2002). However, it has been many years since data was collected specific to the Rocky Mountain region and consequently, local loggers and managers may question the applicability of using this cost data in our own locale. Equipment and labor costs were kept regularly by Montana's commercial timber industry through the 1980s, though this data has been collected (or at least reported) less frequently with the downsizing of the industry. Thus there is a need to update this data to better serve the needs of those remaining, and to serve as a comparison to cost data from 20 years ago.

The ultimate goal of this report is to compile updated, local cost estimates for equipment deemed representative of equipment currently utilized in Montana, as well as regional labor estimates. Comparisons will be made to historic cost data specific to Montana. Future research needs are also identified, as the scope of this paper was limited by time and resources.

Methods:

For this project, we utilized equipment cost data produced roughly 20 years ago by Champion Timberlands, one of Montana's major timber companies. We attempted to replicate the format used in the historic data source almost exactly to maintain a sense of continuity between estimates. The original source had logging costs broken down in "typical engineering format" applied to the costing of individual pieces of equipment across harvest systems and include the break-out of fixed and variable costs. Specific costing aspects of each system were then broken out individually into fixed and variable costs (Caterpillar 2001, Matthews 1942). Production estimates were not included in the historic data, and consequently are not included in this report either.

The equipment costing aspect of this report relies primarily on local expert opinion and data in the form of equipment specification and cost sheets. Two equipment dealers in western Montana were contacted and direct interviews were conducted with the individual in charge of forestry equipment sales at each (Jones 2013, Ployhar 2013). These dealers were chosen based partly on accessibility, but mainly due to their respective brand of machinery being identified as a "major" participant in the local equipment industry. The question was posed to each individual as to what type of equipment is being commonly purchased and utilized in Montana today. Each equipment dealer offered to produce costs for what they considered a full, commonly-utilized "side" of a mechanical logging operation including a feller-buncher, skidder, processor, and log loader. Cost and specification sheets were furnished for each machine. In addition to data furnished by equipment dealers, insurance, tax/depreciation, maintenance, oil/lube, tires and chains, and other associated data was collected from local city and state governmental agencies.

To retain a sense of locality, "rule-of-thumb" methods from expert opinion were used to account for as many equipment cost categories as possible. While we were not able to account for each one, we were able to garner information on fuel usage, oil/lube, and maintenance costs (Jones 2013, Ployhar 2013). Otherwise, methods were used from other published sources (Brinker et al 2002, USDA n.d.). All of these costs were put in Microsoft Excel and "crunched" to produce daily and hourly rates.

Labor costs were assembled using Federal wage data, as well as Worker's Compensation, other insurance data, and other associated costs from city and state agencies, local insurance dealers, and the Montana Logging Association. Similar to the equipment costing, these numbers were "crunched" using Microsoft Excel.

Upon completion of the compilation of cost data, several local loggers were contacted and interviewed to offer input on the validity of these costs. Their input was taken into consideration and added to the Spreadsheet as applicable.

For the sake of comparison, current data was compiled and produced in a format similar to the past report. These historic costs were then inflated to current year dollars using a currency inflator provided by the BBER to aid as a comparison tool.

Assumptions:

Logging costs are incredibly variable due to numerous factors; however, we hope to offer an average cost representative of Montana's timber industry today. Several assumptions are necessary to compute this estimation:

- A 180 day working year with 36 weeks of work (5 day week)
- A 9.5 scheduled machine hour (SMH) day with 1.5 hours of overtime for equipment, and 8.0 SMH for sawyers
- 8.5 productive machine hour (PMH) per day
- Diesel fuel at $3.50 per gallon (off-road diesel)
- Insurance 1.30 per $100 (quote from PayneWest Insurance; based on 60% of new replacement value
- 6.5% interest-financing
- 3% administration cost
- 150 mile per day roundtrip for crew transportation costs

Results:

Table 1-Logging Cost Comparison between 1993 and 2013

Operation	**1993 Total Side Per Day** (Inflated to 2013 dollars)	**2013 Total Side Per Day**	**% Difference**
Sawyer	$333	$ 345	4%
Loader	$706	$ 1,053	49%
Tired Skidder-Large	$632	$ 1,123	78%
Track Skidder-Large	$734	$ 1,123	53%
Feller Buncher	$1,001	$ 1,277	28%
Processor	$945	$ 1,080	14%

The table above illustrates cost data from our historic source (column two) and data from our updated costing exercise (column three) utilizing local information for one complete mechanical logging side including operator wages specific to Montana. In regards to the contemporary data, costs were averaged across machines of comparable size, horsepower, and attachment type to produce a singular cost. As producing detailed costing data for different equipment was one of the goals of this project as means of validation for other research, more detailed data does exist internally and is available upon request

Discussion:

As illustrated above, the cost of running a total side in Montana has significantly increased over the past 20 years beyond inflation. Based on comparison to past data as well as anecdotal interviews with logging professionals, the biggest increase in costs purportedly has been in the purchase price of new equipment, diesel fuel prices, and the increased price of steel. Ultimately, our comparative data suggests that the costs of purchasing and operating equipment are huge factors in the overall increase in logging costs.

To compare initial purchase price between 1993 and 2013, costs were averaged for all equipment between years. It was found that average initial price jumped from $226,330 (inflated) in 1993 to $430,409 in 2013, an increase of 90%. However, comparison between equipment purchase price from our historic data and contemporary data proved challenging based on several factors. Most notably, equipment utilized today is mechanically and technologically much different than 20 years ago. There were observable differences in both weight and horsepower between data sets, with modern equipment having a range of 12-122% more horsepower, thus contributing to increased fuel usage, oil/lube, maintenance, and initial purchase price. Ideally this increase in power would equate to an increase in productivity, though the increase in purchase price might offset the production benefits of purchasing new equipment.

In addition to increased engine power, changing emissions standards have also arguably influenced the initial purchase of logging equipment. Federal emissions standards have been in place since 1994, with several changes occurring since (EPA 2013). These regulatory changes have and will require alterations to equipment engines in the form of advanced emission control technology, but there is a disparity in how much impact this will have on initial purchase price. This range is from a 1% increase up to 30% based on our interviews with local equipment dealers (Dieselnet 2013). Despite the variability in this range, it will be important for logging professionals to be considerate of these changes into the future.

While the mechanical side of logging equipment has changed significantly, there has also been substantial improvement in on-board technology. Most modern equipment has advanced computer systems capable of determining and processing different cut log specifications, and then storing production data for future use. For instance, John Deere is now offering an optional program they call JD Link technology that wirelessly enables mill operators to set cut specs in the mill without having to implement any changes on the machine (Jones 2013). This program also monitors how the machine is operating mechanically and when maintenance is required. Other companies offer similar services, thus ideally enabling loggers and mill operators to interact more seamlessly and improving overall efficiency. Yet, similarly to mechanical advances, there is an underlying cost associated with this improved technology that may be of further consideration when purchasing new equipment.

As stated above, the purchase price of new logging equipment accounts for a large portion of overall cost difference between our historic and contemporary data. However, other factors were brought up during conversations with our interviewees. First, the number of annual days a logger works has decreased over the past 20 years. This is due to a variety of factors, most notably market influences on consumer need and the availability of a consistent supply of timber, and consequently the work availability for loggers. Also, yearly climatic patterns influence the amount of operational days, whether it is an extended spring break-up, or a forest shut down for extreme fire danger. A second influence (and tied to the first) is the increased driving distance to get to a job site. A consequence of decreased logging employment and mill facilities means the same area is covered by fewer contractors, thus those remaining must travel further. This results in increased fuel usage and vehicle maintenance costs and becomes more prevalent on overall operational costs. A final influence is in regards to generally changing make-up of the logging contractor workforce. It's been noted in several recent publications that the logging sector is becoming increasingly older (Allen et al 2008). This is having an effect of all associated labor costs including hourly wage, worker's compensation rate, social security, and other associated taxes. Upcoming changes in the Federal health care mandate will further increase labor costs, though the exact influences are unknown at this point.

Conclusion:

Ultimately, the costs of logging have increased substantially in comparison to data from 20 years ago. While this isn't surprising, it does serve as an important reminder for those involved in Montana's logging industry. While the local economy has seen an upswing in past months, the variable nature of the forest products industry holds our own local economy in a tenuous position. While these external factors certainly play a large role in industry's future, the mere cost of operation may "make or break" an operation. Thus, it is beneficial to constantly update and maintain logging cost data to help ensure the continued success of this vital industry in Montana.

Future Research Needs:

As a result of time limitation, as well as access to data, several aspects of this costing exercise were excluded. Most noticeably, no cable logging equipment was included in this iteration. This is due mainly to the lack of new yarding equipment being bought and sold in the local area. While cable logging is still an important part of Montana's logging sector, most equipment dealers are not selling new equipment locally. That said, it is currently planned to carry this project forward and collect cable logging equipment costs from the remaining local contractors still using this equipment. Also excluded from this report were production values to equate daily cost to cost per ton or board foot, though this is also planned for the next iteration. As a result of the recent upturn in the price of delivered logs, there has been renewed local interest in the use of helicopter logging. Including this data in future research will be addressed based on apparent local interest and availability of infrastructure to provide data. Additionally, comparisons will be made to data from other regions in the United States to assess applicability of utilizing costing tools from other sources.

References:

Allen, T.T., Han-Sup H., and S.R. Shook. 2008. A Structural Assessment of the Contract Logging Sector in the Inland Northwest. Forest Products Journal 58, no. 5:27.

Bilek, E.M. (Ted). 2008. *CHARGEOUT! Discounted cash flow vs. traditional machine rate analysis*. General Technical Report GTR-178. Madison, WI: U.S. Department of Agriculture, Forest Service. Forest Products Laboratory. December. 15 p. Available online at http://www.fpl.fs.fed.us/documnts/fplgtr/fpl_gtr178.pdf, last accessed Apr. 21, 2013.

Brinker, R.W., Kinard, J., Rummer, B., and B. Lanford. 2002. Machine rates for selected harvesting machines. Circular 296 (revised). School of Forestry and Wildlife Sciences, Auburn, AL. 31 p. Available online at http://www.ag.auburn.edu/aaes/communications/circulars/cir296machine.pdf, last accessed Apr. 21, 2013.

Caterpillar Tractor Company. 2001. *Caterpillar Performance Handbook*. Edition 32. October. Peoria, Illinois.

Caterpillar Tractor Company. 2012. *Caterpillar build and quote tool*. Available online at http://buildandquote.cat.com/, last accessed April 9, 2013.

Diesel Net. 2013. *Non-road diesel engines emissions standards*. Available online at http://www.dieselnet.com/standards/us/nonroad.php, last accessed Apr. 21, 2013.

EPA. 2013. *Non-road diesel engines*. Available online at http://www.epa.gov/otaq/nonroad-diesel.htm, last accessed Apr. 21, 2013.

Jones, Bill. 2013. Personal communication. Forestry equipment manager, Triple W Equipment, Missoula, MT 59801.

Matthews, D.M. 1942. *Cost control in the logging industry*. New York, NY: McGraw-Hill Book Company. 374 p. Esp. Chapter III: "Unit costs and machine rates." pp.45-69.

Morgan, T.A., Keegan, C.E., Hayes, S.W., and C.B. Sorenson. 2013. *Montana's forest products industry*. Available online: http://www.bber.umt.edu/forest/outlook.asp, last accessed Apr. 21, 2013.

Ployhar, Mike. 2013. Personal communication. Forestry equipment sales manager, Modern Machinery, Missoula, MT 59801.

USDA Forest Service, Forest Operations Research Unit. n.d. "General Machine Rate Calculation." Website: www.srs.fs.usda.gov/forestops/downloads/MRCalculator.xls Accessed April 9, 2013.

The State of the Logging Workforce in the Southern United States

Dana Mitchell[1] and Erin J. Huffaker[2]

Abstract

There is a need to understand the current state of the logging industry. Many U.S. woods sector full-time jobs have been lost in recent years. When the forest products industry rebounds from the current market slump, will the logging workforce be ready and able to respond?

This paper utilizes publicly available data to examine variables important to understanding the current trends in woods sector employment. Southern US data is also examined to address where loggers live and work, their wages, and the potential impact of population growth and land use on the industry.

Introduction

Since 2005, the US woods sector (paper and solid wood, including primary and secondary wood-manufacturing) has seen a loss of 294,000 full-time jobs (Smith and Guldin, 2012). During this timeframe, 113,000 full-time woods sector jobs were lost in the southern states. When the forest products industry rebounds from the current market slump, how will the logging workforce respond?

The Wood Supply Research Institute (WSRI) has assisted with funding a long-term logger study that began in 1990. The project provided several annual reports with information on costs and trends in the logging industry using data that had been collected over more than 15 years. The last report was written with data collected in 2006 (Stuart et al, 2008). Over the years, some of the baseline loggers that had been the basis for the study had gone out of business and other logging businesses were selected to fill the void. Funding problems and the time-lag in reporting suspended that research project. A revamped project is expanding the geographical area for data collection and reducing the time-lag between data collection and reporting, however, much of the data from this study is privately funded and not currently publicly available.

Another study funded by WSRI examined supplier-consumer relationships. The study found that a large percentage (40%) of loggers and truckers were operating their

[1] Research Engineer, USDA For. Serv. Southern Res. Stn., 521 Devall Drive, Auburn, AL danamitchell@fs.fed.us

[2] Engineering Technician, USDA For. Serv. Southern Res. Stn., 521 Devall Drive, Auburn, AL

businesses at a loss financially, or at best break-even (Taylor, 2012). It is expected that many businesses cannot remain viable for long when operating under these types of financial conditions. An increased demand for wood by the forest products industry should improve the financial health of logging businesses.

The health of logging businesses is important to the wood products industry because of the supply and demand nature of their relationship. One indicator of the health of the wood products industry is the number of housing starts across the nation. In fact, housing starts are often cited as an indicator of investment spending and the overall economic health of the nation. Current data from the US Census Bureau (2013) indicates just how much this data fluctuates (Figure 1) on a quarterly basis. The consumer price index, mortgage interest rates, and many other variables can impact the housing starts trend.

The US Census Bureau also reports housing starts data on a regional basis (Figure 2). Examination of housing starts in the southern states region may be particularly useful because approximately 33%of the nation's forested lands are located in the 13 southern states (USDA, 2012). In fact, half of the total acreage in the south is forested. The US Census Bureau includes the following states in their definition of the US South Region: Alabama, Arkansas, Delaware, District of Columbia, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, and West Virginia. From the period April 2005 – April 2013, 50% of the housing starts were in the US-South region. Examining the April 2013 data, the US South had 47% of the housing starts. Unfortunately, the readily summarized regional data includes additional states in their definition of the US South, some of which contained densely populated metropolitan areas. However, this information is readily available on the US Census Bureau's website (2012) and aids in understanding the impact of the woods sector industry in the 13 southern states. These trends can result in impacts on logging jobs and the vigor (or lethargy) of logging businesses.

The southern region woods sector is in a unique position with a large forested land base coupled with the highest regional percentage of housing starts. Since the woods products industry typically includes forestry and logging, furniture, paper, and wood products; one can easily see that forestry and logging play an essential role. This paper examines southern logging industry to identify factors that may impact the logging workforce in the southern United States. Questions addressed include:

1. Where are the mills? The logging companies?
2. Where do the loggers live? How much are they paid?
3. What are some of the potential future impacts from population growth and land use changes?

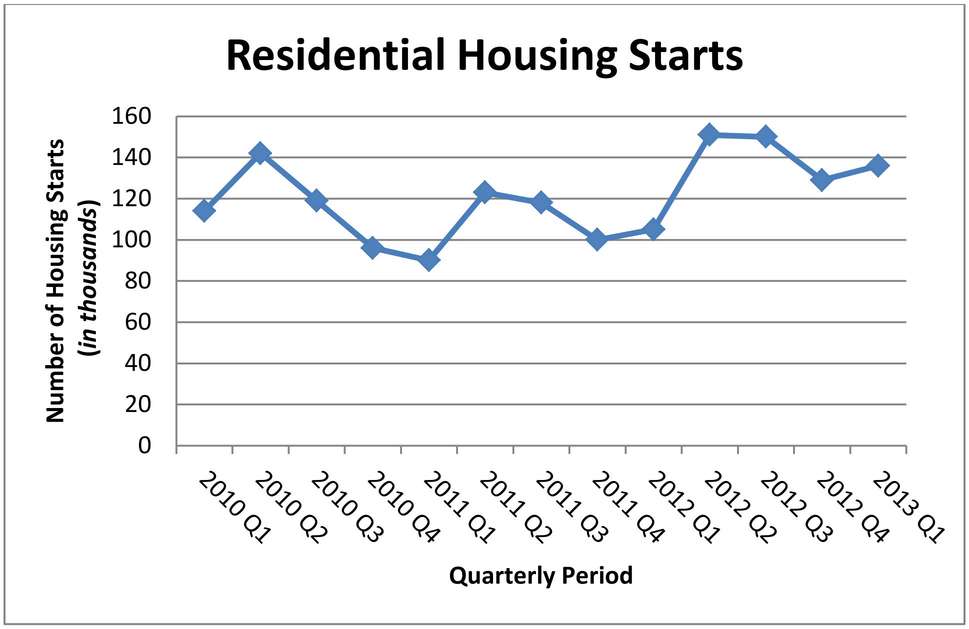


Figure 1. National Housing Starts by Quarter

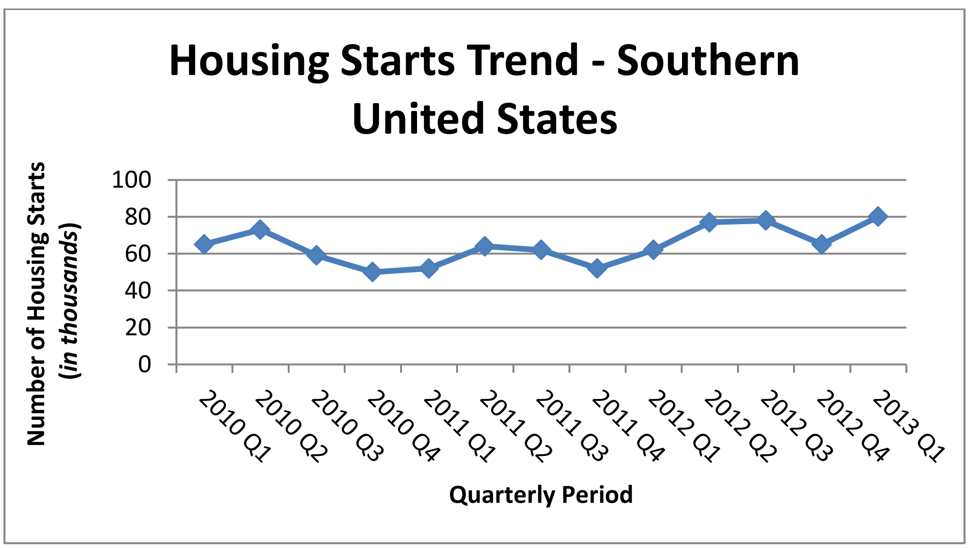


Figure 2. Southern Region Housing Starts by Quarter

The Southern Workforce

There are several sources of information that can be accessed to gather data for analyzing various aspects of forestry. Some are mailed surveys, which can report interesting data, but these frequently have a low response rate. Others are longer term surveys that collect information over a period of time, sometimes from the same set of respondents. As time goes on, businesses come and go, funding limits data collection, and other obstacles can occur. Interview data gathered person-to-person can result in meaningful information because questions can be restated and answers can be further explored as compared to mailed or other types of non-personal contact surveys. Unfortunately, substantial time and expense are required to perform person-to-person statistically relevant interviews.

An easy and inexpensive way to gather information regarding the logging workforce is to use readily available data from a variety of sources. Data from the US Census includes a vast amount of information. The US Department of Labor's Bureau of Labor and Statistics (BLS) is the 'principle agency responsible for measuring labor market activity, working conditions, and price changes in the economy' (BLS, 2013). In addition, the USDA Forest Service's treesearch website (http://www.treesearch.fs.fed.us/pubs/), Forest Inventory and Analysis (FIA) website (http://www.fia.fs.fed.us/) and other research and development websites provide additional sources of information. These sources were used to gather information regarding the southern US logging workforce and identify potential driving forces that could impact the workforce.

A series of maps were developed to gain an understanding of the current southern logging workforce. Since the logging workforce generally delivers wood to primary wood-using mills, a map was developed to see where the mills were located. Figure 3 is a graphical display of all of the mills in the southern states in 2011 (FIA, 2013). FIA data was again employed to see how much timber volume was removed from each county in 2011 (Figure 4). Lastly, the location of logging businesses according to the US Census (2010) is displayed in Figure 5.

Figures 3 and 4 provide a graphical display of where timber is produced in relation to the mill locations. Darker colors on the timber removal map (Figure 4) indicate higher timber removals. These overlay well on the mill map (Figure3) indicating that the wood is generally sourced closer to the end-user. The location of the logging businesses (Figure 5) is not quite as heavily populated near the mills. This indicates that the logging businesses that provide the wood are more scattered across the counties and do not necessarily congregate near mills.

The number of logging workers (North American Industry Classification System (NAICS) code 1133) in each county was queried using the American Fact Finder tool from the US Census (Figure 6). This data was categorized in the database, thus limiting the ability to provide further refinement. The first category included counties with less than 20 employees, while the next category included counties with 20 to 99 employees. At the regional scale, and without local knowledge, this data is somewhat limited in application. It is apparent that some of the counties with few logging businesses may actually be the home for many logging employees. One could assume that the few logging businesses in that county are large, or that the logging workers work in a different county than where they live. Local knowledge must be used to substantiate any county-level assumptions.

In general, it appears that logging employees live in more rural areas. A comparison of population densities (shown in Figure 7), and the logging employees by county (Figure 6) clearly indicates that few logging employees live in high population areas. For instance, the population densities in the 13 counties around Atlanta, GA are greater than 500 people per square mile. For this same area, 6 counties have 0 to 3 logging employees each and 5 counties have 4 to 19 logging employees each. Conversely, low population counties, such as those located just north of Mobile, AL, are home to 20 to 99 logging employees each.

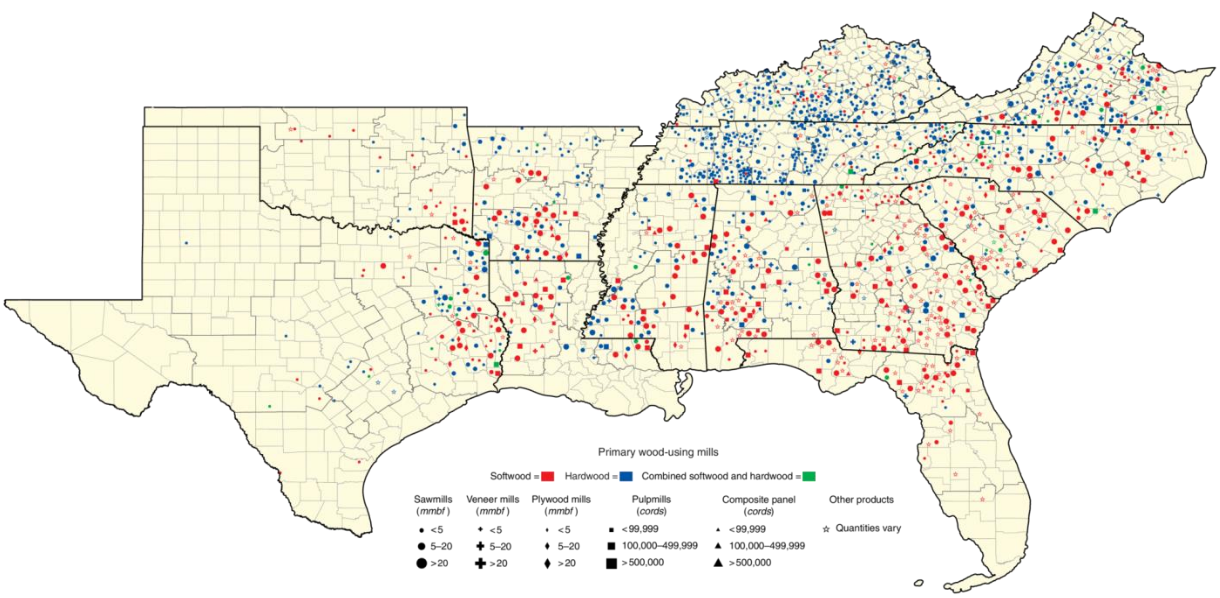


Figure 3. Primary Wood-Using Mills

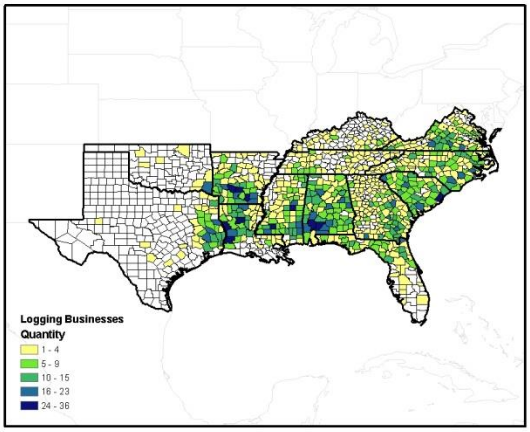


Figure 4. Location of Logging Businesses (US Census, 2010)

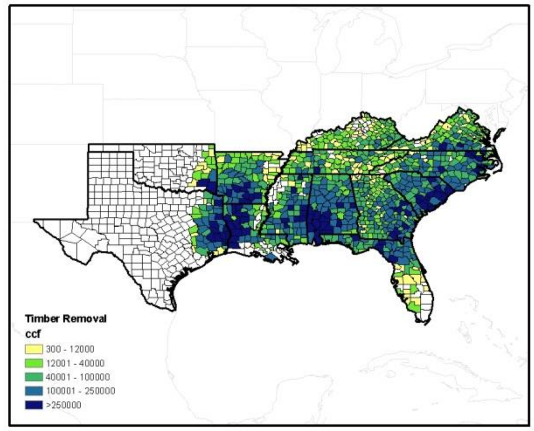


Figure 5. Location of Timber Removals (Bentley et al, 2011)

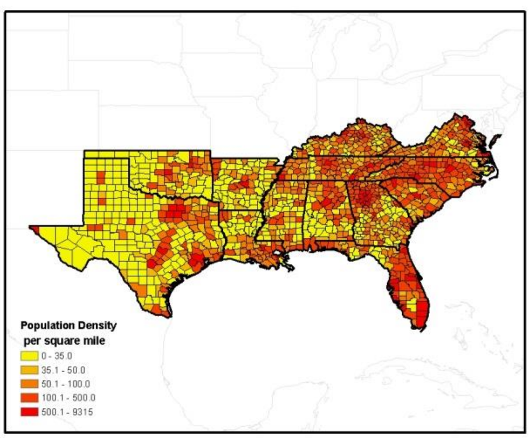


Figure 7. Population Density per Square Mile by County

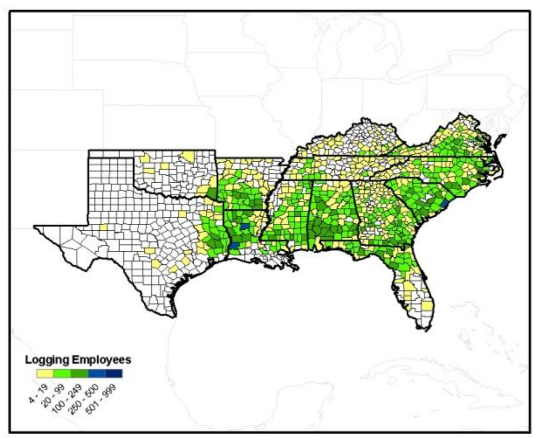


Figure 6. Logging Employees by County

Potential Future Driving Forces

Readily available data provides a snapshot of the current industry as shown in the previous figures. Some driving forces could bring about a change in the way these maps appear in the future. The Southern Forest Futures Project (Wear and Greis, 2012) performed a science- and computer modeling-based analysis of several scenarios to examine a 'variety of possible futures that could shape forests and the many ecosystem services and values that forests provide'. In their analysis, they forecast changes for 2020. Figures 8 and 9 display the population growth counties forecasted for 2020 as well as the land use change.

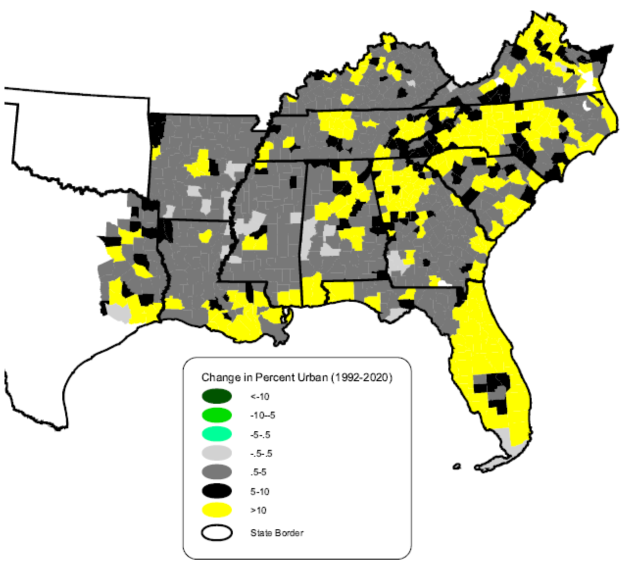


Figure 8. Population Forecast from 1992 - 2020.

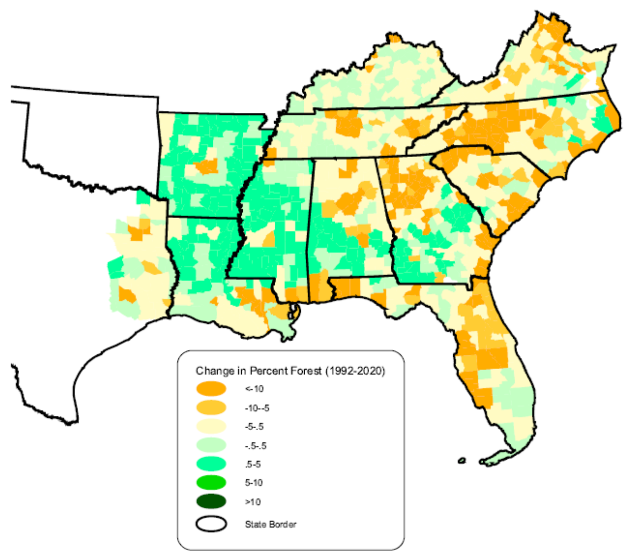


Figure 9. Forested Land Forecast from 1992 - 2020.

Given this 2020 scenario forecast, we considered some of the possible impacts to the logging community. The percentage changes shown in Figures 8 and 9 are based on the year 1992. Therefore, the relationship to the 2011 US Census Bureau-based maps isn't across the same time frame. However, the comparisons are useful and may identify trends that could impact the logging community.

In the period of 1992 to 2020, Figure 8 indicates high rates of population growth in Mississippi in the counties surrounding the capital, along the gulf coast, counties just to the south of Memphis, TN, and also in Lee County (Tupelo). Figure 7 indicates that these counties are already densely populated and Figure 6 shows that these counties are currently home to few loggers. Conversely, the counties in the southeastern corner of Georgia are home to many loggers, but those counties are projected to have a fairly high rate of urbanization. Since loggers generally live in more rural areas, how will the population change impact them? Will local policies affect loggers' ability to continue working in the same occupation? Will current logging labor rates be able to compete against new industries?

Potential losses of forest lands are visually displayed in Figure 9 and coincide with areas of increasing population density (Figure 8). Large contiguous areas in NW Georgia and areas in the northern portion of Alabama indicate a reduction in forested land for the period of 1992 – 2020. Both of these areas are currently home to logging employees. Local knowledge of current industries is needed to further refine this information. It is possible that people who identified themselves as loggers in the US Census are not actually employed in that profession, or even that smaller wood sector markets exist in the identified areas and can continue to support a small number of logging employees.

Logging Businesses in the South

In an effort to gain information on logging businesses, data from the US Census Bureau's County Business Patterns website was examined. This data provides general information, but it does have one significant limitation. The US Census includes a nonemployer status which can include businesses that do not report any paid employees. Some logging businesses won't be reported in the County Business Patterns reports because they fall into this nonemployer status category. However, the data provides readily available information and can aid in identifying trends.

The number of logging businesses has decreased from 5707 businesses in the southern 13 states in 2003/2004 to 4415 in 2009 (Table 1). This is a loss of 23% of the logging businesses across the southern states. Kentucky had the greatest loss (47%) of logging businesses. It is important to note that none of the southern states showed an increase in logging businesses during this time frame.

Table 1. Change in the Number of Timber Logging Business by State

State	2003/2004 Number of Timber & Logging Businesses	2009 Number of Timber & Logging Businesses
Alabama	822	626
Arkansas	523	382
Florida	316	242
Georgia	698	596
Kentucky	166	88
Louisiana	466	350
Mississippi	604	488
North Carolina	643	472
Oklahoma	46	36
South Carolina	456	347
Tennessee	199	146
Texas	305	257
Virginia	463	385
Total Businesses	**5707**	**4415**

Source: US Census Bureau, County Business Patterns

Logging Equipment Operator Salaries in the South

Examining logging equipment operator salaries (Standard Occupational Classification Code (SOC) 454022) was not very definitive in determining current trends in the southern logging industry. Georgia data (Figure 10) indicates that wages are higher in the areas with more dense populations (Atlanta, Macon and Valdosta). The counties along the interstates include the full range of average annual logging equipment operator wages.

Georgia's logging equipment operator wages from 2006 to the year 2011 (Figures 10 and 11) were compared (BLS, 2013). Wage data for all counties was not available. It is readily apparent that wages have fluctuated in both upward and downward directions in several counties. From 2006 to 2011, wages in many of the counties along the Florida border have increased. This area is forecast to have population growth and a decrease in forested land. A decrease in forested land could be expected to reduce the demand for logging equipment operator jobs, but as previously noted, loggers may work in a different county than where they live. Competition for employees could increase wages, the dataset may have a limited sample size at the county level, or the dataset could include workers who are identified as being logging equipment operators when their positions are not in traditional forestry-related operations. There can be many additional explanations as to why the data can't provide definitive answers, so local knowledge would be needed to examine the data at a finer scale.

One area of interest is in the southeastern corner of the state (Brantley, Camden and Glynn Counties) where forecasts include both population growth and a decrease in forested lands (Figures 8 and 9). Logging equipment operator wages in Glynn County are among the highest in the state. Logging equipment operator annual wages in Brantley County have decreased from 2006 to 2011. During this period, wages in Camden County have remained in the same category ($30,001 – 35,000 per annum). Continued population growth and forecasted land use changes could potentially impact the availability of jobs and/or wages paid for this occupation. But, this data comparison further indicates that local knowledge is important for validating this data and for performing finer-scaled analyses.

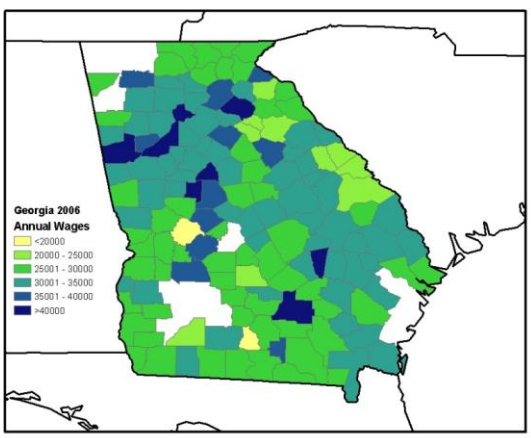


Figure 8. Annual Wages for Logging Equipment Operators in Georgia, 2006.

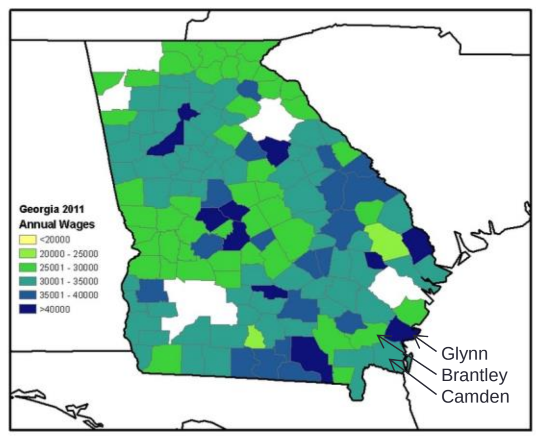


Figure 9. Annual Wages for Logging Equipment Operators in Georgia, 2011.

Summary

This review of publicly available data provides evidence that changes in logging businesses are occurring. These changes may continue due to potential future driving forces, such as population fluctuations and land use changes. Local knowledge of areas of concern is needed to validate the data, since much of it is self-reported to government entities. However, this data is available and can be used to provide broad, regional and state-wide trends of the logging workforce in the southern regions of the United States.

References

Bentley, J.W.; Tony Johnson; and B. Hendricks. 2011. Alabama’s timber industry - an assessment of timber product output and use, 2009. Resource Bulletin SRS–176. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 31 p.

BLS. 2013. BLS Information, About BLS. http://www.bls.gov/bls/infohome.htm *Accessed March 4, 2013.*

FIA. 2013. Forest Inventory Data Online (FIDO). http://www.fia.fs.fed.us/tools-data/default.asp *Accessed March 4, 2013*.

Smith, W.B., and R.W. Guldin. 2012. Forest Sector Reeling during Economic Downturn. Society of American Foresters, The Forestry Source: 17(1): 2pp.

Stuart, William B., L.A. Grace, C.B. Altizer, and J.J. Smith. 2008. 2006 Preliminary Logging Cost Indices. 17p.

Taylor, D. 2012. WSRI supplier-consumer relations project: How can we change the culture of a supply system in crisis? Forest Operations Review (14)2: 8-13.

US Census Bureau, 2010. The US Census, 2010. https://www.census.gov/2010census/ *Accessed March 4, 2013*.

US Census Bureau. 2013. New Residential Construction in April 2013. 1p.

USDA. 2012. Forest Inventory and Analysis: Fiscal Year 2011 Business Report. FS-999.

Wear, D. and J.G. Greis. 2012. The Southern Forest Futures Project: Summary Report. Gen. Tech. Rep. SRS-GTR-168. Asheville, NC: USDA-Forest Service, Southern Research Station. 54 p.

A GIS-based method for locating and planning centralized biomass grinding operations

Timothy D. Montgomery[1], Han-Sup Han[2], Anil Kizhakkepurakkal[3], Joel A. Bisson[3]

1. Graduate Research Assistant, Department of Forestry and Wildland Resources, Humboldt State University, Arcata, Californian U.S.A
2. Professor, Department of Forestry and Wild Wildland Resources, Humboldt State University, Arcata, Californian U.S.A
3. Lecturer, Department of Forestry and Wild Wildland Resources, Humboldt State University, Arcata, Californian U.S.A
4. Research Associate, , Department of Forestry and Wildland Resources, Humboldt State University, Arcata, Californian U.S.A

Abstract

The use of centralized grinding operations for biomass recovery in Humboldt County, CA has proven to be an effective logistics strategy for the production of bioenergy from woody biomass fuel and for achieving forestland management objectives. Forestland managers and biomass contractors are faced with a variety of challenges when considering the location for centralized biomass grinding operations in mountainous terrain. This article uses a Geographic Information System approach to identify feasible centralized biomass grinding sites for biomass recovery operations. The approach employs existing forest road networks, slope conditions, and processing area requirements to locate centralized landings. Network analysis is used to determine feasible centralized locations based on pre-haul distance. It is also used as a planning tool to determine available biomass per centralized location as well as pre-haul costs and distance. The study area covered over 506,600 acres of private industrial timberland in northern Humboldt County with 56,494 bone dry tons (BDT) of biomass available for bioenergy production in 2013. The suitability analysis identified 95 centralized grinding locations within the study area. Through network analysis, 37 of these locations were chosen as feasible centralized locations based on a round-trip pre-hauling distance of less than 4.62 miles. Biomass availability per centralized location ranged from 552 BDT to 3,647 BDT with an average of 1,503 available BDT. Round-tip pre-haul distances averaged 1.42 miles with an average production cost of $4.13/BDT.

Keywords: bioenergy, biomass, dump truck, GIS, network analysis, suitability analysis

Introduction

High costs of collection and transportation coupled with limited access to remote locations has proven to be a significant barrier to the utilization of woody biomass for bioenergy production (Young et al. 1988). Centralized grinding operations utilizing modified dump trucks to pre-haul forest residues to a centralized landing and chip vans to transport comminuted residues to energy facilities have proven to be an effective logistics strategy in overcoming the barriers to biomass utilization in Humboldt County. In this article, forest residues are defined as dispersed or piled remnants of timber harvesting operations, such as tree tops, branches, and small diameter trees that are left in a harvested unit as a result of cut-to-length or roadside whole-tree processing systems (Anderson et al., 2012). The location, slope gradient, and ease of access to forest residues used in bioenergy production are highly variable across the landscape (Johnson et al., 2012). Existing landings or open spaces from timber harvesting operations can provide suitable areas for centralized grinding locations and are preferred because little to no landing preparation is required in some cases (Alcorn, 2013). However, not all existing landings meet the slope, area, and access requirements needed for centralized grinding. Logistical arrangements including grinding location and haul distance on forest roads are a challenge in the western US where roads are designed to accommodate stinger-steer logging trucks, which can make log landings inaccessible by chip truck (Han et. al, 2010). In some cases, contractors can spend hours on forest roads searching for suitable sites that meet the requirements for locating a centralized grinding site (Alcorn, 2013).

A GIS modeling approach was used in this study to locate suitable areas for centralized biomass grinding operations based on forest freight accessibility, terrain requirements, and pre-hauling transportation distance. These locations are then used to plan equipment requirements, determine pre-haul costs, and estimate available biomass per grinding site.

The study area used to create the model covered 506,600 acres of private industrial timberland in northern Humboldt County, CA where timber is typically harvested using a clearcut silvicultural system. Model parameters are based on the expertise of a biomass contractor and a silviculturist with over 15 years of collective experience conducting biomass recovery operations in and around the study area. The operation utilizes a loader in a unit to load forest residues into a dump truck where it is pre-hauled to a centralized landing. The residues are then loaded into a grinder using an additional loader located in the centralized landing. The comminuted forest residues or "hog fuel" is "hot" loaded into trailers and hauled to a trailer landing by a modified all-wheel drive truck where it is then picked up and transported to an energy facility using a conventional highway truck. The use of all-wheel drive trucks allows for increased access to forest residues as they are able to navigate roads that are inaccessible by a conventional highway truck.

Although chip vans greatly increase access, they do not have the capability of loading unloaded trailers onto the truck chassis, which limits their ability to reverse and turn around, thus requiring centralized landings to be in areas that have through access or turnarounds. Additionally, the locations of centralized landings are further constricted by area and slope requirements that can make existing landings for timber harvesting unfeasible. A centralized grinding area should be roughly 10,000 ft^2 or larger in order to accommodate a horizontal grinder, loader, chip van, and piled biomass (Morris, 2013). Unloading and piling slash in a landing using a dump truck requires centralized areas to be less than three percent in slope or the operator risks tipping the dump truck backwards or on its side (Alcorn, 2013).

The location of centralized grinding sites is also influenced by dump truck pre-hauling distances and grinder productivity. System balance of the biomass recovery operation is determined by the production rate of the 1006-hp grinder, which is capable of comminuting 38.04 bone dry tons (BDT) per productive machine hour (PMH) (Bisson, 2013). In a similar cost and productivity study of centralized grinding using hook-lift trucks to pre-haul bundled forest residues, Harril et. al (2010) reported a 1,000-hp grinder productivity of 33.14 BDT/PMH. In both cases, an efficient operation is achieved through avoiding idling or delay time of the grinder by creating a stock pile of available biomass at the centralized landing that meets or exceeds the grinder's production rate. The contractor in this study is capable of running up to three dump trucks simultaneously, which are capable of accessing forest residues within a maximum 4.62 mile round trip pre-hauling distance and maintaining a productivity of 38.04 BDT/PMH. When pre-hauling distances are between 0.68 miles and 2.5 miles two dump trucks are used and distances less than 0.68 miles require only one dump truck. Units that do not have a centralized grinding location within 4.62 round-trip miles are considered inaccessible because the dump trucks can no longer match the production rate of the grinder, thus causing a delay.

The purpose of this study was to locate potential sites for centralized grinding in biomass recovery operations using suitability analysis. Network analysis is then used to find the closest path distance from a harvest site to a centralized grinding area. Locating centralized grinding areas prior to field work may save contractors time in the field finding landings. Network analysis can then be used as a planning tool to estimate pre-hauling costs, distances, and available biomass per centralized landing.

Methods

Suitability Analysis to identify potential centralized biomass grinding sites

All selected landings were located on or near a mainline road, greater than or equal to 10,000 ft^2, and less than 3% in slope. Three types of suitable locations were considered for a potential centralized grinding site: (a) those that are located in a harvest unit, on an intersection, (b) in a harvest unit and within 20-ft of a road (c) outside of a harvest unit on a road intersection. Vector-based shape-files containing harvest unit boundaries, roads, and watercourses were provided by a private industrial landowner in northern Humboldt County. A 107.64 ft^2 digital elevation model (DEM) was provided by Humboldt State University.

Landings were selected to only include those that were on or near permanent mainline forest roads that could allow for chip van through access. Mainline roads are considered suitable locations because road surfaces are graveled or highly compacted soils that allow for the grinder to operate. In addition, mainline roads run parallel to ridge tops where biomass is piled after cable yarding operations. Through access mainline roads were selected by deleting any road segments that intersected with "dangles" or dead ends. A dangle is the start or end point of any line that is not connected to another line at any location along that line (ESRI, 2012). Seasonal roads, spur roads, and dead end roads were not excluded from the analysis as they represent possible access points from a centralized landing to a harvested unit. Grinders can be placed in the intersection of spur roads where a chip van can pull in from a through road for loading (Morris, 2013). To reflect these conditions a road intersect points layer was created with a 20-ft buffer to include areas within close proximity to a road intersect.

Although biomass contractors can create landings using cut and fill construction to meet desired slope conditions, the amount earth moving is often negligible (Alcorn, 2013). Pixels with a slope value of less than 3% were converted to polygons. Any polygon greater than 10,000 ft^2, excluding any portion that was in a watercourse and lake protection zone (WLPZ) or equipment exclusion zone (EEZ) was selected. A 20-ft buffer was created for polygons that were located within a harvested unit. If a polygon's buffer region intersected a permanent road it was also selected. In harvested units, trees and stumps can be removed in order to create a suitable area and provide access to roads (Alcorn, 2013). All vector layers were then converted into 107.64-ft^2 resolution raster files used in the suitability analysis. Suitability factors, shown in Table 1, were ranked based on professional expertise and guidance.

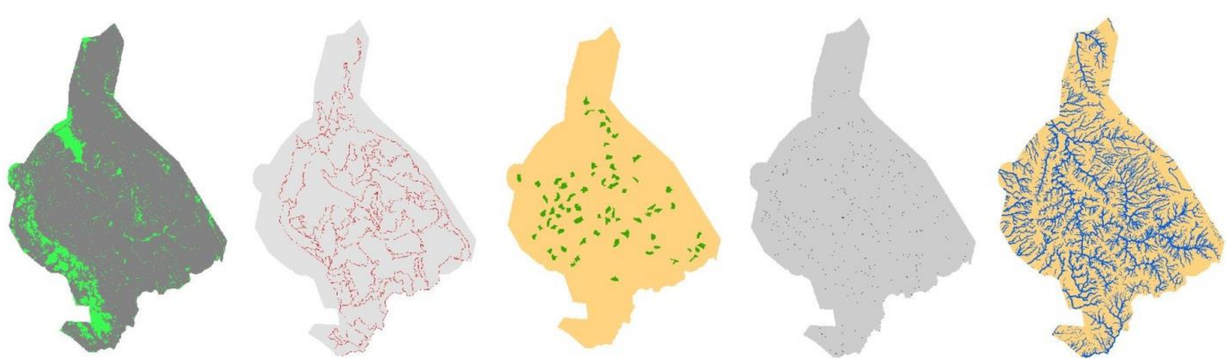
Table 1. Centralized biomass grinding sites suitability criteria and ranking values

Criteria and Ranking	
Suitability values	Assigned influence
Chip van accessibility/ located on mainline road)	3
Slope <= 3%	3
Within harvest unit and 20 ft or less from road	2
20 ft or less to road intersection/spur road access	1
Total	9

Soil type was not included as a model parameter as biomass operations occur during late spring and summer months when soils are dry. In addition, mainline road surfaces are often rocked or highly compacted soils allowing for operations to occur. Hog fuel can also be scattered throughout the centralized grinding site to provide traction for machinery (Alcorn, 2013).

WLPZs and EEZs were assigned zero values and areas outside WLPZs and EEZs were given a value of one and multiplied by the sum of the suitability values. The following map algebra expression was used to calculate suitable centralized landing locations:

([Main_Rds] + [Slope_rclss] + [intersection] +[Hrvst_unit]) * [WLPZ]



(3% Slope + Mainline Roads + Biomass Harvest + Road Junctions) x WLPZ/EEZ

Figure 1. Factors considered for the suitability analysis used to locate centralized landing locations.

Cells with a value between 8 and 10 were selected as possible landing locations with 10 being the most preferred. A value of 10 represents a landing that is located in a unit, on a through road, within 20 feet of a road intersection, less than or equal to 3% in slope, and is greater than or equal to 10,000 ft^2. A cell with a value of 9 is located within a harvest a unit, and meets slope, area, and through road access requirements. A cell value of 8 is the least preferable and is located outside of a harvest unit on a road intersection while meeting slope and area requirements.

Network Analysis to determine the closest centralized processing sites

The study area consisted of 71 units that were available for biomass harvest. Biomass available per acre is assumed constant at 34.9 BDT/acre and was determined using data collected in 2012 by a private contractor. BDT per acre is calculated using the average scale-weight per chip truck and acres operated per harvest unit. Recoverable biomass per unit ranged from 341 BDT to 1400 BDT with an average of 806 BDT/unit. Network Analysis was used to determine the closest centralized grinding site from a biomass harvest unit and as a planning tool for determining the costs and BDT per grinding site. The geographic centroid of forest stands was not considered for this analysis as terrain features can isolate adjacent stands resulting in unfeasible pre-haul distances. Rather than using the centroid of multiple stands, a single point was created in the center of each harvest unit and snapped to the nearest road edge within the unit. By snapping to the nearest road segment, the model assumes that each unit will have a pre-haul distance regardless of logging method and slash arrangement. The acceptable cell values created in the suitability model were converted to polygons and a 20-ft buffer was added and spatially dissolved to create contiguous polygons from bordering and nearby cells of the same value.

Network analysis was used to find the closest available centralized grinding site for each biomass harvest unit. A vector-based network model was used in this study because it is likely to be more applicable than a raster model for analyzing precisely defined or existing paths such as road networks; whereas raster models are more concerned with finding routes with no predefined paths (Husdal, 1999). Routes were created by converting centralized grinding locations and harvest units to points. The geographic centroid of harvest units were snapped to the nearest road segment within the unit and used as the end destination of the route. Round trip pre-hauling distance was used to determine (a) whether or not a harvest unit was within a feasible distance to a centralized location, (b) the amount of dump trucks needed per centralized location, and (c) pre-hauling costs. In harvest units with more than one available centralized site the highest ranked location were selected as the default location. The analysis assumes that biomass operations will occur at every unit and that there is no minimum BDT requirement per centralized grinding site. The Analysis uses route distance in miles and regression analysis from a detailed time study by Bisson et. al (2013) to calculate cycle time (min), production rate (BDT/PMH), and pre-haul cost ($/BDT) for each route.

Results

The research area consisted of 2,053,670 cells (107.64 ft^2 each); with 654 cells containing possible centralized landing locations. A summary of the suitability analysis is shown in Table 2.

Table 2. Centralized landing locations, cell count, and contiguous polygons.

Cell Value	Cell Count	Polygons
7	417	79
8	203	7
9	34	9
Total	**654**	**95**

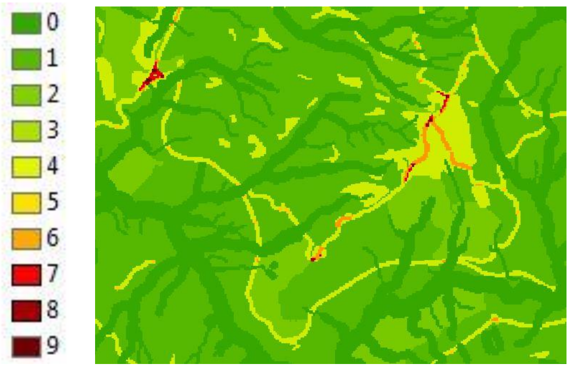


Figure 2. Suitability analysis results.

Out of the 95 possible centralized landing locations, 37 were selected as closest facilities to one or more harvested unit. Sixteen centralized landings were located in a biomass harvest unit and several locations were located inside the same unit. A total of 11 landings located inside a unit were chosen as closest facilities. One out of the 71-biomass harvest units was excluded for exceeding the maximum round trip pre-haul distance of 4.62 miles. The average number of biomass units per centralized landing was 1.90 with a minimum of one unit per landing and a maximum of four units per centralized landing. The average number of dump trucks required per pre-haul was 1.89 and ranged from one to three dump trucks per landing. Assuming a nine hour work day with a work season of 100 days it would take two seasons to recover all available biomass. Summary statistics of available biomass per acre and work hours per centralized landing are shown in Table 3. A summary of the network analysis is shown in Table 4 and uses nearest route distances and field data from a detailed time and motion study conducted by Bisson et al (2013) which also evaluated centralized biomass recovery operations in northern California. A summary of the dump truck data used to calculate pre-haul cycle time, costs, and productivity is shown in Table 5.

Table 3. Summary of Biomass per unit, available biomass, work hours per centralized landing.

	Acres per harvest unit	Biomass per harvest unit (BDT/acre)	Avaiable biomass per centralized landing (BDT)	Work hours per centralized landing (PMH)
Mean	23.1	805.7	1503.3	47.2
Min	9.8	3401.9	551.5	15.8
Max	40.1	1400.5	3647.0	112.8
SD	6.1	212.3	741.9	23.2
Total	1615.0	56396.5	56051.0	1744.9
n	71	71	70	37

Table 4. Round trip distance, cycle time, production rate, cost using Network Analysis and regression analysis from detailed time study.

	Round-trip distance (mi)	Cycle time (min)	Prodcution rate (BDT/PMH)	Pre-haul cost ($/BDT)
Average	1.42	12.28	30.40	4.13
Min	0.23	6.60	14.69	2.21
Max	3.57	22.58	50.29	7.59
n	70	70	70	70

Table 5. Round trip distance, cycle time, production rate, pre-haul cost from detailed time and motion study (Bisson et. al 2013).

	Round-trip distance (mi)	Cycle time (min)	Prodcution rate (BDT/PMH)	Pre-haul cost ($/BDT)
Average	0.96	12.69	26.16	4.26
Min	0.10	5.70	14.01	1.92
Max	2.18	23.68	58.22	7.96
n	75	75	75	75

Discussion

A two–part methodology for locating and planning centralized grinding operations has been described. This project was designed to assess potential centralized landing locations using GIS-based suitability modeling. Network analysis was used to locate the nearest biomass harvest units, determine pre-haul feasibility, pre-haul distance, and provide cost estimates. This research indicates that many existing landings used for timber harvesting may not be suitable for centralized biomass operations as they do not meet desired area, slope, and through access requirements needed for centralized landings.

Average pre-haul distances calculated using suitability and network analysis were significantly higher than those observed in the detailed time study. Despite longer pre-haul distances, average cycle times and pre-haul costs were lower. Additionally, production rates were higher compared to the results of the time and motion study. Under estimations of cycle time and cost as well as over estimation production rates could have been have caused by the error in extrapolation of the regression analysis. Additional error could have resulted from assuming a constant and uniform BDT per acre, which does not take into account the spatial variation and distribution of slash within a harvested unit. Using a single haul route for each unit could have also had a significant contribution to the discrepancy between the GIS analysis and the observed times. In addition, the regression equation only takes into account slopes of ± 4% whereas the network analysis assumes that any gradient of road can be navigated by a dump truck, which may have resulted in underestimated cycle times.

Using a deterministic spreadsheet model, Johnson et al. (2012) predicted a modified dump truck production rate of 1.51 BDT/PMH at a cost of $26.31/BDT for an assumed 5 mile round-trip pre-haul, which is drastically different than both production rates and costs observed in the detailed time study and predicted in the network analysis. This difference indicates the importance of planning to allow for minimal pre-haul distances, which lowers costs and increases productivity.

References

Alcorn, M. 2013. Personal communication. Green Diamond Resource Company, Blue Lake, CA.

Anderson, N; Chung, W; Loeffler, D; Jones, J. 2012. A productivity and cost comparison of two systems for producing biomass fuel from roadside forest treatment residues. Forest Products Journal. Vol. 62 Issue 3, 12p.

Bisson, J; Han, S; Han, H. 2013. Evaluating the system logistics of a biomass recovery operation in northern California. In review. Issue 4.

ESRI. 2012. ArcGIS 10.1 Desktop Help. Environmental Systems Research Institute (ESRI) Inc. Available from: http://webhelp.esri.com/arcgisdesktop/10.1/index.cfm [Accessed; May 1, 2013]

Johnson, L; Lippke, B; Oneil, E. 2012. Modeling Biomass Collection and Woods Processing Life-Cycle Analysis. Forest Products Journal. Vol 62, 16p.

Han, H; Halbrook J; Pan, F; Salazar, L. 2010. Economic evaluation of a roll-off trucking system removing forest biomass resulting from shaded fuelbreak treatments. Biomass & Energy Journal. Vol. 34: 1006-1016.

Harril, H and H.-S. Han. 2010. Application of hook-lift trucks in centralized logging slash grinding operations. Biofuels. Vol. 1(3):399-408.

Husdal, J (1999) *Network analysis – network versus vector – A comparison study*. Unpublished course paper for the MSc in GIS. University of Leicester, UK.

Morris, S. 2013. Personal communication. Steve Morris Logging and Contracting, Blue Lake, CA.

Morris, S. 2012. Morris 2012 HSU Copy. File Last modified 5/14/2013. Excel Spreadsheet.

Young, T.M.; Ostermeier, D.M.; Domenech, D.W. 1988. Average wood chip trucking costs for the Southeastern United States. Society of American Foresters, Southern Journal of Applied Forestry, Vol. 12, 3p.

Cost and sediment reduction effectiveness of BMPs for a wood panel bridge on a haul road stream crossing in the Virginia Piedmont

Morris, Brian C.[1], Bolding, M. Chad[2]; Aust, W. Mike[3]

Abstract

The history and settlement in the south eastern United States has resulted in many legacy forest roads with design features and water control structures that are inadequate by today's standards. To aid landowners in determining whether to replace legacy stream crossings with more effective structures, a wooden bridge was installed and replaced an existing legacy ford. The 24 foot wooden panel bridge was used to upgrade an existing ford on a haul road stream crossing on Virginia Tech's Reynolds Homestead Forest Research Center. During bridge installation the construction materials, labor, and equipment costs were documented. The bridge was initially installed with minimal BMPs (bare running surface and fill slopes). Following a series of rainfall simulation experiments, additional BMPs were added including geo-textile fabric and rock on the running surface of the road. The final BMP treatment consisted of the addition of rock to the fill slopes. Rainfall simulation experiments were conducted after each BMP level with three rainfall intensities (approximately 0.5, 1.5, and 2 inches per hour) for thirty minutes each. During rainfall simulation, upstream and downstream water samples were collected. Maximum sediment concentrations during rainfall for the bridge with bare road surface (Bare), rocked road surface (Gravel), and armored fill/cutslopes (Gravel + Rip-Rap) were; Gravel > Gravel+Rip-Rap > Bare. The total sediment delivery from the Bare treatment was 17% less than the Gravel treatment. This is likely due to the washing of the newly added rock during the rainfall simulation as well as subsurface water flow which was introducing sediment to the channel.

Introduction

Stream sedimentation occurs when eroded material enters a stream channel. Stream crossings provide an erosion source (i.e. the road surface, cut and fill slopes) with limited space for water control structures. Due to the erosion source and limited water control structures, material eroded from the road has a high probability of reaching the stream. Due to the high rate of connectivity Taylor et al. (1999, p. 17) stated, "Forest road stream crossings are a major sediment source in forest streams…". The recent United States Supreme Court ruling and potential upcoming lawsuits in regard to stream crossings and their treatment as a non-point source pollutant has prompted land managers and researchers to question the future of regulations associated with stream crossings. The potential changes in regulation of erosion from forest operations has prompted interest in identifying erosion control measures that are both economically

[1]Graduate Research Assistant, Department of Forest Resources and Environmental Conservation, Virginia Polytechnic Institute and State University, 228 Cheatham Hall (0324), Blacksburg, VA 24061
[2]Associate Professor, Department of Forest Resources and Environmental Conservation, Virginia Polytechnic Institute and State University, 228 Cheatham Hall (0324), Blacksburg, VA 24061
[3]Professor, Department of Forest Resources and Environmental Conservation, Virginia Polytechnic Institute and State University, 228 Cheatham Hall (0324), Blacksburg, VA 24061

and environmentally efficient (Boston, 2012). In order to better understand the erosion control measures for stream crossings, studies must be designed such that approach erosion is separated from crossing structure erosion (Taylor et al., 1999).

Objectives

This study was designed to estimate the total cost and sediment delivery potential of panel bridge stream crossings by completing the following objectives:

- Determine total cost of bridge installation,
- Determine total cost of additional BMPs for a panel bridge,
- Determine the sediment reduction efficiency of BMPs for a panel bridge.

Methods

This study was conducted on the property of Virginia Tech's Reynolds Homestead Forest Resources Research Center. The stream crossing location is comprised of a legacy forest road (>100 years old) and a 1^{st} order perennial stream. The original stream crossing consisted of an unimproved ford which did not have a sound rock bottom and had steep approaches that did not allow for the road to be perpendicular to the stream. The poor alignment, steep approaches, and soft channel bottom led to difficulty crossing the stream. For this study, the ford was abandoned and the road was realigned to allow for the road to cross the stream at right angles. Steep stream banks and large roots prevented the use of another ford and the past agricultural practices left a stream which meanders and could present problems for a culvert crossing. A 24 foot long by 12 foot wide white oak (*Quercus alba*) 3 panel bridge was used for the crossing. The bridge consists of 3 panels which are each 24ft x 4ft x 0.75ft. The western approach utilized rock filled gabion baskets (3ft x 3ft x 9ft long) with fill soil added behind the gabion. The eastern approach did not require additional abutments. Gabion baskets were filled with #3-0 sized rock (approximately 2in to 8in stone) provided by a local quarry. Fill material and bare soil beneath the panel on both approaches was covered with geotextile and approximately 3 inches of Virginia Department of Transportation (VDOT) #5 rock (average 3/4inch stones). The gabion basket was used to provide for a stable abutment that would resist channel erosion and provide structural support. The VDOT #5s were placed below the panel to allow for easy leveling of the panels as well as to promote water drainage beneath the bridge to increase the lifespan of the bridge panels. Water samples were collected during the construction phase as well as rainfall simulations. The rainfall simulations were conducted on the bridge with no BMPs in place (Bare) which consisted of the bridge panel with finished abutments, but not road surface rock. The next level of BMPs (Gravel) consisted of rocking the running surface of the road while the final level of BMPs (Gravel + Rip-Rap) consisted of covering all bare soil. Costs including materials, equipment use and labor where all tracked during the construction of the bridge and installation of additional BMPs.

Rainfall simulations were conducted to test the stream sedimentation of a first order stream prior to the installation of a wood panel bridge as well as at three levels of

BMPs. The rainfall simulation utilized an 18 horsepower centrifugal pump with a 3 inch outlet which fed 100 feet of 3 inch double jacket fire hose. The 4 inch inlet of the pump was submerged in a pond which was constructed downstream of the crossing. During the 30 minute rainfall simulations, the pump pressurized the fire hose and connected PVC manifold and 8 sprinkler risers to 50lbs/in^2. The 8 Wobler© sprinkler heads were secured on the top of 10foott tall 1inch diameter PVC risers. The sprinkler heads utilized an interchangeable nozzle which was used to alter the rainfall rate during the simulations by changing the orifice diameter in the nozzle. The rainfall simulations lasted for 30 minutes. During the rainfall simulations and for 30 minutes after the completion of the simulation, upstream (66ft from crossing) water samples were collected every 10 minutes while downstream (66ft from crossing) water samples were taken every 5 minutes.

Water samples were collected by ISCO 4700 automatic water samplers. Samples of 250mL were transported to the lab to be filtered through pre-weighed 47mm TSS filters (manufactured by ProWeigh) and dried at 105°C for 24 hours. The filters were then weighed and the sediment concentration was determined by subtracting the original filter weight from the final filter weight and dividing by the water sample volume (250mL) to obtain a sediment contribution in g/mL. Stream discharge measurements were conducting using the salt dilution method outlined by Moore (2004; 2005). Stream stage was recorded using HOBO water level loggers in the stream at both upstream and downstream water sampling locations. Atmospheric pressure was recorded by a third HOBO located at the upstream water sampling location. HOBOWARE was used to determine the stage height at 1 minute intervals during the simulations. The stage and discharge measurements were used to create a discharge rating curve. The discharge and sediment contribution values were used to determine total mass of sediment contribution during construction and simulation events. The total mass of upstream sediment was subtracted from the downstream sediment level to determine the total mass of sediment which entered the stream at the crossing.

Results

Bridge installation was completed utilizing a John Deere 450E bulldozer (70hp) and a New Holland TN750 Farm Tractor (75hp) with a 3-point backhoe attachment. The bridge was transported using a bulldozer transport truck at a rate of $85/hr including operator wages. The bridge was placed by a contractor with an excavator at a contract rate of $85/hr. The abutment construction and bridge placement required 52 man-hours including equipment operation. This included the construction of gabion baskets and application of geotextile and rock as well as the placement of the panels (Table 1). The application of geotextile and rock on the running surface required 2 man-hours, 100 feet of geotextile and 5 tons of rock. The application of rip-rap required 5 man hours and 5 tons of #3-0 rock.

The total bridge installation cost was $5,297.50 while the application of rock added $290 to the construction cost and rip-rap added another $200, resulting in a total cost of $5,787.50. The application of rock increased the total bridge cost by 5% and the application of rip-rap accounted for 4% of the installation cost.

Table 1: Cost of bridge installation and additional BMPs

BMP	Materials	Quantity	Cost/Unit	Delivery Cost ($85/hr)	Material Cost	Total Cost
Bare	Bridge	1	$ 2,325	$ 595	$ 2,325	$ 2,920
	Gabion Basket (3x9)	2	$ 95	$ -	$ 190	$ 190
	Gabion Basket (1x9)	2	$ 60	$ -	$ 120	$ 120
	GeoTextile (feet)	40	$ 1.50	$ -	$ 60	$ 60
	Rock 3-0s (tons)	15	$ 20	$ -	$ 300	$ 300
	Rock VDOT #5 (tons)	5	$ 20	$ -	$ 100	$ 100
	Excavator	4	$ 85	$ -	$ 340	$ 340
	Labor (hours)	52	$ 20	$ -	$ 1,040	$ 1,040
	Dozer (hours)	2	$ 20	$ -	$ 40	$ 40
	Backhoe (hours)	7.5	$ 25	$ -	$ 187.50	$187.50
	Bridge Installation Total					**$ 5,297.50**
Rock	Labor (hours)	2	$ 20	$ -	$ 40	$ 40
	GeoTextile (feet)	100	$ 1.50	$ -	$ 150	$ 150
	Rock VDOT #5 (tons)	5	$ 20	$ -	$ 100	$ 100
	Rock Application Total					**$ 290**
Rip-Rap	Labor (hours)	5	$ 20	$ -	$ 100	$ 100
	Rock 3-0s (tons)	5	$ 20	$ -	$ 100	$ 100
	Rip-Rap Application Total					**$ 200**
Total Construction plus BMP cost						**$ 5,787.50**

The rainfall simulation events resulted in rainfall rates of 0.72in/hr, 2.16in/hr, and 2.27in/hr for the low, medium and high intensity simulations, respectively. Rainfall was simulated for 30 minutes. Rainfall simulations resulted in increased sediment levels in the stream with a maximum sediment concentration occurring near 20 to 25 minutes into the simulation (Figure 1).

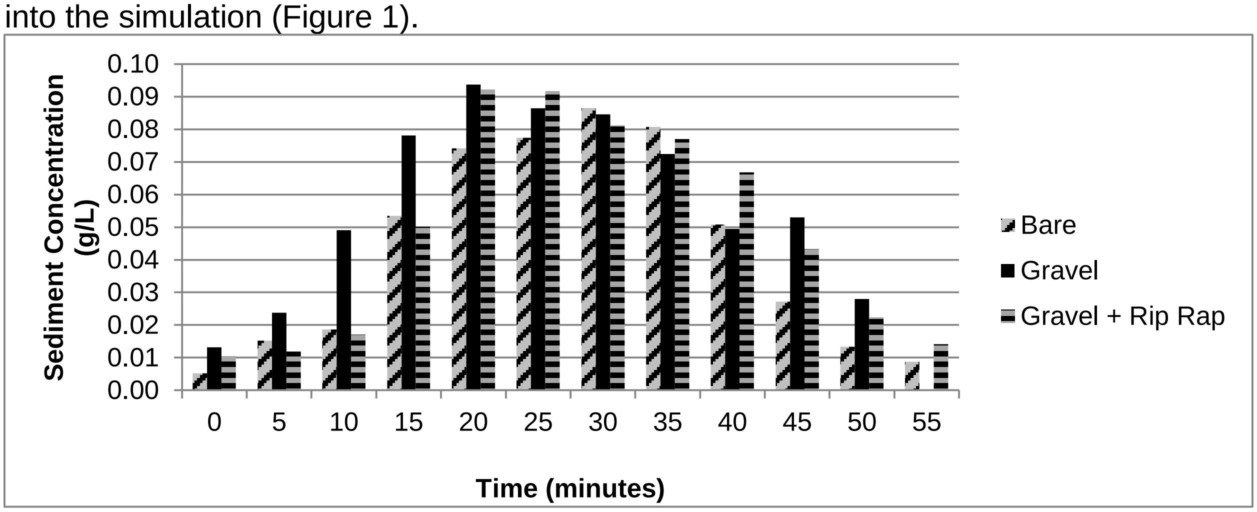


Figure 1: Average sediment contribution by BMP for all rainfall simulations

Following the end of the rainfall simulation the sediment levels decreased, however the bare simulation resulted in a faster decline in sediment concentrations. The Bare treatment resulted in the lowest average sediment contribution, while the Gravel produced the largest average (Figure 2). The Gravel also produced the largest total mass of sediment, producing 1.24 tons of sediment during the three rainfall simulations while the Gravel + Rip-Rap treatment produced 1.20 tons and the Bare treatment produced 1.02 tons.

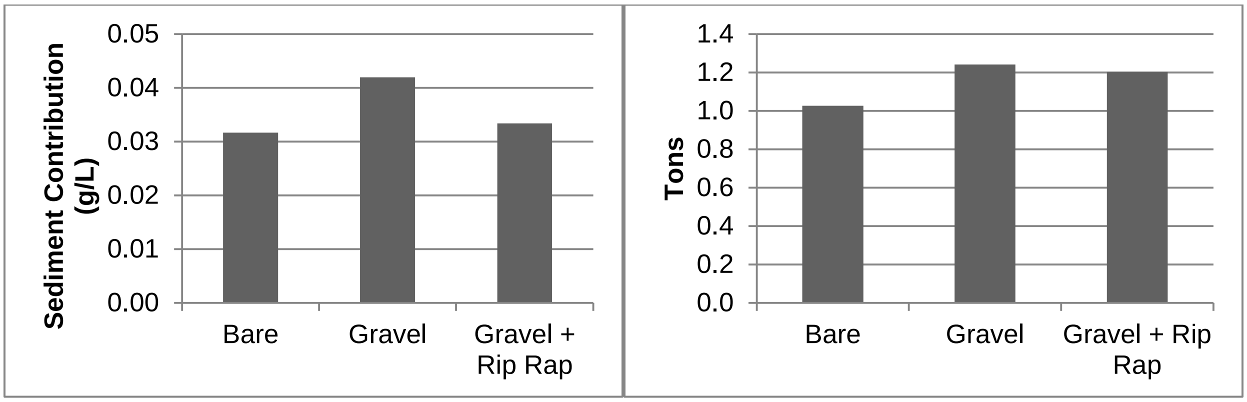


Figure 2: Average sediment contribution (g/L) by BMP treatment for all rainfall simulations (left) and total sediment contribution (tons) by BMP treatment (right)

Although the Gravel treatment produced the greatest total mass of sediment, the Gravel + Rip-Rap produced more sediment in the Low intensity rainfall simulation (Figure 3) and did not return to base line sediment levels as quickly as the Gravel and Bare treatments, resulting in similar cumulative sediment contributions between Gravel and Gravel + Rip-Rap.

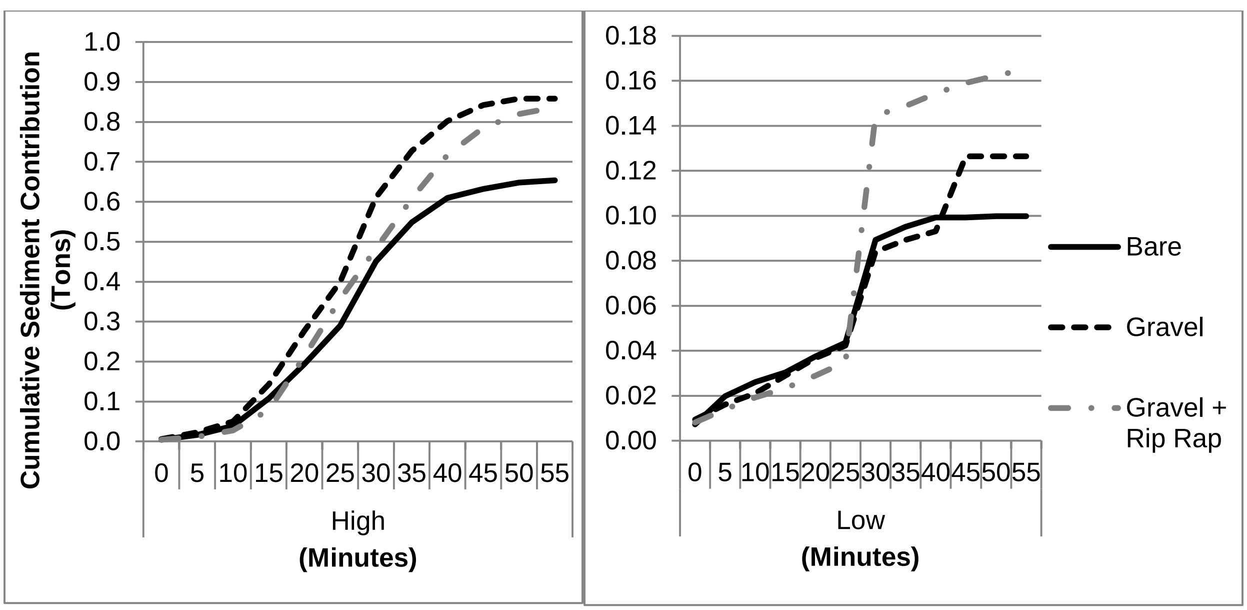


Figure 3: Cumulative sediment contribution over time since beginning of rainfall by BMP treatment for High (left) and Low (right) rainfall simulations

In order to measure the effectiveness of the increased BMPs a sediment reduction efficiency value was calculated. This value is the sediment contribution of the Bare treatment divided by the difference between the bare treatment and the treatment being considered (i.e. SRE=Bare/(Gravel-Bare). The sediment reduction efficiency for the three treatments shows that the Gravel and Gravel + Rip-Rap result in an increase in sediment yield when the additional BMPs are implemented due to the negative efficiency rating (Table 2).

Table 2: Sediment reduction efficiency of BMPs based from total sediment contribution (tons)

BMP	Total Sediment Contribution (Tons)	Sediment Reduction (Tons)	Sediment Reduction Efficiency
Bare	1.02	0.00	0%
Gravel	1.24	-0.21	-17%
Gravel + Rip-Rap	1.20	-0.18	-15%

Conclusions

The bridge installation cost was approximately double the $2717 found by McKee et al. (2012) for wood panel bridge installations in Virginia and approximately two thirds the cost of steel bridges reported at $9068. The costs reported were based upon a 2009 survey of logging contractors throughout Virginia. The average wood panel bridge installed in the region likely does not utilize gabion baskets for abutments nor geotextile and rock below the bridge panels. Further, if the bridge were to be set directly on the stream banks without rock and abutments, the labor required for installation would be greatly reduced. Also, if the bridge is transported and installed with equipment which is owned and operated by the logging contractor as part of the logging operation, these costs may not be included in the reported bridge cost. The total Bare installation cost of $5297.50 is reasonable for a permanent wood bridge with reinforced abutments. The additional costs of $290 and $200 for the addition of Gravel and Gravel + Rip-Rap are also reasonable. However, initial consideration of the sediment reduction efficiency calls the additional cost into question. The sediment reduction efficiency only takes into account the sediment reduction effectiveness of BMPs in the first storm following construction. In the lifespan of the bridge the additional BMPs will likely result in decreased erosion from the road surface and fill slopes as well as facilitate traffic during wet periods that may be difficult with a bare road surface. The long term effectiveness of the BMPs should be further investigated to determine the true effectiveness over the lifespan of the crossing.

The sediment concentration increased following the initiation of rainfall simulation and peaked 20 to 30 minutes into the simulation and the simulation was stopped at 30 minutes. The sediment concentration then decreased to near baseline levels within an additional 30 minutes. The Gravel treatment increased sediment production faster than the Bare and Gravel + Rip-Rap treatments, likely due to the dust on the gravel being washed by the rainfall simulation. The Gravel + Rip-Rap response was slower, however reached a peak near that of the Gravel treatment. The total sediment production from the three treatments was within 0.215 tons.

The similarity in total sediment contribution and lack of sediment reduction from additional BMPs could be due to the dust being washed from the rock and the soil disturbance from construction activities as well as other sources of sediment contributing to the total sediment load. During simulations visual observations suggested that there was subsurface flow entering the channel from beneath the gabion basket that was contributing sediment to the channel. The bank behind the gabion basket had trees and stumps removed prior to installing the gabion baskets and back filling with soil. It is possible that water was flowing either through the bridge or down the approach and under the bridge or through old root channels and entering the channel through the gabion basket. Visual observation suggested that BMPs did not result in a reduction of this source of sediment.

Although the additional BMPs did not result in immediate sediment reduction as shown by rainfall simulation, the long term sediment reduction will likely result in increased sediment reduction efficiency, suggesting that the use of such BMPs should be considered. The costs of $290 and $200 for Gravel and Gravel + Rip-Rap would likely be offset during the lifespan of the crossing and may result in a decreased total cost over the life of the bridge. The application of rock on the road surface and fill slopes will likely reduce future maintenance requirements and ease traffic consideration during inclement weather and should thus be considered.

Literature Cited

Boston K. 2012. Impact of the Ninth Circuit Court Ruling (Northwest Environmental Defense Center v. Brown) Regarding Forest Roads and the Clean Water Act. *Journal of Forestry.* 110:344-346.

McKee SE. 2012. Stream Crossing Methods, Costs, and Closure Best Management Practices for Virginia Loggers. *Southern Journal of Applied Forestry*. 36:33-37.

Moore R. D. 2004. Introduction to salt dilution gauging for streamflow measurement: Part 1. *Streamline Watershed Management Bulletin.* 7(4):20-23

Moore R.D. 2005. Slug injection using salt in solution. *Streamline Watershed Management Bulletin.* 8(1):11-15.

Taylor SE, Rummer RB, Yoo KH, Welch RA, Thompson JD. 1999. What We Know -- and Don't Know -- about Water Quality at Stream Crossings. *Journal of Forestry.* 97:12-17.

Shift Length and Time of Day Impacts on Forest Operations Productivity and Value Recovery in Southern Hemisphere Plantations

Glen Murphy[1], Philippe Passicot[2], Hamish Marshall[3], and Andy Dick[4]

Abstract

Data-bases maintained by two southern hemisphere companies in Chile and New Zealand allowed us to evaluate the effects of shift length and time of day on productivity and value recovery.

A Chilean long-term data base, containing over 30,000 machine-day records, provided the opportunity to assess the effects of work schedules on the productivity mechanized processing of radiata pine stems into logs and mechanized harvesting of eucalypt trees. Daily production increased as working hours increased. However, average hourly productivity fell by 9 to 30% as the working day length for equipment was extended from 9 to 18 hours. .

A second data-base, containing over 120,000 records on radiata pine stems processed during 200 work shifts, allowed us to gauge the impact of time of day on value recovery and productivity of a scanning optimizer and a mechanized processor operating in a central processing yard in New Zealand. Analyses indicate there were no or little differences in productivity or value recovery for the scanning optimizer between the first shift operating mainly in daylight hours and the second shift operating mainly during night hours. No difference in productivity was noted between daylight and dark for the mechanized processor. Possible reasons for these seemingly conflicting Chilean and New Zealand results are covered in the paper.

Keywords: work shifts, mechanized harvesting, central processing yards, human factors, productivity, value recovery

Introduction

Over the last three decades extended working hours – multiple shifts in particular – have been tried and failed in some parts of the world but in other parts have been used successfully for many years to increase production. In some countries, such as Australia, New Zealand, Sweden, Brazil, Uruguay, Chile and the south eastern USA, there is renewed interest in extended shift and multiple shift forest operations. Meeting the growing demand for improved monetary returns, increasing production efficiency and reducing obsolescence of forestry equipment are reasons given for this renewed interest.

[1] Waiariki Institute of Technology, Rotorua, New Zealand
[2] Forestal Mininco, Los Angeles, Chile
[3] Interpine Forestry Ltd., Rotorua, New Zealand
[4] Logjiztix Ltd., Auckland, New Zealand

Kirk (1998) noted, however, that studies worldwide have linked poorly designed work schedules, with mental and physical fatigue, low productivity and low value recovery. Many researchers from a wide range of industries, including forestry, have found that hourly production declines as the shift length increases (Vernon 1921, Golsse 1991, Nevison 1992, Hanna et al. 2005). Productivity can also be lower for night shifts than for day shifts. Kerin and Carbone (2003) report an average drop in productivity of 5% for night shifts across all major U.S. industries based on surveys of employees and managers from over 1000 companies. Studies of forest harvesting operations in North America and Australasia report a 4 to 40% drop in hourly productivity for night shifts versus day shifts (Maxwell 1982, Nicholls et al. 2004, Mitchell 2008).

Murphy and Vanderberg (2007) and Mitchell (2008) note that, while there is a potential for a reduction in logging costs resulting from increased daily production by working extended hours, the size of the production increase is sometimes insufficient for logging cost reductions to be realised. They also note that the impacts of extended hours on other tangible and intangible costs such as value recovery losses and human factors (such employee turnover rates, accident risk, and opportunity for employees to participate in social affairs and domestic activities) need to be considered.

In this paper, we report the results of two case studies looking at the effects of extended working hours on the productivity and value recovery of (1) in-forest operations in Chile and (2) an off-forest, central processing yard in New Zealand. Results are based on long-term data of that have been collected by indirect methods.

Methods

<u>Chilean Study</u>

Forestal Mininco is one of the largest forest companies in Chile with an annual harvest of about 8.6 million m^3. This study relates only to their ground-based operations. In pine plantations tree-length harvesting systems are used. Delimbing and processing is carried out at roadside with a dangle-head processor on an excavator base (e.g. Waratah 622 processor on Komatsu P200 excavator). In eucalypt plantations cut-to-length harvesting systems are used. Trees are felled, debarked and processed into logs with a mechanised harvester (e.g. Valmet 370 or 380) and then the logs are extracted to roadside with a forwarder. Both the processors in pine plantations and the harvesters in eucalypt plantations are fitted with halogen or xenon lighting systems which produce 30 lux or greater of illuminance in the boom working area for night operation.

Forestal Mininco's logging contractors usually work 30 days per month. Four types of work schedules are used in both pine and eucalypt plantations. These include (a) single shift of 9 work hours, (b) single shift of 12 work hours, (c) double shift of 16 work hours, and (d) double shift of 18 work hours.

For each shift there is a single operator per machine. The operator works for about four hours then takes a "lunch" break (~ 1 hour). For the 12-hour single shift the operator takes additional short rest and food breaks (~10 minutes).

Machine operators record daily tree count data obtained from the machines' computers. Average tree size for the stand is combined with tree counts to obtain productivity per shift hour (m^3/hr). Over 22 thousand data points (one productivity value for one machine for one day) collected on processors and over 9 thousand collected on harvesters were analyzed to determine productivity by species, tree size, season, work schedule and equipment type.

In Chile, approximately 75% of daily costs for mechanised harvesting operations are related to equipment costs and 25% are related to labor costs. Fixed costs for depreciation, insurance, and interest account for about half of equipment related daily costs. The combined effects of changes in daily production and spreading fixed costs over greater numbers of scheduled hours were evaluated for different work schedule designs.

New Zealand Study

Panpac Forest Products Limited is an integrated forest products company that owns 33,000 hectares of forest plantation on the east coast of the North Island. Their Forestry and Logistics Division manages an annual volume of 1.5 million m^3 of which about 0.75 to 0.9 million m^3 comes from their own estate. Panpac produces pulp, lumber, export chip and export logs from its operations.

In 2004 began operating the Panpac "3PY" (Pan Pac Processing Yard) attached to their lumber and pulp processing plants. Delimbed stems, or stem segments, are transported from their forests to the 3PY. The stems are then passed through a two (or three) machine mobile optimizing plant, known as Logmaister. The system consists of a scanner cab that runs parallel to a delimbed stem, creating a stem profile (up to 38 m in length) that is virtually bucked by the Logmaister optimiser algorithm (Figure 1). A secondary machine with a processing head mounted on an excavator base takes the scanned solution (wirelessly) and cuts the log sorts as prescribed by the Logmaister scanner. Cutting strategies and log grade prices are relayed from company offices wirelessly and all production data is uploaded, instantly, to a remote server and reports are available via internet and direct SQL query.

The Logmaister system operates for six days per week, two shifts per day. The first shift for the scanner runs from 4am to 1.30pm. The second shift runs from 2pm to 10pm or until a "sufficient" stockpile of scanned stems has been built up. Finishing times for the second shift can extend to 3am. One 30 minute break per shift is taken. For each shift there is a single machine operator. One, sometimes two, processors cut the stems into logs. Shift lengths for the processors vary from 8 to 12 hours. The 3PY is well lit with overhead floodlights.

The time of day, machine operator, number of quality codes called, and stem attributes measured are automatically recorded for each stem that is scanned or processed. Records from approximately 120,000 radiata pine stems scanned and processed during 200 work shifts were analyzed to determine productivity and value recovery by tree size, time of day, operator, and equipment type. Changes in markets were accounted for by virtually re-bucking the scanned stems using a standard set of log types and prices.

Figure 1. The Logmaister scanner (left) runs on rails parallel to the log and virtually bucks the stem. The bucked stem solution is wirelessly passed to a second machine (right) with a processor head which cuts the stems into logs.

Results

Chilean Study

Increasing the number of hours worked per day generally resulted in greater daily production for both types of operations; processors in radiata pine plantations and harvesters in eucalypt plantations (Figure 2). The exception was for processors where extending the working hours from 16 to 18 resulted in no increase in daily production. Figure 2 also shows that increasing the number of hours worked per day resulted in a drop in average hourly productivity for both processors and harvesters; that is, the rate of production decreases as the working day length is increased. However, the magnitude of the drop in productivity differs between processors and harvesters, between seasons, between species and between tree size categories.

Operator fatigue and mechanical problems are more exacerbated by extended working hours during the hot summers (up to 34% drop) than the cooler winters (up to 29% drop) for both processor and harvester operations. Processor productivity declines at a faster relative rate for big trees (up to 28% drop) than small trees (up to 7% drop) as the number of working hours per day is increased. Productivity drops were also larger for harvesters working in *E. globulus* stands than in *E. nitens* stands.

Estimated costs per unit of production increased by close to 30% for the processors and 15% for the harvesters when scheduled hours per day was increased from 9 to 18. Unit production costs were greater for all three work schedules above 9 hours per day. Lower hourly productivity associated with longer work schedules negated the reduction in hourly fixed costs.

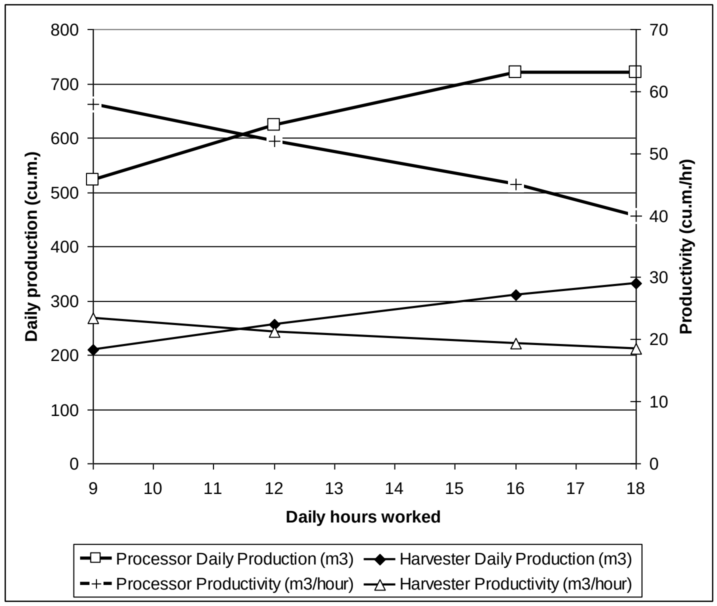


Figure 2. Effect of daily hours worked in Chile on daily production and average hourly productivity for mechanised processors operating in radiata pine plantations and harvesters operating in eucalypt plantations. Production and productivity are the averages for all seasons, all tree size classes, and all species for each machine type.

New Zealand Study

Preliminary analysis of the data indicates that there was no statistically significant difference ($p=0.05$) in hourly scanner productivity between the first (123 m^3 h^{-1}, 56 stems h^{-1}) and second (105 m^3 h^{-1}, 59 stems h^{-1}) shifts of the day. When hours in which rest breaks or end of shift activities (usually tidying up small pieces) were excluded, no statistically significant difference in productivity was found between hours of daylight (134 m^3 h^{-1}) and dark (135 m^3 h^{-1}).

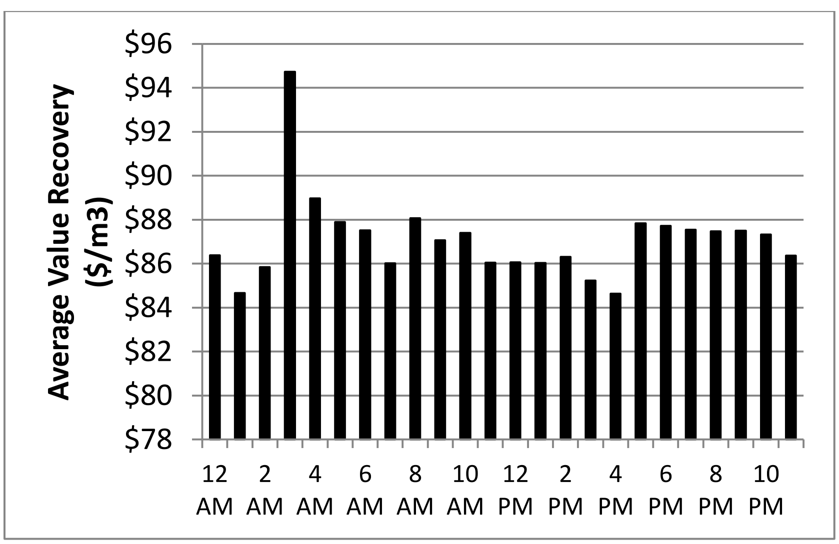


Figure 3. Effect of time of day on average value recovered based on measured stem dimensions, actual quality calls, and virtual bucking of over 120,000 stems by five scanner operators in New Zealand.

Analysis of the processor productivity data indicated that there was no statistically significant difference in productivity between daylight hours (63 m^3 h^{-1}) and dark hours (69 m^3 h^{-1}). More stems per hour were processed during daylight hours but these were smaller in piece size than stems processed during dark hours.

Figure 3 shows the average value ($/m3) recovered at different times of the day. The average value recovery was the same for the first and second shifts ($87.11 per m3). Differences at different times of the day were partially due to differences in average piece size. More detailed analysis revealed that there were significant differences in value recovery between the five scanner operators. Once operator differences were accounted for a 1% difference in recovery was found between daylight hours and dark hours; dark hour recovery being higher. The difference was statistically significant at p=0.05 level.

Discussion and Concluding Comments

The case study of on-forest Chilean harvesting operations showed that, although daily production increased with extended working hours and multiple shift schedules, the increased production would likely be insufficient to reduce unit production costs below those of a 9-hour single shift. Other forest operations researchers have identified approaches for improving this situation. Gingras (2004) comments that with proper equipment selection (i.e., a good lighting package), maintenance scheduling (i.e., during the day shift where possible), and production planning (e.g. allocating the worst ground for the day shift) the differences between the productivity of day and night work shifts can be minimised for forest harvesting operations. Swedish experience has highlighted the importance of focusing on the human factor. Gellerstedt (1997) notes that high levels of harvesting crew productivity can be sustained throughout the day by rotating jobs within a crew and allowing operators to select the day or evening shift that suits them best in a multi-shift operation.

The case study of the off-forest central processing yard in New Zealand runs counter to the Chilean study in that no difference in productivity for the scanning optimizer was found between the first shift operating mainly in daylight hours and the second shift operating mainly during night hours. Similarly, no difference in the productivity of processing stems into logs was found between daylight and darkness hours. These findings agree, however, with those of Rose (2007) who essentially found no drop in productivity for the night shift compared with the day shift of a large, non-mobile, centralized processing yard in New Zealand. Very good lighting outside of normal daylight hours was a feature of the Logmaister operation (and the CPY studied by Rose 2007); this was considerably better than the illumination from the halogen or xenon lighting packages attached to the in-forest log processing and harvesting operations in the Chilean study.

A small difference in average value recovery was found in the New Zealand study; recovery being higher during hours of darkness. This was unexpected. Comment is often made in the literature on the effect of circadian rhythm on error rates which are at their highest between mid-night and 6 am, peaking in the early hours of the morning (2 to 4 am) (Folkard and Tucker 2003). It was expected that increased error rates would lead to lower value recovery. Two possible reasons for no drop in value recovery are good lighting and operating conditions for the scanner operator, and the use of a scanning optimizer. The operator identifies and calls changes in quality along the stem but does not have to decide what log types should be cut. Future research should explore the impact of time of day on value recovery for processors operating on-forest, particularly if these are not fitted with an optimizing computer.

Further work is needed on work schedule design. Understanding the effects of extended work hours and different work schedules on productivity and value recovery of both on- and off-forest mechanised operations will allow planners to better manage log supply, labor force requirements, and harvesting economics.

Literature Cited

Folkard, S., & Tucker, P. (2003). Shift work, safety and productivity. *Occupational Medicine*. 53, 95-101.

Gellerstedt, S. (1997). Job-rotation rosters for mechanised operations. LIRO Report Volume 22, Number 10. Logging Industry Research Organisation, Rotorua, New Zealand. 12 pp.

Gingras, J.F. (2004). Night shift blues? Do those extra shifts pay? *Canadian Forest Industries*. April 2004.

Golsse, J.-M. (1991). Effects of shift length on hourly productivity: a preliminary review. *Canadian Forest Industries*. August/September 1991. p. 34-39.

Hanna, A.S., Taylor, C.S., & Sullivan K.T. (2005). Impact of extended overtime on construction labour productivity. *J. of Construction Engineering and Management* 131(6), 734-739.

Kerin, A., & Carbone, J. (2003). Financial opportunities in extended hours operations: Managing costs, risks, and liabilities (Lexington, Massachusetts, Circadian Technologies).

Kirk, P. (1998). The impact of shift length on processor operator fatigue. LIRO Report Volume 23, Number 18. Logging Industry Research Organisation, Rotorua, New Zealand. 12 pp.

Maxwell, D. (1982). A production analysis of the night shift in a forest operation. B. Sc. Thesis. University of New Brunswick. 42pp.

Mitchell, D. (2008). Extended working hours in the Southeastern logging industry. PhD thesis. Auburn University, Auburn, Alabama. 162pp.

Murphy, G., & Vanderberg, M. (2007). Modelling the economics of extended shift and 24/7 forest harvesting. *New Zealand Journal of Forestry*. August. pp. 14-19.

Nevison, J. (1992). White collar project management questionnaire report. Oak Associates, Concord, MA.

Nicholls, A., Bren, L.; & Humphreys, N. (2004). Harvester productivity and operator fatigue: working extended hours. *Int. J. of Forest Engineering* 15(2), 57-65.

Rose, K. (2007). Analysis of shift pattern effects on productivity and value at Kaingaroa Processing Plant (KPP). Unpublished dissertation, New Zealand School of Forestry, University of Canterbury, Christchurch, New Zealand. 50pp.

Vernon, H.M. (1921). Industrial fatigue and efficiency. George Routledge & Sons, Ltd. New York. 264pp.

A GIS-based approach to identify suitable locations for bioenergy plantations in northern Kentucky

Sandhya Nepal[1] and Marco Contreras[2]

[1]Graduate Research Assistant, Department of Forestry, University of Kentucky
[2]Assistant Professor of Forest Management, Department of Forestry, University of Kentucky

Abstract

Biomass has recently gained considerable attention in southeastern United States, particularly in Kentucky, because of its potential to replace fossil fuels and develop a sustainable bioenergy industry. Currently, land managers and decision makers are promoting the production of biomass in the forestry sector to establish a sustainable biomass and biofuel industry. Dedicated plantations could offer a reliable and stable biomass supply, but there is limited research evaluating their economic feasibility and identifying suitable locations in the region. This study analyzed the economic feasibility of three short rotation woody crops for bioenergy plantations. A GIS-based approach was developed to identify optimal locations for plantations. To prevent competition with food production and avoid conversion of natural forests, only pasture/hay and unused land parcels were considered as potential plantation sites. Our approach was based on: i) soil productivity, ii) biomass prices, iii) establishment, management and harvesting costs, and iv) transportation costs to conversion facilities. Site index was used to estimate potential bioenergy yield for each land parcel (i.e. 30×30 meter grid-cell). Off-road transportation costs were determined based on the distance from the land parcel to the closest entry point along existing roads. On-road transportation cost was determined based on distance from existing road entry points to the nearest conversion facility. Biomass prices and production costs were combined to calculate land expectation value (LEV) for each land parcel and determine a break-even point of biomass yield. For demonstration purposes, we applied our approach to Trimble County in northern Kentucky, which represents conditions commonly found in southeastern states (i.e. land cover, ownership, and existing facilities).

I. INTRODUCTION

Bioenergy has gained considerable attention in the southeast US mainly because the region offers excellent climate and growing conditions for producing short rotation bioenergy crops that have the potential to partially replace fossil fuels and develop a sustainable bioenergy industry (Hinchee et al., 2009). Within the region, Kentucky produces 12 million tons of biomass per year from agriculture and forest resources, but the state needs to produce 25 million tons per year by 2025 to meet the federal renewable fuel standard and the state renewable portfolio (Governor's Office for Agricultural Policy and Energy and Educational Cabinet, 2009). To help meet the state's needs, the establishment of dedicated energy plantations can offer a significant source of bioenergy and has the potential to secure adequate feedstock to sustain a biomass and bioenergy industry (Staudhammer et al., 2011).

The success of a bioenergy industry depends on sustainable and cost-effective biomass production, which is determined by suitable species, site conditions and soil productivity, and plantation and management practices (Simmons et al., 2008). The location of plantations and the costs associated with transporting biomass to conversion facilities are major factors on the feasibility of dedicated energy plantations. Therefore, it is essential to identify appropriate locations for plantations by considering potential biomass yield and the associated transportation costs to existing facilities. Factors affecting the suitability of plantation locations can change over time because of the nature of bioenergy crops, market structure, government incentives, and current economy. To address these challenges, developing appropriate approaches to locate optimal bioenergy plantation sites has become an important research topic; however, only a few studies have developed models to address the problem (Banos et al., 2011). Graham et al. (2000) developed a GIS-based model to identify suitable locations for switchgrass (*Panicum virgatum*) plantations as an energy crop feedstock based on production and transportation costs as well as on negative environmental implications such as soil erosion and loss of nitrogen. Moreover, Dubuc (2007) developed a GIS-based tool to identify the best location for bioenergy crops with respect to transportation cost to the closest conversion facility. These studies have been helpful to understand the relevance of locating bioenergy plantations but have not considered multiple species with different site condition requirements.

In Kentucky, bioenergy plantations can offer a reliable and stable biomass supply for the bioenergy industry, but to our knowledge, there are no studies considering multiple bioenergy crops and their potential site specific biomass production yields to identify suitable plantation locations to meet future demands. This study analyzed the economic feasibility of three short rotation woody crops for bioenergy plantations by developing a GIS-based approach to identify suitable plantation locations. Site suitability decisions were based on expected biomass productivity, biomass prices, and production costs (establishment and management, harvesting, and transportation costs). Our approach combined biomass prices and production costs to determine the break-even biomass yield (amount of biomass required to produce a LEV=0) for each land parcel. This break-even biomass amount was then compared with the land parcel's expected biomass yield for each species to determine the location's suitability for bioenergy plantations conversion. Results obtained from the study provide a clear understanding of acceptable locations for bioenergy plantations and the various factors that influence location decisions.

II. METHODOLOGY

A. Study Area

We selected Trimble County in northern Kentucky to demonstrate our approach to identify suitable locations for bioenergy plantations because it presents conditions commonly found throughout the eastern US including diverse land use, mostly privately owned small land parcels, and the presence of a coal plant with the ability to co-fire biomass with coal. The total area of the county is 40,457 ha, with an assortment of land cover types identified by the USDA National Agricultural Statistics Services (USDA, 2012), including: evergreen/deciduous forests, pasture/hay, other agricultural crops, and developed areas (Figure 1, left). As aforementioned, to prevent competition with food production and avoid conversion of natural forests, only areas identified as pasture/hay (10,019 ha) and barren lands (46 ha) were included in the analysis as potential locations for bioenergy plantations (Figure 1, right). This land cover data was obtained from the USDA National Agricultural Statistics Services (USDA, 2012), which is available in a raster format with a 30 meter resolution. To maintain consistency with this input, our approach considered each 30 meter pixel of pasture/hay or barren land as a land parcel that could potentially serve as a suitable site for establishing bioenergy plantations.

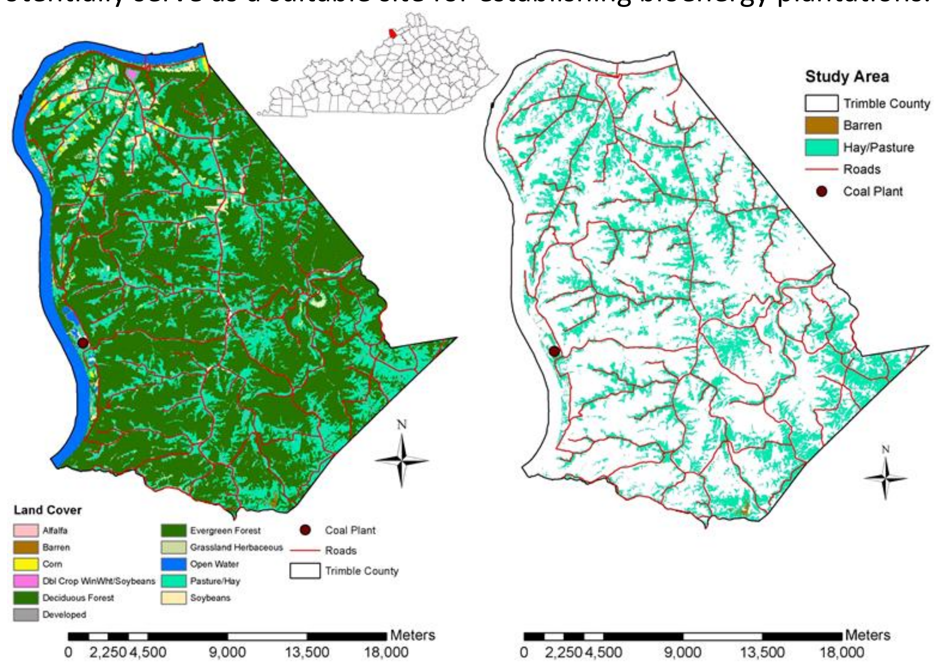


Figure 1. Land cover in Trimble County in northern KY (left) and location of pasture/hay and barren land use (right)

B. Biomass Price and Costs

Based on preliminary economic feasibility analysis and following recommendations by Kline and Coleman (2010), we considered the following three tree species for woody biomass plantations: American sycamore (*Platanus occidentalis* L.), eastern cottonwood (*Populus deltoides* Bartr.), and sweetgum (*Liquidambar styraciflua* L.*).*

While biomass prices fluctuate over time across the eastern US, Kline and Coleman (2010) reported prices between $35 and 45/ton for the species considered in this study. Given this range, we assumed an average biomass price of $40/ton.

Establishment and management costs vary widely for the three species. Considering a rotation age of 12 years for sweetgum and cottonwood, Kline and Coleman (2010) reported cost ranges of $778-1,742/ha and $865-2,457/ha, respectively. Table 1 shows the cost ranges incurred at different years throughout the rotation for sweetgum and cottonwood reported by Kline and Coleman (2010). Establishment and management costs for American sycamore were assumed to be similar to those of sweetgum but considering a rotation age of 8 years (Davis and Trettin, 2006). Harvesting costs for all three species were assumed to be $45/ton as suggested by Nesbit et al. (2011).

Transportation cost is another important influence on the economic feasibility of bioenergy plantations. In our approach, transportation cost was dependent on the cost of transporting biomass from the pixel to an existing road and then transporting the biomass on the road to the coal plant. To represent potential locations where off-road biomass transportation routes would converge with the existing road systems (road entry points), points were created along the existing road layer in ArcMap 10 using the Construct Points feature at a 30m interval. While distances between points occasionally fell below the 30m spacing due overlapping pathways within the road network, distance between points never exceeded 30m. To find the off-road distance of a pixel to an existing road entry point, we used the Euclidean Distance and Euclidean Allocation functions in the Spatial Analyst ArcToolbox in ArcMap 10. For each pixel, the Euclidean Allocation tool identified the existing road entry point closest to the pixel while the Euclidean Distance tool calculated the distance from the center of each pixel to the road entry point. On-road distance was determined in ArcMap 10 using the New Closest Facility function in the Network Analyst ArcToolbox, which provides the shortest distance and the associated route along the road layer from each road entry point to the coal plant. After off-road and on-road distances were determined, we calculated off-road and on-road transportation costs by using a transportation cost of 25¢/ton/km (Governor's Office for Agricultural Policy and Energy and Educational Cabinet, 2009). Off-road transportation costs can vary significantly based on harvesting machine, but because of the lack of detailed information on biomass harvesting in Kentucky, we assumed that off-road transportation costs were twice as expensive as on-road transportation, thus a transportation cost of 50¢/ton/km was considered in this application.

Table 1. Estimated production costs for Sweetgum and Cottonwood (Kline and Coleman, 2010)

		Sweetgum		Cottonwood	
		Cost range ($/ha)		Cost range ($/ha)	
		min	max	min	max
Year 1	Site preparation	247	494	247	988
	Planting stock	185	247	185	247
	Planting	99	124	99	124
	Herbicide	161	395	161	395
	Pesticide				86
Year 2	Herbicide	86	173	86	173
	Pesticide			86	86
Year 3	Pesticide				86
Year 4	Pesticide				86
	Fertilize		62		62
Year 6	Fertilize		62		
Year 8	Fertilize		62		62
Year 10	Fertilize		62		
Year 12	Fertilize		62		62
Total		778	1742	865	2457

C. Biomass Yield Estimation

For each species, expected biomass yield for each pixel was estimated based on site index, which was calculated following procedures outlined by Baker and Broadfoot (1979). This site index calculation gives a weighted score for four major soil factors: physical condition, moisture availability during the growing season, nutrient availability, and aeration. Within each major soil factor, several sub-factors (soil-site properties) are assessed and weighted to comprise the total score. As an example, Table 2 presents the weight of each major soil factor and their associated sub-factors for the calculation of index for cottonwood. Following the Baker and Broadfoot (1979) procedure, each soil-site property is given a soil-quality rating (best, medium, and poor) and assigned a score. In this study, soil-site properties for each pixel were obtained from spatial and tabular soil data from the SSURGO database (http://soils.usda.gov/survey/geography/ssurgo/), matched as closely as possible to the range of conditions provided by Baker and Broadfoot (1979) and assigned the appropriate scores. Site index was then calculated by adding all scores assigned to a given pixel. Site index values in the range of 80-130ft, 75-125ft, and 80-130ft were considered acceptable for cottonwood, sweetgum and American sycamore, respectively (as recommended by Baker and Broadfoot (1979). Consequently, pixels with site index values below these ranges were considered unsuitable for plantations of that species while remaining pixels were categorized as high, medium, or low productivity (Table 3). Potential biomass yield by pixel for each of the three species was then predicted based on site index classes using data presented by Kline and Coleman (2010) (see Table 4).

Table 2. Contribution of major soil factors and sub-factors to the calculation of site index for cottonwood

Physical condition (35%)	Moisture availability (35%)	Nutrient availability (20%)	Aeration (10%)
Soil depth (35%)	Water table depth (20%)	Geological source (30%)	Structure (25%)
Texture (25%)	Presence of pans (20%)	Land use (20%)	Swampiness (25%)
Compaction (20%)	Topographic position (15%)	Organic matter (20%)	Mottling (25%)
Structure (10%)	Microsite (15%)	Topsoil depth (10%)	Soil Color (25%)
Land use (10%)	Structure (10%)	Soil Age (10%)	
	Texture (10%)	pH (10%)	
	Flooding (5%)		
	Land use (5%)		

Table 3. Categorization of site index values into site index classes for the estimation of potential biomass yield

Site index range (ft)			Site Index Class
Cottonwood	Sweetgum	American Sycamore	
80-90	75-85	80-90	Low
90-110	85-105	90-110	Medium
110-130	105-125	110-130	High

Table 4. Potential biomass yield expected by site class and species

Species	High (ton/ha/yr.)	Medium (ton/ha/yr.)	Low (ton/ha/yr.)
Cottonwood	6	5	3
Sweetgum	8	6	4
American Sycamore	11	9	7

D. Identifying Suitable Sites

Biomass prices and production costs (establishment and management, harvesting, and transportation) were combined to determine the break-even yield, the amount of biomass required to produce a LEV of zero. LEV was calculated following the Faustmann's approach (Susaeta et al., 2012):

$$LEV = \frac{[PV - C]e^{-rt}}{1 - e^{-rt}}$$

where P is the price of biomass (\$/ton), V is the biomass volume (ton), C is the total production cost (\$), r is the discount rate and t is the optimal rotation age. In this calculation, a discount rate of 5% was assumed, and all costs were discounted from the rotation years in which they would occur.

For each species, the break-even yield for each pixel was compared with the estimated biomass yield for that pixel to determine suitability for locating bioenergy plantations. Pixels with break-even yield values lower than the estimated biomass productivity obtained from the site index calculation were considered suitable for bioenergy plantations whereas pixels with break-even yield values higher than the estimated biomass productivity were considered unsuitable for a given species.

III. RESULTS AND DISCUSSION

A. Break-even biomass values

Although we considered only pasture/hay and barren land cover types (about 10,065 ha) as potential location for bioenergy, we determined transportation costs from each pixel within the county to examine their relationship with distance from the coal plant. Total transportation cost ranged from \$0.18/ton for pixels near the coal plant to \$8.32/ton for pixels farthest away (Figure 2). Off-road transportation distance varied between 0 and 1.82 km (0.91 km average) resulting in costs in the range of \$0 to 0.9/ton. On-road transportation distance were between 0 and 32 km with an average of 16 km, which is shorter than typical hauling distances for timber transport, resulting in hauling costs between \$0.18 and 8.18/ton.

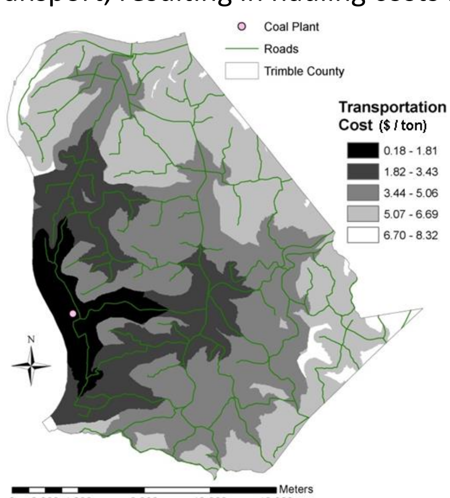


Figure 2. Total transportation cost of each pixel in the study area

After combining production costs (establishment and management, harvesting, and transportation) with the biomass price at the coal plant, the break-even biomass amount by pixel was calculated for the three species. Results indicate a similar break-even biomass pattern for the three species (Figure 3). As biomass price as well as establishment and management, and harvesting costs were constant for the break-even analysis, the amount of biomass required to obtain a positive financial return is completely dependent on transportation cost. Consequently, the pattern of break-even biomass amount by pixel resembles that of total transportation cost for all three species. Values for break-even biomass amount were relatively similar among species; 5.58-7.01 ton/ha for American sycamore, 4.66-5.86 ton/ha for sweetgum, and 6.18-7.76 ton/ha for cottonwood.

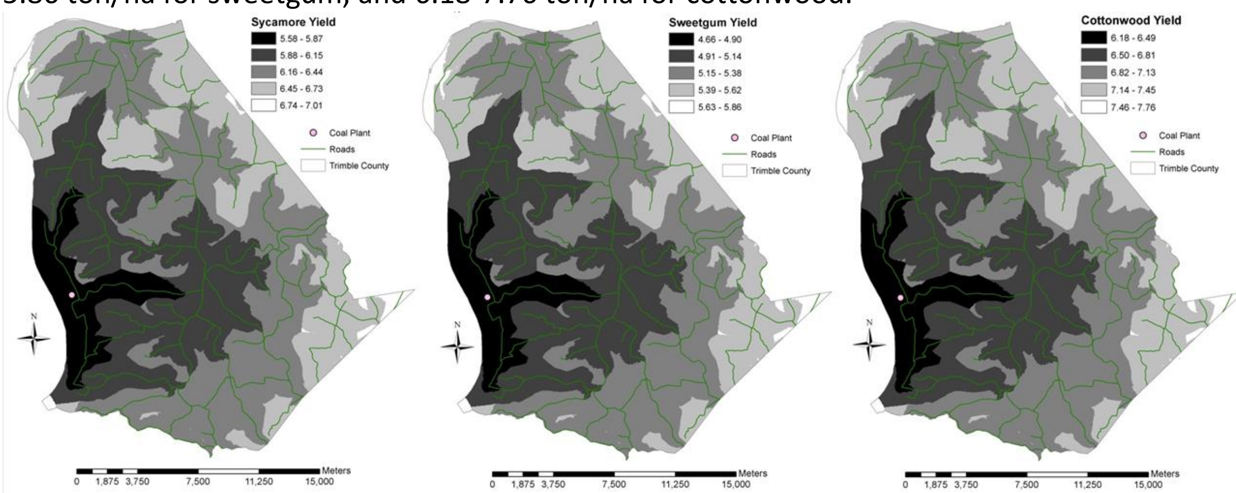


Figure 3. Distribution of break-even biomass amount by pixel for all three species.

B. Expected Biomass Productivity

While the results of the break-even biomass analysis for the three species are dependent on transportation cost, the selection of sites suitable for plantations depends on site index and the resulting expected biomass productivity for the respective species. Site index calculations, conducted to evaluate whether a pixel had the potential to produce the biomass yield required to provide a positive economic return, showed a wide range of values throughout the study area for all three species. Site indices ranged from 25 to 96 ft. for sycamore, from 21 to 94 ft. for sweetgum, and from 14 to 92 ft. for cottonwood. However, as aforementioned, sites with site index values below 80 ft. for sycamore and cottonwood, and 75 ft. for sweetgum are considered unsuitable for establishing biomass plantations (see Table 3). Consequently, approximately 18.9%, 56.4%, and 11.3% of the entire county is suitable for biomass planting sycamore, sweetgum, and cottonwood respectively (Figure 4). For all these three species, suitable plantation sites fall into the low and medium site index class, but the low site class area is much larger (Table 5).

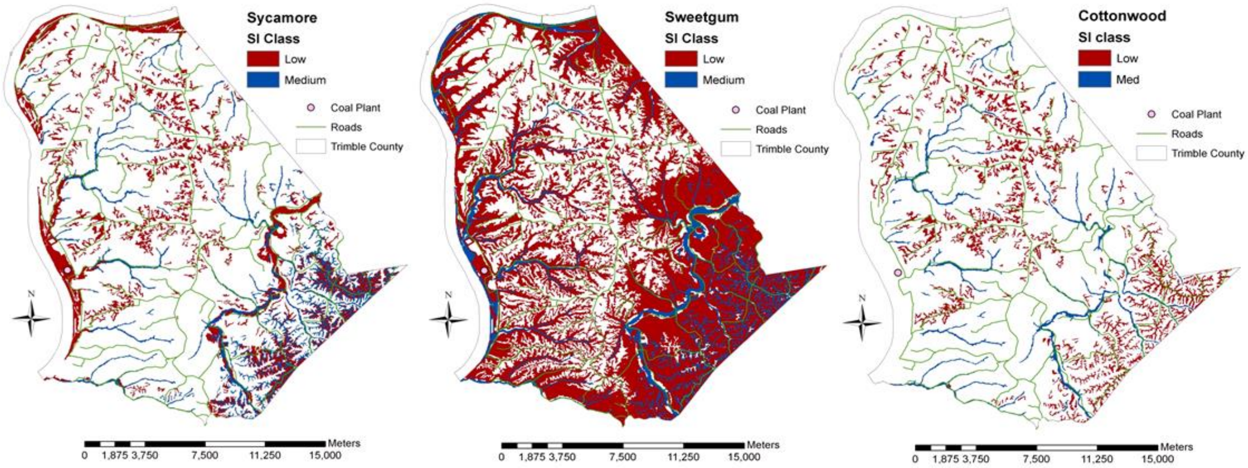


Figure 4. Distribution of break-even biomass amount by pixel for all three species.

Table 5. Area in ha categorized under low and medium site classes for each species

Species	Area (ha) under different site index classes		
	Low	Medium	Total
Sycamore	5,054	2,588	7,642
Sweetgum	19,299	3,601	22,830
Cottonwood	3,293	1,294	4,587

C. Suitable Biomass Plantation Sites

To identify suitable sites for biomass plantations, only areas with pasture/hay and barren land cover types were analyzed, and the break-even yields were compared with expected biomass productivity by pixel for each species. For cottonwood, potential biomass yield is expected to be 5 and 3 ton/ha/yr. for medium and low site index classes, respectively (see Table 4). However, the range of break-even biomass amount required to provide a positive economic return is larger, 6.18-7.76 ton/ha/yr. Consequently, our results indicate that cottonwood is not suitable as biomass plantation in the study area, mainly because of its relatively high site index requirements and low biomass productivity compared with the other two species. On the other hand, almost all the area classified as medium and low site index classes would be suitable for sycamore biomass plantations because the range of break-even values (5.58-7.01 ton/ha/yr.) are below the expected biomass yield, 9 and 7 ton/ha/yr. for medium and low site index classes. However, when considering pasture/hay and barren pixels only, the final area suitable for sycamore biomass plantations is 1,902 ha, all of which is classified as low site index (Figure 5b). Lastly, areas classified as low site index class for sweetgum are not suitable for biomass plantations because the expected biomass yield (4 ton/ha/yr.) is lower than the minimum break-even biomass amount required to provide a positive economic return (4.66 ton/ha/yr.). Then, from all areas classified as medium site index class, providing an expected biomass yield of 6 ton/ha/yr. (see Table 4), only 1,320 ha were on pasture/hay and barren pixels and identified as suitable for sweetgum biomass plantations (Figure 5a). When overlapping suitable plantation areas for both species, 294 ha are identified as suitable for both species, 1026 ha suitable for sweetgum, and 1608 ha for sycamore plantations only (Figure 5c).

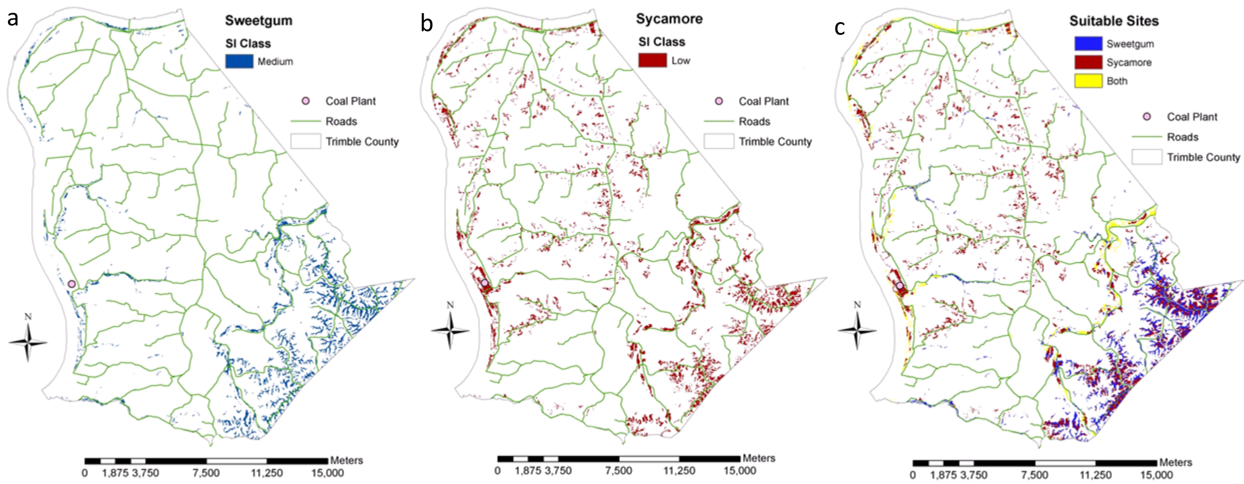


Figure 5. Areas suitable for biomass plantation for sweetgum (a), sycamore (b), and for both species (c)

Results from our GIS-based approach identify areas within Trimble County where it is economically feasible to establish biomass plantations. Transportation distance and the resulting transportation cost have a significant effect on the resulting pattern of suitable sites. Although, suitable areas were found throughout the study area, there is a large portion in the southeastern part of the county which is relatively distant from the coal plant. This is mainly attributed to favorable site conditions. Based on production costs, biomass price and expected yield, there is no area suitable for establishing cottonwood plantations and about 2,928 ha are suitable for sweetgum and/or sycamore. As low site index class areas for sycamore are more productive than medium site index class areas for sweetgum, if areas suitable for sycamore are planted first and then the remaining areas suitable for sweetgum, the total 2,928 ha has the potential to produce about 19,470 ton/yr.

IV. CONCLUSIONS

In this study, we developed a GIS-based approach to identify suitable locations for biomass plantation based on production costs, biomass price, and site productivity for multiple potential woody biomass tree species. Results of the approach applied to Trimble County in northern Kentucky provide an objective evaluation of main factors such as transportation costs and site productivity influencing the economic viability of growing bioenergy crops. Our approach has several potential applications in the assessment of the feasibility of establishing bioenergy plantations. Besides, identifying suitable locations for plantations, it also allows the selection of tree species for a given site. The approach can also be used as a tool to conduct sensitivity analysis and evaluate the effect of changes in biomass prices and transportation costs and other market conditions on the total area suitable for plantations, their spatial patterns, and the total amount of biomass production. Similarly, this approach could be used to evaluate the impact of different policy incentives and determine the most efficient policy decisions to promote a sustainable biomass industry.

V. REFERENCES

Baker, J.B., W.M. Broadfoot. 1979. A practical field method of site evaluation for commercially important southern hardwoods. Gen. Tech. Rep. SO-26. US Department of Agriculture/ Forest Service, Southern Research Station.

Banos, R., F. Manzano-Aguglibaro, F.G. Montoya, C. Gil, A. Alcayde, J. Gomez. 2011. Optimization methods applied to renewable and sustainable energy: A review. Renewable and Sustainable Energy Reviews 15(4):1753-1766.

Davis, A.A., C.C. Trettin. 2006. Sycamore and Sweetgum plantation productivity on former agricultural land in South Carolina. Biomass and Bioenergy 30:769-777.

Dubuc, C. 2007. GIS-based accessibility analysis for network optimal location model: An application for bio-energy projects of the mineral industry in the UK. Available online at http://cybergeo.revues.org/12653, last accessed March 05, 2013.

Governor's Office for Agricultural Policy and Energy and Environmental Cabinet. 2009. Final report from the executive task force on biomass and biofuels development in Kentucky. Available online at http://energy.ky.gov/Documents/BTF/Final%20Report.pdf; last accessed April 29, 2013.

Graham, R.L., B.C. English, C.E. Noon. 2000. A Geographic Information System-based modeling system for evaluating the cost of delivered energy crop feedstock. Biomass and Bioenergy 18(4):309-329.

Hinchee, M., W. Rottmann, L. Mullinax, C. Zhang, S. Chang, M. Cunningham, L. Pearson, N. Nehra. 2009. Short-rotation woody crops for bioenergy and biofuels applications. In Vitro Cell. Dev. Biol. - Plant 45(6):619-629.

Kline, K.L., M.D. Coleman. 2010. Woody energy crops in the southern United States: Two centuries of practitioner experience. Biomass and Bioenergy 34(12): 1655-1666.

Nesbit, T.S., J.R.R. Alavalapati, P. Dwivedi, M.V. Marinescu. 2011. Economics of ethanol production using feedstock from slash pine (*Pinus elliottii*) plantations in the Southern United States. South. J. Appl. For 35(2): 61-66.

Simmons, B.A., D. Loque, H.W. Blanch. 2008. Next-generation biomass feedstocks for biofuel production. Genome Biology 9:242.

Staudhammer, C., L.A. Hermansen-Baez, D. Carter, E.A. Macie. 2011. Wood to energy: using southern interface fuels for bioenergy. Gen. Tech. Rep. SRS-132. Asheville, NC: Department of Agriculture Forest Service, Southern Research Station.

Susaeta A., P. Lal, J. Alavalapati, E. Mercer, D. Carter. 2012. Economics of intercropping loblolly pine and switchgrass for bioenergy markets in the southern United States. Agroforestry Systems 86(2): 287-298.

United States Department of Agriculture (USDA) 2012. Cropland Data Layer. Available online at http://nassgeodata.gmu.edu/CropScape/; last accessed May 3, 2013.

Forest Engineering – Professional Practice in Oregon

Marvin Pyles[1] and Kevin Boston[2],

Abstract

All professions evolve over time. One characteristic of that evolution is the degree to which government regulations place requirements on professional practice. Regulations can specify not only what professionals must do as a part of their practice, but also limit who can engage in professional practice. In the case of industrial forestry in Oregon, regulatory oversight of professional practice extends well back into early part of the 20th century, but has significantly increased over the past 30 to 40 years. The resulting complex web of requirements placed on the professional practice involved in classical industrial forestry makes a clear understanding of regulations a prerequisite to lawful professional practice. This paper reviews the laws that govern the professional practice of engineering in the context of industrial forestry in Oregon, and suggests some potential pitfalls that heretofore may not have been recognized by forest land owners, consultants, and contractors. The changing face of forest land ownership and management adds to the challenges facing the individual professional in striving to maintain sound, legal, and ethical practice.

Introduction

Forest Engineering, under its earlier name, Logging Engineering, became part of the regulated practice of Engineering in the state of Oregon with the passage of the first registration law in 1919 [General Laws of Oregon, Chapter 381, 1919; OSBEE, 1919-1996]. As we approach the centennial of the practice of Forest Engineering, a look at the current state of the law and how Forest Engineering practice is currently conducted in Oregon is informative and suggests questions about the responsiveness of the professional Forest Engineering community now and into the future.

In a very real sense, the social license granted to the industrial forestry enterprise by society is in the hands of the professional Forest Engineering community. The primary source of contentious outcomes from industrial forestry is operations that fall under the exclusive practice of the Forest Engineers. If we adhere to the “rule of law”, both in spirit and letter, and are responsive to changing societal values towards many forest practices, then there is good reason to believe that our profession and the industry are sustainable into the future and that social license will be maintained. If we do not work to maintain social license, it is our contention that flexibility that exists through Forest

[1] Professor of Forest Engineering and Associate Department Head, Department of Forest Engineering, Resources and Management, College of Forestry, Oregon State University.
[2] Associate Professor of Forest Engineering, Department of Forest Engineering, Resources and Management, College of Forestry, Oregon State University.

Engineering practice could be replaced with prescriptive regulations. The result of such a regulation system would be a less competitive forestry sector.

Background

Through the majority of the twentieth century, Forest Engineering was not expressly included in the practice of engineering; however, the definition of the practice of Engineering which stated, "…The practice of said profession embraces the design and the supervision of the construction of public and private utilities such as railroads, bridges, …, roads, …, cranes, …, drainage works…." [General Laws of Oregon, Chapter 381, section 1(2)] would encompass many aspects of industrial forestry. One could reasonably argue that listing of cranes should be considered to include cable yarders in the way that they were used in timber harvesting. This said, there can be little doubt that the design and construction supervision of the forest transportation network which included railroads in 1919 was the practice of engineering, and therefore fell under the authority of the engineering registration statute.

The statue was revised in 1973 and the design and construction supervision tasks were replaced with, " 'Practice of Engineering' means any professional service or creative work requiring engineering education, training and experience and the application of special knowledge of the mathematical, physical and engineering sciences to such professional services or creative work as consultation, investigation, evaluation, planning, design and services during construction for the purpose of assuring compliance with specifications and design, in connection with any public or private utilities, structures, buildings, machines, equipment, processes, works, or projects." [Oregon Revised Statutes (ORS) 672.005 section 1(1)]. The broad nature of this language avoids any attempt to create a list of specific engineering tasks, which could need to change frequently in response to changes in the Practice of Engineering. This language has essentially remained constant since 1973, placing virtually all currently practicing forest engineering professionals in the state of Oregon under this authority for their entire careers.

It should also be noted that in 1997, the definition of the practice of engineering was modified to include, permissively, "Surveying to determine area or topography… Surveying to establish lines, grades or elevations, or to determine or estimate quantities or materials required, removed or in place … Surveying required for design and construction layout of engineering and architectural infrastructure." In 2005, ORS 672.005 was amended to include the above statements on surveying with exclusive language that parallels the definition of professional land surveying and parts of photogrammetry. Property boundary surveying however, is an exclusive practice of professional Land Surveying.

What is the Practice of Forest Engineering? – the Logic

The broad definition of the practice of engineering that has been a part of the statute since 1973 requires people in the forest industry to consider the definition of the

Practice of Engineering to determine whether a particular task is or is not the Practice of Engineering. There is a natural and legal hierarchy involved in this determination:

1. The individual uses the test of reasonable interpretation of the statute, often using a plain language interpretation of the rules.

2. The individual requests an interpretation from their legal counsel.

3. The individual requests an interpretation from the Oregon State Board of Examiners for Engineering and Land Surveying (OSBEELS).

We would like to present a logical and rational pathway for individuals to judge whether their workplace activities meet the criteria for engineering practice. We begin with the definition of engineering presented from the statute. The definition indicates that engineering is work that requires education, training, and experience. From this it is logical to look at the educational, training, and experience requirements for earning registration as an Engineer.

The Oregon Revised Statutes specify that "…an applicant shall provide evidence of graduation in an approved engineering curriculum of four years or more from a school or college approved by the State Board of Examiners for Engineering and Land Surveying." [ORS 672.105(1)]. The State Board of Examiners for Engineering and Land Surveying (OSBEELS) is the agency to administer this act and has rule making authority. OSBEELS has promulgated rules that state, "…a curriculum satisfactory to the Board shall include: (a) Graduation from an EAC of ABET accredited engineering program…" [Oregon Administrative Rules (OAR) 820-010-0225(3)(a)]. "EAC of ABET" refers to the Engineering Accreditation Commission of ABET (formerly the Accreditation Board for Engineering and Technology). It is logical that the components of an ABET accredited Forest Engineering program are then the Practice of Forest Engineering. The Forest Engineering Program at Oregon State University (OSU) is the only ABET accredited Forest Engineering Program in the Western United States. Hence, a listing of the engineering "investigation, evaluation, planning, [and] design" tasks that are a part of the Forest Engineering Educational Program at OSU can be interpreted as the practice of Forest Engineering in Oregon as specified by OSBEELS. Furthermore, for those states that have similar rules regarding licensing, the components of the OSU Forest Engineering degree may be considered as the practice of engineering there as well.

What is the Practice of Forest Engineering? – the Detail

Forest Engineering education at OSU can be divided into five sub-disciplines:

- Engineering Surveying
- Harvesting Process Engineering
- Operations Analysis and Production Planning
- Forest Transportation Engineering
- Soil and Water Resource Engineering

The integration of these five sub-disciplines results in the engineering ability to carry out the traditional tasks of the harvest planning process that includes the design of roads, riparian zones, environmental leave areas, harvest units, and harvesting systems, all of which share the common elements of being physically feasible, environmentally acceptable, operationally efficient, and operationally safe.

While there are elements of Forest Engineering education that are shared by the broader practice of forestry there are some that are clearly the practice of engineering. Examples of the former include the design of riparian buffers and environmental leave areas, and many aspects of operations analysis and production planning which can often take the form of business decisions based on measurements. We argue that those elements of design that are clearly the practice of engineering are engineering surveying to develop data used in the road and harvest unit design process, forest road design [which includes stream crossing design whether by a bridge or a culvert], and harvest design.

Examples of the practice of engineering:

- Surveying an existing stream crossing for a culvert replacement project.
    - Developing the aquatic and topographic site data at an existing stream crossing necessary for the design of a replacement includes “Surveying to determine area or topography”; “Surveying to establish lines, grades or elevations”, and “Surveying to determine or estimate quantities or materials required”, all of which at part of the definition of Engineering Practice [ORS 672.005(1)].
- Design of a stream crossing culvert installation.
    - The Oregon Revised Statutes that govern the design of stream crossing culvert installations include statues and administrative rules on Fish Passage [ORS 509.585 and 610; OAR 635-412-0035], Forest Practices [ORS 527.610 to 527.770, 527.990(1) and 527.992; OAR 629-625-0320], and Engineering [ORS 672.002 to 672.325; OAR 820 division 10 through 20].
- Surveying for road design or road construction staking.
    - Any route survey in which a series of cross sections are obtained at selected stations along the alignment of a planned road includes “Surveying to determine area or topography”; “Surveying to establish lines, grades or elevations”, and “Surveying to determine or estimate quantities or materials required”, all of which at part of the definition of Engineering Practice [ORS 672.005(1)].
- Development of a road design, with or without the aid of road design software that identifies stationing, elevations along the road alignment [vertical curves], horizontal alignment [horizontal curves], and excavation and/or fill quantities.
    - Design of a forest road requires application of “special knowledge of mathematics and engineering science” that is taught in engineering

coursework in the ABET accredited Forest Engineering Program at OSU, therefore, by the logic presented above, it is the practice of engineering.

  - Furthermore, the only means of ensuring a “safe place of employment” [ORS 654.010 - part of the Oregon Occupational Safety and Health Statutes], that being the forest road used by truck drivers hauling equipment and logs, is through the practice of engineering.
  - Forest road design carried out by untrained individuals will likely not include consideration of safe horizontal and vertical alignment, leaving the landowner open to “negligence per se” court judgments in the event of a workplace injury.

- Selection of a landing location and yarder characteristics for a cable yarding harvest unit.
  - It is easy to reason through this example. The safety of logging workers is first related to the design of a cable harvest unit. Poor unit design will result in insufficient deflection to yard the required payloads. If the required payloads are attempted, the result could be failure of either the operating lines or guyline anchors. Failures of this type can easily cause injury or death to logging workers. Designing cable harvest units for safe and productive payloads requires application of “special knowledge of mathematics and engineering science”, therefore, it is the practice of engineering.

The Industrial Exemption and Other Special Cases

One requirement for engineering work is the use of a stamp to identify that an engineer with a valid registration performed the work. “ORS 672.020 (2) … Every final document including drawings, specifications, designs, reports, narratives, maps and plans issued by a registrant shall be stamped with the seal and signed by the registrant. The signature and stamp of a registrant constitute a certification that the document was prepared by the registrant or under the supervision and control of the registrant.”

There is a very high probability that most forest operations in Oregon have used Forest Engineering practices without benefit of a set of final documents, or plans, validated by an engineering stamp as required. For example, we consider the design of a road or a stream crossing, or design of a cable harvest unit to be engineering under the statute that must be sealed by the registered engineer of record for the operation. In the case of a forest access road for example, the final documents could be either a set of plans or a detailed station by station listing of road alignment, road width, surfacing thickness, drainage provisions, etc. In the case of a stream crossing, the written plan that must be submitted to the Oregon Department of Forestry as a part of the notification process under the forest practice rules [OAR 629-625-0100] is a final engineering document that must be prepared by a registrant or under the direction of a registrant and sealed.

So, the combined regulations and statutes require that an individual must be a Registered Engineer to do engineering work, and that the registrant must seal their work once it is in final form. Although, there are only a limited number of courts or agency interpretations that have clarified the practice of engineering, we believe that either the OSBEELS or the courts would agree that design provisions contained in a contract are final documents in that contracts establish rights and obligations among the parties that formed the contract.

Many practitioners in Oregon have stated that they are not subject to the licensing and sealing requirements due to the industrial exemption. The industrial exemption from the engineering registration statutes exists in nearly all states, but varies in detail and form. In Oregon, the "Industrial Exemption" provides exemption from the registration statutes for,

"…(5) An individual, firm, partnership or corporation practicing engineering or land surveying:

(a) On property owned or leased by the individual, firm, partnership or corporation, or on property in which the individual, firm, partnership or corporation has an interest, estate or possessory right; and

(b) That affects exclusively the property or interests of the individual, firm, partnership or corporation, unless the safety or health of the public, including employees and visitors, is involved.

(6) The performance of engineering work by a person, or by full-time employees of the person, provided:

(a) The work is in connection with or incidental to the operations of the person; and

(b) The engineering work is not offered directly to the public…." [ORS 672.060]

A textural interpretation of a statute must avoid the interpretation of one segment that will render another segment superfluous or unnecessary and that provisions and exceptions be interpreted narrowly (Eskridge et al., 2006). A selective reading of this statute can lead an individual to believe that they are exempt from the registration statutes. Selective reading is not allowed under the canons of statutory interpretation. Section (5) which includes subsection (a) and (b), joined by the conjunctive "and" applies to nearly all privately held forest lands, and clearly states that in cases where employee safety or health is involved, there is NO exemption. Section (6) might appear to qualify some engineering work for exemption if corporate personhood is applicable, but Section (6) does not negate the provisions of section (5).

Given this explanation of what a reasonable interpretation of the statutes and rules is, why is it likely that most forest operations are designed illegally? There are three somewhat obvious reasons;

1) The individuals who are Registered Forest Engineers are not aware of the requirement that they seal their final documents.

2) The individuals who are not Registered Forest Engineers are unaware of the Engineering Registrations statutes and rules.

3) Both Registered and non-registered individuals believe that the “Industrial Exemption” applies to their work.

It is our contention that a forest engineering professional who is not a Registered Engineer and who engages in Engineering Practice as defined above on behalf of his/her timber company employer is violating the law. There is no other reasonable way to interpret the statute.

Maintaining Social License

This brings us back to our basic thesis – Engineering Practice is an essential element of maintaining social license by the forest industry. Corporate Social Responsibility is the mechanism for maintaining social license. Corporate Social Responsibility concerns the role of business in society and societal expectations that companies “do good” (Lister 2011). The rise of triple bottom-line accounting of economic, social and environmental objectives is becoming more common in all industries, the forest industry included. It has been showed in other extractive industries, mining for example, that mines have closed for a failure to capture or maintain social license, and not as a result of resource exhaustion (Franks, 2010). Thus, there is an economic driver for corporate social responsibility. The adherence to professional codes, such as those found in credentialed professions, Forest Engineering in this case, is an important part of maintaining or enhancing corporate social responsibility. Ethical conflicts are a part of professional practice, the resolution of which can be aided by adherence to a professional code, thereby demonstrating social responsibility. Valentine and Fleischman (2008) argue that lapses in ethical behavior - not following engineering registration law is our example – endangers the credibility of the entire profession, and the enterprise that it supports.

Literature Cited

Eskridge, N.W. Jr., P.P. Frickey, E. Garrett. 2006. Legislative and Statutory Interpretation. Foundation Press. Pp 405.

Franks, D. 2010. Technological Future Discussion Paper: Technology Assessment and the CSIRO Minerals Downunder National Research Flagship, Cluster Research Report 2.1.

Lister J. 2011. Corporate Social Responsibility and the State.: International Approaches to Forest Co-Regulation. UBC Press pp 282.

OSBEE, Oregon State Board of Engineering Examiners meeting minutes 1919-1996

Valentine, S, and G. Fleischman. 2008. Professional Ethical Standards, Corporate Social Responsibility, and the Perceived Role of Ethics and Social Responsibility. Journal of Business Ethics 82:657-666.

Influence of Moisture Loss, Seasonality, and Species on Weight to Volume Relationships of Commercial Sawlogs in Idaho

Jarred D. Saralecos[1] and Robert F. Keefe[1]

[1] Department of Forest, Rangeland, and Fire Sciences, College of Natural Resources, University of Idaho, 975 W. 6th St., Moscow, Idaho 83844-1133, USA

ABSTRACT

The Idaho Department of Lands has begun increasing the number of timber sales sold on a weight basis, rather than on scaled board foot volumes. Technology increases in scaling systems and improved accuracy of the process has made weight scaling a common practice in industrial forestry. A well integrated process in the US South, weight scaling in the Northwest United States relies primarily on internal and unpublished research. The Idaho Department of Lands and the University of Idaho are conducting a two year analysis to develop statewide, regression-based weight to volume relationships. These relationships and their accuracy are vital to the cooperation and understanding of weight scaling between landowners, logging contractors, and mills. Impacts of moisture loss, seasonality, and species on weight to volume relationships are being evaluated.

INTRODUCTION

Many regions of the United States have employed the use of weight scaling for decades. However, the Pacific Northwest is relatively new to weight scaling and its application. While over 97% of wood harvested in interior British Columbia is weight scaled (British Columbia Ministry of Forests, Lands, and Natural Resource Operations, 2011), there have been few formal weight to volume relationship studies to determine the driving factors affecting weight and volume of sawlogs. Weight scaling studies have been completed in the Southeastern United States, identifying variables associated with predicting volume from weight of sawlogs (Taras, 1956; Page and Bois, 1961; Row and Guttenberg, 1966; Van Deusen et al., 1981). Several states have even adopted conversion factors that account for local and regional variation in logs (Dicke, 1999). In contrast, research in the western United States such as *Yerkes, 1966; Donnelly and Barger, 1977; and Markstrom and King, 1993* are scattered over location and time. The diversity of species and local topographic effects on climate in mountainous terrain increases the difficulty associated with establishing these relationships in the Northwest US. A lack of published research and growing industrial interest has suggested a formal weight to volume study identifying important factors affecting the relationships is needed.

The current organization and infrastructure of weight scaling in the western United States is firmly established. Weigh stations and conversions factors are present at the majority of mills and sample weight scaling continually increases the accuracy in predicting volume. Research on weight scaling accuracy has shown efficiency and economical benefits (Donnelly and Barger, 1977; Amateis et al., 1984). However, land owners and contractors have found it challenging to adopt the new system of measurement because of uncertainty in the relative importance of factors affecting weight to volume conversion based on Scribner Decimal C log scaling rule. Manufacturers in the forest products industry rarely share production and efficiency numbers with others (Via and Shupe, 2005). Many landowners, sawmills, and contractors use proprietary conversion relationships. However, improvements in weight to volume relationships for Idaho could not only benefit landowners and mills in inventory and sale, but help to identify the factors that affect weight conversion throughout the year. Multiple studies have examined weight scaling for multiple products (Guttenberg and Fasick, 1973; Amateis et al., 1984), accuracy (Yerkes, 1966), and effects of moisture (Yerkes, 1967; Lothner et al., 1974). However, few studies evaluating potential variability in weight to volume relationships from moisture loss, seasonality, and species have been conducted in the Northwest. An in-depth collection of scaled and weighed log loads from multiple mill locations across the state over a two year period will improve estimates of the connection between weight and volume of commercial softwood logs. Determining and understanding the variables with the greatest statistical significance is necessary for developing models to predict accurate weight to volume relationships.

OBJECTIVES

The primary goal of this study is to identify the environmental and operational variables that explain the majority of variation in the weight to volume relationship. The effect of moisture content, seasonality, and species on sawlog weight will be quantified. Current weight scaling practices only record net truck weight, predicting volume from established conversion factors. We hypothesize that increased temperatures associated with summer months will significantly affect wood moisture content and weight to volume conversion factors.

We are researching sawlog scaling information with the following objectives as goals:

1. To identify the sawlog variables with the greatest influence on weight to volume conversions.
2. To assess the accuracy of predicting sawlog volume in board feet and cubic feet from net truckload weights.
3. To compare the differences between weight to volume regressions for tons to board feet and tons to cubic feet.

METHODS

A stratified random sample of truck loads, stratified by IDL supervisory area harvest volume, species, month of harvest, and species sort is being collected statewide. All loads are being scaled for Scribner and cubic foot volume, as well as additional log and delivery characteristics potentially affecting weight to volume relationships. Sales included in the study are sampled from the thirteen supervisory area offices statewide.

The number of sales selected in each supervisory area is stratified by annual harvest volume using proportional allocation. Scale volumes are collected by IDL check scalers. All sample scaling data is being recorded from active harvest operations and follows a common protocol to ensure congruent and accurate data. Each harvest follows a pattern of delivery for sawlogs in weekly intervals (Table 1).

Table 1. Treatments determining quantity and interval of sample scaling for each harvest operation.

Treatment	Species	Weeks Since Harvest	Loads per Week
1	1	1	4
1	1	2	4
1	1	3	4
1	1	4	4
2	2	1	4
2	2	2	4
2	2	3	4
2	2	4	4

The effects of moisture loss, region and species composition on weight to volume relationships of sawlogs are viewed over time intervals of 1-4 weeks. Using two species from every harvest, a total of 32 truckloads of data are measured. For each delivered sample load, Idaho Department of Lands check scalers collected the scaling data in Figure 1. Net volumes serve as predicted variables and the additional data are explanatory variables. The unique test load card identified each load as it entered the log yard. All scaling data was uploaded and transferred to the University of Idaho along with hard copies. Test trucks weighed into the log yard and loads were removed for scaling. The trucks weighed leaving to assess total net weight of the load. The study will run from October 2012 and May 2014, culminating in approximately 2000 scaled loads across multiple species, seasons, and diameter classes.

IDL TEST LOAD
REQUIRED SCALE DATA

INBOUND TICKET NUMBER:	**DATE:**
AREA OFFICE:	**TEST WEEK NUMBER: 1 2 3 4**
DESTINATION:	**SCALER NAME:**
SALE NAME:	**SPECIES:**
SALE #:	**CONTRACTOR:**
SCRIBNER GROSS:	**SCRIBNER NET:**
CUBIC GROSS:	**PIECE COUNT:**
CUBIC NET:	**LOAD NET TONS:**
AVG DIAMETER:	**AVG LENGTH:**

Figure 1. The data collected from each test load by check scalers.

RESULTS

The first 6 months of data collection included 177 test loads from November 2012 to February 2013. Testing was suspended during spring break up and is scheduled to commence again in May. At this time, only a portion of the projected 2000 test loads have been collected and analyzed. Some preliminary analysis has shown variation between conversion factors based on harvest region and species. Results showing statistically significant predictability in defect are also present (Figure 2). The ability to account for defected wood in weight scaling helps explain a portion of the error in volume prediction (Fonseca, 2005). Further results will become available as testing resumes and the potential effects of seasonality and moisture loss are evaluated. The distribution of early data collected is related in Table 2. Initial data from winter, 2012-2013 show clear connections between net weight and scaled Scriber volume with only 10% of the total samples collected. Average small-end diameter and harvest region also show an effect in predicting volume as additional variables to weight (Figure 3). More detailed analysis will be conducted as collection continues in 2013. Final analysis and conclusions will be drawn in the spring of 2014 when sampling is finished.

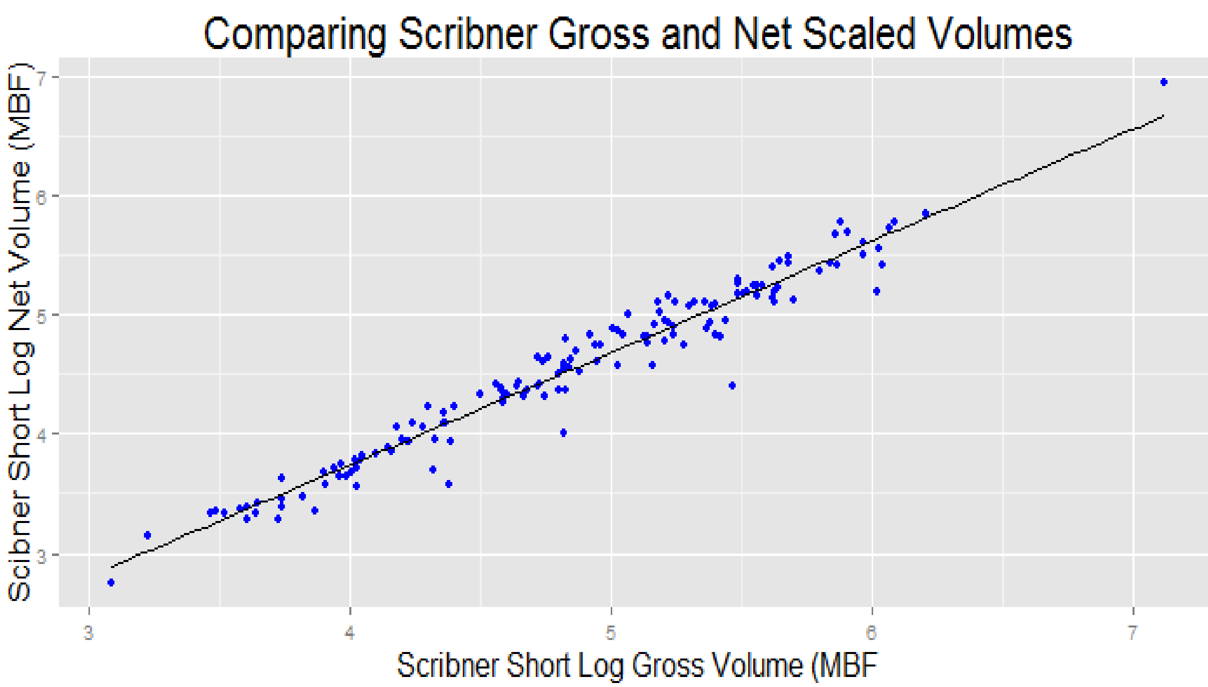


Figure 2 The comparison of net and gross scaled board feet, suggests a significant relationship.

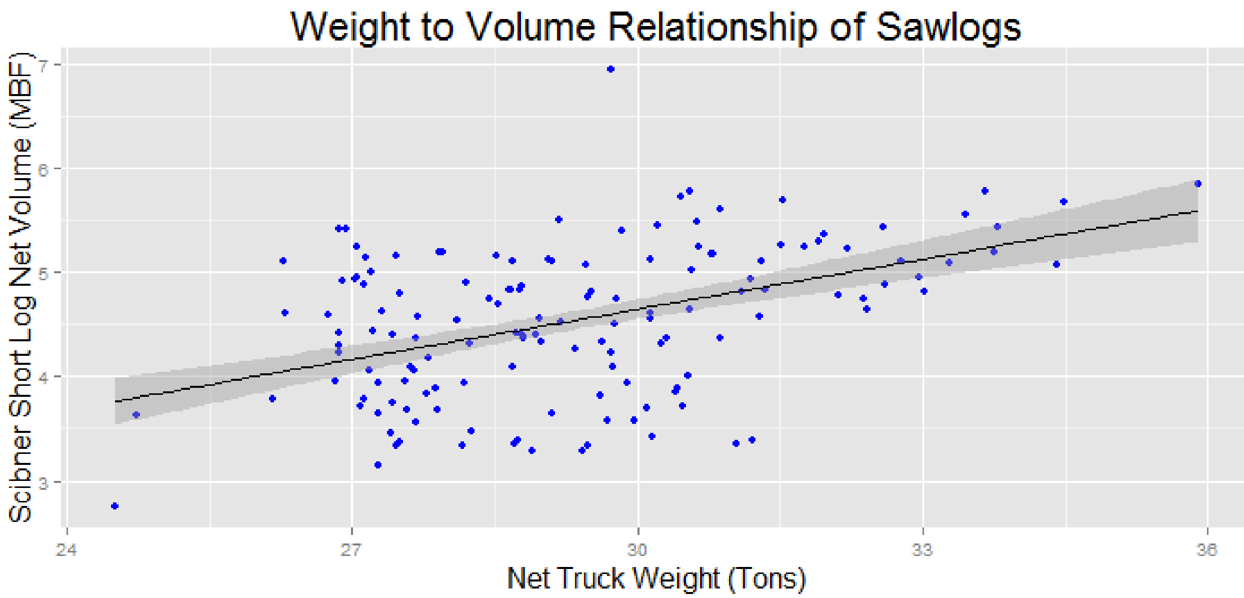


Figure 3 The predicted net volume of sawlogs using weight, average small-end diameter, and harvest region as explanatory variables.

Table 2. The distribution of collected data for the first round of testing across Idaho.

Supervisory Areas	Mill Destinations	Species Sorts	Sample Sales	Contractors
6	6	4	6	6

ACKNOWLEDGEMENTS

This study is supported and funded by the Idaho Department of Lands and the Associated Logging Contractors of Idaho.

LITERATURE CITED

Amateis, Ralph L., Harold E. Burkhart, Brian J. Greber, and E. Eric Watson. 1984. "A Comparison of Approaches for Predicting Multiple-Products Yields from Weight-Scaling Data." *For. Sci.*30(4):991-98.

British Columbia Ministry of Forests, Lands, and Natural Resource Operations Scaling Manual. 2011. *Weight Scale Sampling.* Crown Publication. Victoria, British Columbia, Canada 14-1-4-34.

Dicke, Stephen, and Parker, Robert. 1999. *Pine Timber Volume-To-Weight Conversions*. Starkville: Mississippi State University. Cooperative Extension Service. Publication 2244.

Donnelly, Dennis M., and Barger, Roland L. 1977. *Weight Scaling for Southwestern Ponderosa Pine*. Fort Collins: USDA Rocky Mountain Forest and Range Experiment Sta. Tech. Rep. no. RM-181.

Fonseca, Matthew A. 2005. *The Measurement of Roundwood: Methodologies and Conversion Ratios*. Wallingford, UK: CABI Pub.269p.

Guttenberg, Sam, and Clyde A. Fasick. 1973. Scaling Multiple Products by Weight. *Journal of Forest Products* 23: 34-37.

Lothner, David, C. Marden, Richard M., and Edwin Kallio. 1974. Weight-Volume Relationships of Aspen and Winter-Cut Black Spruce Pulpwood in Northern Minnesota. *St. Paul, MN: U.S. Dept. of Agriculture, Forest Service, North Central Forest Experiment Station*. *Research Note NC-174.*

Markstrom, Donald C., and Rudy M. King. 1993. *Cubic Foot/Weight Scaling of Rocky Mountain Area Sawtimber*. Fort Collins: USDA Rocky Mountain Forest and Range Experiment Sta. Tech. no. RM-311.

Page, H. Rufus and Bois, J. Paul. 1961*. Buying and Selling Southern Yellow Pine Sawlogs By Weight*. Georgia Forest Research Council. Report no. 7.

Row, Clark, and Sam Guttenberg. 1966. Determining Weight-Volume Relationships for Sawlogs. *Journal of Forest Products* 16.5:39-47.

Taras, Michael A. 1956. *Buying Pulpwood by Weight as Compared with Volume Measure.* USDA Southeastern Forest Experiment Sta. November.

Van Deusen, Paul, W.F. Watson, and John Evans. 1981. *Predicting Board Foot Volume from the Weight of a Load of Logs.* Mississippi Agricultural and Forestry Experiment Sta*.* April. Technical Bulletin 108.

Via, B. D., Shupe, T. F. 2005. Relationship of species and season to sawmill by-rpoduct production: A case study. *Journal of Forest Products* 55. 7/8 35-41p.

Yerkes, Vern P. 1966. *Weight and Cubic-Foot Relationships for Black Hills Ponderosa Pine Sawlogs.* U.S. Forest Service, Department of Agriculture. Research Note RM – 78.

Yerkes, Vern P. 1967. *Effect of seasonal stem moisture variation and log storage on weight of Black Hills ponderosa pine.* U.S. Forest Service, Department of Agriculture. Research Note RM – 96.

The effect of weight posted bridges in Alabama on stumpage prices and haul distances for forest products

Mathew F. Smidt[1]

Abstract

Public budgets for county and state roads are under pressure due to the wide array of demands on public funding. Increasingly urban areas demand more infrastructure spending due to higher traffic volumes and simply greater political support. However property and income taxes from timber harvesting may be especially important in rural, timber dependent counties and are affected by county road infrastructure. In Alabama I analyzed bridge postings and road information by county to determine if those conditions were related to county average stumpage prices. That relationship may signal some impact on total stumpage revenue and tax receipts for the county and state. In addition we looked at county level impacts on haul distance using GIS analysis.

Introduction

Comments about the U.S aging infrastructure were quite common as interest increased in directing public money in ways that would provide long term benefit and stimulate local economies. Collapses of aging and sometimes inadequately constructed or maintained bridges on high traffic volume highways stimulates even more political and bureaucratic activity due to potential for loss of life and major disruptions in the transportation network.

While the disruption of major arteries are important to forestry, the transport of raw forest products involves the use of private roads that provide access to public roads managed by several layers of local and state government. The state highway system has its origins prior to 1920 (Weber, 2005) and the farm to market road system in the US south was developed and expanded following WW II (Lewis, 1968). Budget constraints and local demands often result in minimal investment in rural roads which service a few landowners and local traffic. Counties are often responsible for road maintenance and have viewed posting weight limits (Grebner *et al.*, 2005) and county ordinances (Cubbage and Raney, 1987; Jackson *et al.*, 1993) as methods to manage logging activities that might damage rural roads.

In Alabama recent legislative efforts have increased the availability of funding to improve local roads mainly by repairing and replacing weight limited (or posted) bridges many of which were built more than 50 years ago. There is still concern that this funding won't be used to address this problem because the counties do not want to allocate the limited resources to rural roads or that higher traffic roads in more developed areas of the counties satisfy greater public interest. I prepared this analysis to examine the county level impact of posted roads on county level timber harvesting parameters and stumpage prices.

[1] School of Forestry and Wildlife Sciences, Auburn University

Methods

The Alabama Department of Transportation (ALDOT) made available a GIS layer of posted bridges that provided critical data for this analysis. The file attributes show that standards in collecting location and attribute data varied by county. The points for the posted bridges were snapped to the edge of the road or the intersection of the road and the stream. The road GIS layer was made available by ALDOT and the stream data was acquired through the Geospatial Data Gateway (NRCS, 2013).

The three main products from the analysis of the presence of posted bridges were the 1) forest area with no commercial vehicle access via public road due to the presence of posted bridges, 2) the change in private road travel distance to reach the nearest county road which had unrestricted access to a state highway, and 3) the change in public road travel distance to reach a the state highway. Since projecting product destination from the forest seemed speculative, I used the state highway location as a proxy for the nearest access to the market even though the nearest road might add several additional miles of haul distance to the desired mill.

Spatial analysis was completed in ArcMap 10.0 (ESRI, 2010). The GIS procedures used for the intermediate and final steps for each of the 3 main products are presented in Table 1. Analysis was all based on the raster data using a 15 m pixel. The private road distance was incorporated into a cost raster which converted non forest, high density urban and streams to no data. To determine private road distance I calculated a cost factor of 2 for the 15 m pixels which accounted for an external yarding distance of 260 m and a winding factor of 1.2. The remaining area (mainly agriculture and pasture) was given a cost factor of 1 since this property must be accessed to reach forestland.

Results

Some of the posted bridges dated to the early 1900's but the median age of bridges was 54. By decade the median was the 1950's with 653 bridges. Five hundred eighty of the bridges were built in the 1960's. Figure 1 show the distribution of posted bridges by county. Of the four counties with the most posted bridges 2 are in south central Alabama and 2 are in the north east. Only one has a significant metropolitan area (Huntsville, Madison County).

Inaccessible area has been a significant concern as the posted bridges may isolate areas from access to main roads. In the analysis those areas could be identified as changes in total area from cost distance without and with posted bridges. Inaccessible areas have no data in one of the raster files. Seven counties had more 500 acres inaccessible. Baldwin County had more than 37000 acres inaccessible and Pickens was a distant second with just over 6000 acres. Some of the counties with many inaccessible areas were border counties where there may have been some public access across the state line.

Table 1. Generalized GIS procedures.

Layer	Actions	Values
NCLD landcover	Reclassify	Forest (41,42,43)=2; Operable nonforest (21-23, 31, 52, 71, 81, 82) = 1; Inoperable nonforest (11, 24, 90, 95) = no data
	Resample	30 to 15 m pixels (nearest)
Roads	Separated into layers	State highways (U,S), Local (M, C, O, and null), and interstate (I)
	Buffer and Raster	Local (15 m buffer) and coverted to raster 15m pixel, Local=0,
Streams	Merge	HUCs merged to 1 layer
	Buffer and raster	30 m buffer converted to 15 m pixel, rasters transferred the landcover as no data
Posted bridges	Edits	Snapped locations to road edge or intersection of stream and roads
	Buffer and raster	30 m buffer and 15 m pixel
Cost raster without posted bridges (CostAll)	Cell statistics	Landcover raster with local road pixels crossing all streams
Cost raster with posted bridges (CostPB)	Cell statistics	Landcover raster with posted bridge locations converted to no data
Cost distance	Cost distance	Landcover cost distance (CostAll and CostPB) to the state road polyline layer
Road travel (RoadAll and RoadPB)	Cell statistics	Cost raster with only local roads, and streams (all other landcover = no data). In RoadPB posted bridges = nodata
Euclidean distance	Euclidean distance	Road cost raster (RoadAll and RoadPB) to the state road polyline layer.

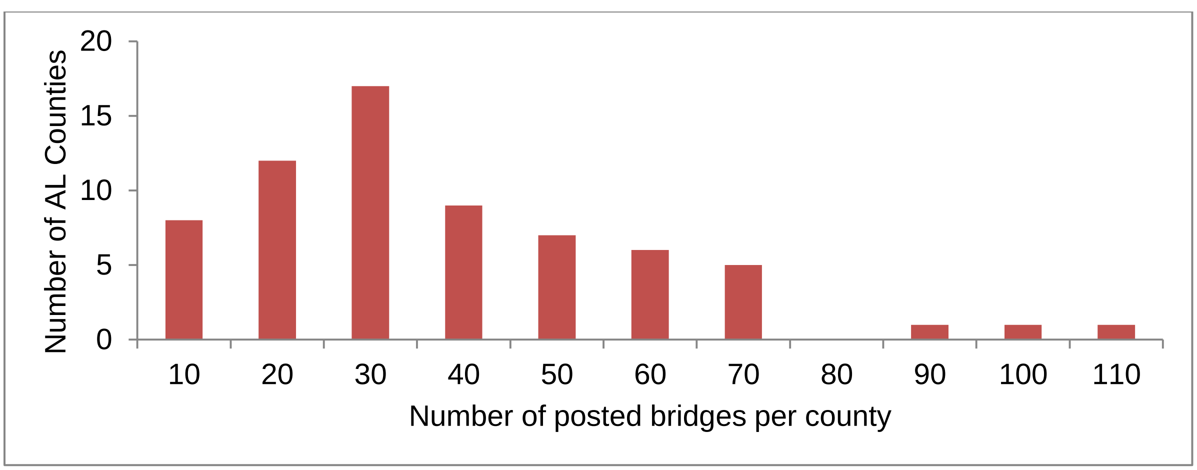


Figure 1. Summary of posted bridge number by county for the 67 Alabama counties.

Private road distance to the nearest public road with access to a state highway could also be affected by posted bridge restrictions. The distribution of private road haul distance means is shown in Figure 2. In general mean and maximum distance increased little for the majority of counties due to bridge restrictions. Only 5 counties have means that increased 5% or more due to posted bridges and 8 counties exceeded that threshold for the maximum distance. While I considered that all the named streams were impassable since bridge costs appropriate for truck travel could not be justified by small acreage owners, there were likely many more unmapped drainages that would have similarly limited private road access.

Public road distance measures the distance from each point on the county road system to the nearest state highway. The measure shows considerable impact due to posted bridges (Figure 3). Over half the counties had increases in the mean distance of more than 5%. The change in maximum distance showed greater variability with several counties showing increases of more than 15%. Distance to the nearest state highway varied considerably with a range from 2 to 7 miles (Figure 2).

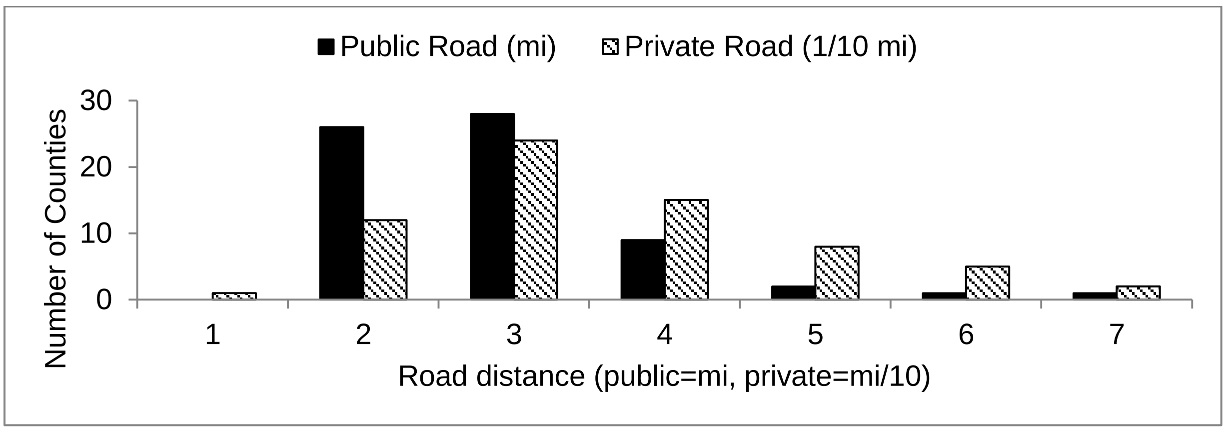


Figure 2. Mean public and private road haul distance including posted bridge restrictions.

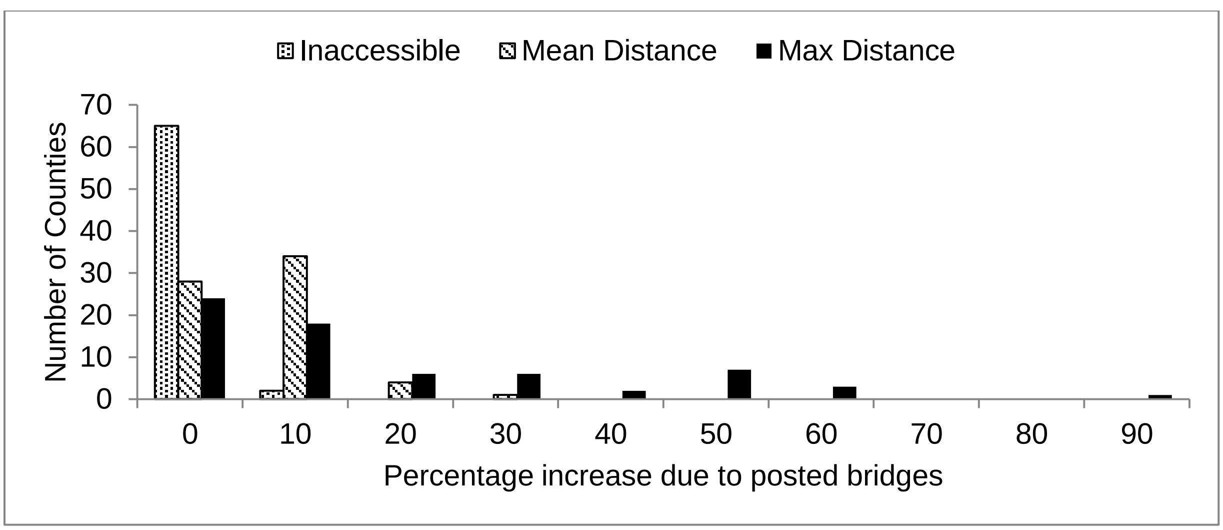


Figure 3. Changes in distance from points in the local roads to state highway access due to posted bridges.

The public interest in spending public funds on bridges to improve forest land access may be justified by two types of public benefit. Stumpage prices are somewhat related to current use land value for property taxes assessment. Personal income tax receipts may increase if repairing posted bridges increases stumpage price. In addition improved accessibility may stimulate harvest activity because forest owners see better prices and buyers see better transportation options. In addition the increase in income could lead to direct and indirect economic impact.

I performed regression analysis to determine if posted bridges impacted stumpage prices. In Alabama county stumpage and harvest volume data are available from severance tax receipts. The results are published annually (AFC, 2012). I used average county stumpage value ($\$/ft^3$) as the dependent variable. Variables in the full model included county volume from FIA - TPO data (e.g. total harvest, % hardwood volume, % pulpwood etc.), competition variables (e.g. mills per county, mills in adjacent counties) and all the GIS variables by county. Stepwise selection (p=0.15) resulted in the model in Table 2. The model was significant (F=6.03, MSE=0.02221, R^2=0.3307). In general parameter estimates had signs that would be expected. In so far as the effect of posted bridges the net result on stumpage prices might be negative to neutral. When the parameter estimates for GIS variables were applied to the counties there was a net negative effect on 34 counties with a minimum of -$\$0.16/ft^3$ and a maximum of 0.12. The mean was negative (-$\$0.0066/ft^3$)

Discussion

While it seems rational that increased transportation costs on public or private roads would negatively influence stumpage price, modeling stumpage price at the county level to determine the effect presented challenges. Even in counties with many posted bridges most of the forest land in the county will have relatively good access to local and state roads. As a result the average effect of posted bridges on private road distance was quite small (increase of 1.5%). Public road travel distance seemed to have more effect on stumpage but the variable might be closely related to overall road conditions or simply indicate the difference between more rural and more urban counties.

If counties were to repair enough bridges to reduce the maximum public road distance by 25% (when compared to no access restrictions) the average (by county) change in stumpage would be $\$0.01/ft^3$. This reduction could be the equivalent of fixing 1 bridge. Since the maximum was usually 5 to 10 times the mean that change would have little impact on the public road mean (or private road change). The average county difference due to the reduction in maximum public road travel (25%) was an increase of $150,000 in stumpage receipts per year. There were 33 counties with an effect of less than $50000, 8 counties where the net effect was over $500000 per year and 2 of those with an effect of more than $1 million per year.

Table 2. Regression equation with dependent variable average county stumpage price ($\$/ft^3$). Maximum impact is the variable range multiplied by the parameter estimate

Variable	Partial R^2	Estimate	Pr > F	Maximum impact ($\$/ft^3$)
Intercept		0.433	< 0.0001	
Total County Volume (FIA - TPO)	0.1864	0.00000496	0.0863	NA
Private Rd Change	0.0279	1.19788	0.0961	0.14
Public Rd Max	0.0285	-0.00000805	0.0139	-0.37
Public Rd Mean	0.0505	0.00003835	0.0359	0.35
Adjacent County Sawmills	0.0373	0.01366	0.0173	0.22

Literature cited

AFC (2012).Forest resource report 2011. 48 Montgomery, AL: Alabama Forestry Commission.

Cubbage, F. W. & Raney, K. P. (1987). County logging and tree protection ordinances in Georgia. *Southern Journal of Applied Forestry* 11(2): 76-82.

ESRI (2010).ArcMap 10.0.

Grebner, D. L., Grace, L. A., Stuart, W. & Gilliland, D. P. (2005). A practical framework for evaluating hauling costs. 16(2): 115-128.

Jackson, B. D., Greene, W. D. & Baxter, M. L. (1993). Local regulation of timber harvesting and trucking in Georgia. *Southern Journal of Applied Forestry* 17(4): 200-206.

Lewis, J. E. (1968). Changes in highway mobility in the United States South: 1940 to 1960. *The Professional Geographer* 20(6): 382-387.

NRCS (2013).Geospatial Data Gateway Vol. 2013: USDA.

Weber, J. (2005). The morphogenesis of state highway networks in the United States. *Journal of Historical Geography* 31(4): 723-743.

Factors Affecting Fuel Consumption and Harvesting Costs

Mathew Smidt and Tom Gallagher, Auburn School of Forestry and Wildlife Sciences

Fuel is a significant component of consumable costs, and recent price swings have severely impacted the cost of delivering material to consuming mills. In addition, petroleum prices directly and indirectly influence other consumable costs. At the fundamental level the attributes that affect the amount of engine power and machine time that are needed to produce a ton of wood at roadside include mechanization, the degree of processing, optimization of the transportation system, and the terrain. At a practical level those attributes would be reflected by machine size, regional location, harvest intensity (partial cut vs. clearcut), system type, tract size, piece size, terrain, harvest planning, merchandising requirements, etc. Some constraints are imposed by location (piece size, region) and some may be imposed by SFI/FSC requirements (planning issues and sale size). Finally contractor and operator efficiency and contractors' machine choices and machine condition have considerable effect on machine time and fuel consumption per ton, but those differences have often been ignored or normalized in the desire to describe an average operation. Fuel data is being collected from loggers to estimate consumption per ton of wood produced. Several variables are included in the study to determine their impact. Data collection is on-going; summaries will be given for information to date. Keywords: fuel consumption,

Loggers are most concerned about the system they operate and the equipment they own and they have the opportunity to collect relevant data for production and cost analysis and forecasting. For the forestry community, those data are difficult to obtain and when collected represent a limited number of systems and machines. For broader goals there is need for reliable estimates for harvesting machine productivity and cost which has been addressed through development of Rules of Thumb (ROT) and monitoring and research of timber harvesting operations. Researchers have spent most of their effort in the estimation of production rates of harvesting components since production has the largest single impact on cost per unit for both the individual activity or machine and the harvesting system. Over time studies have attempted to fill knowledge gaps on machine reliability (Tufts and Hitt, 1983) and operational efficiency (Greene *et al.*, 2004), but those factors can be highly variable. At the same time, practical and theoretical approaches have been used to estimate machine maintenance and repair costs (Brinker *et al.*, 2002; Miyata, 1980).

Interest in fuel use as a component of cost resulted in the development of rules of thumb for estimation by engine power and machine type. While the ROTs present a static view of fuel consumption, other authors have identified the importance of operating parameters and technological development on fuel consumption per unit of output. While fuel is still a minor cost component compared to ownership and labor costs, the price volatility strongly affects the small profit margins in logging. Estimates of fuel cost per unit production may allow fuel price to be addressed in pricing systems. For some time consumers have compared materials for sustainability by their lifecycle energy or resource use. This interest has grown as consumers are interested in calculating the carbon offset by replacing fossil fuels with biomass energy.

The most significant fundamental work regarding fuel use by forest machines is the description of Work-Load Factor (WLF) by Sundberg and Silversides (1996) (Sundberg and Silversides, 1996). The WLF is a ratio of the power demanded by machine function to the power available from the machine. The WLF acknowledges that machine fuel consumption will vary based on the demands expressed by the system and the operator. The ROT for fuel consumption indicates an expected WLF between 0.4 and 0.6. Machine design and selection and perhaps enhanced operational efficiency has lowered fuel consumption per unit over time (Lindholm and Berg, 2005). At least some fuel saving in modern machines involves computer control of engine power output based on engine power demand.

Data has also shown how systems can affect fuel use per unit volume based on processing, operational efficiency, and machine selection (Sundberg and Svanqvist, 1987; Sambo, 2002). Researchers found that larger (heavier, more powerful engines) machines have reduced fuel consumption per unit output because of increased efficiency of handling or transporting the trees (Athanassiadis *et al.*, 1999). In the USA, there has been no systematic effort to monitor fuel consumption on harvesting systems. Episodic fuel price increases have prompted wood suppliers and industries to establish or enhance data collection effort, but none of those efforts contributed to general knowledge.

Individual harvesting machine and system research or demonstration projects have collected fuel consumption data. Specific objectives of those studies may include developing a more accurate production cost or comparing options where fuel use might contribute to the differences. The objective of this project was to consolidate data from production studies where fuel consumption and productivity were measured in order to document fuel consumption in regard to both machine and harvest variability.

Methods

The literature survey for machine fuel use in logging involved resulted in over 1000 estimates of machine production from the late 1970's to the present. Basic data entry for each estimate or data point was intended to include productivity, fuel use, average tree size, harvest type, machine type, terrain, and engine power. For skidders and forwarders we added cycle distance. Fuel consumption was included when the measurement was made during the study or in local operating conditions. The majority of the studies did not have all of the data. On harvests where the average tree size was not given, we estimated it in classes (0.085 m^3 per tree, 0.17, 0.255, and etc) based on the study description. For harvest intensity we recorded only partial cut or clearcut which could be inferred from the details of every study (precise removal volume per area was often unavailable). We expressed productivity as volume per productive machine hour (PMH) since most study units presented a volume estimate. We converted weight to volume using recognized species density estimates or regional estimates for mixed species harvests.

Results

In order to provide some indication of whether studies with fuel estimates were representative of all production studies, we provided the basic statistics for production (mean, standard deviation, and sample number) and the mean publication year. We used machine model year in the few cases where it was available. With the exception of forwarders the age range of the studies for each machine were similar (Table 1). Grapple skidder and feller-buncher data were probably the most dissimilar in production among the more frequent machines. Since many of the studies lack key data elements, it is hard to determine the source of the difference. It could be related to site conditions, machine size, or some combination of the two.

Table 1. Summary data for logging productivity studies with and without fuel estimates for most frequent machines.

Machine	No fuel estimate			Fuel estimate		
	Productivity (m^3 pmh^{-1}) (SD)	Mean year	Number	Productivity (m^3 pmh^{-1}) (SD)	Mean year	Number
Delimber	40.4(26.7)	1989	35	37.3(9.3)	1986	7
Feller-buncher	39.2(29.6)	1990	148	56.3(46.6)	1992	30
Forwarder	18.4(9.1)	1994	71	18.5(4.3)	2007	9
Grapple Skidder	46.3(43.1)	1992	80	30.1(15.5)	1991	40
Harvester	19.0(21.9)	1994	152	13.4(4.1)	1998	22
Loader	77.2(42.2)	1996	36	73.9(24.4)	1995	8
Processor	30.5(21.3)	1991	105	42.6(23.2)	1990	13

Average fuel consumption for general machine type is given in Table 2. The variability was largest for the grapple skidder. Many of the loaders in the studies were tracked loaders leading to higher than expected fuel consumption when compared to expectations for knuckleboom loaders commonly used in the eastern U.S. Variability in fuel consumption for grapple skidders was reduced when fuel consumption was calculated on a volume basis. In a few cases, notably the processor and forwarder, fuel consumption expressed on a per unit volume basis had greater variability than on an hourly basis.

To address issues that might affect fuel consumption in full tree systems, we further analyzed grapple skidder and feller-buncher fuel consumption. Figure 1 shows that fuel consumption was affected by both tree size and productivity for grapple skidders. Although there was considerable variability, the trend between productivity and a tree size was generally positive. Fuel consumption was highly variable across the range in productivity and tree size. Other variables (bunch size, terrain, and turn distance) may play a large role both in

Table 2. Fuel consumption mean and standard deviation for most frequent machines. Range (upper and lower) is based on a two tailed T-test with p=0.05.

	Fuel use (l pmh^{-1})		Fuel use (l m^{-3})			
Machine	Mean	SD	Mean	SD	Upper	Lower
Delimber	17.3	4.4	0.490	0.201	0.746	0.235
Feller-buncher	26.2	9.5	0.701	0.432	1.207	0.195
Forwarder	11.1	1.7	0.623	0.169	0.833	0.413
Grapple Skidder	23.6	23.0	0.739	0.453	1.268	0.211
Harvester	19.1	8.8	1.438	0.653	2.210	0.666
Loader	26.3	2.7	0.372	0.096	0.492	0.253
Processor	22.5	4.1	0.677	0.352	1.101	0.254

productivity and fuel consumption. For feller-bunchers the trend between productivity and tree size was closer (Figure 2). Fuel consumption per unit volume decreased in response to higher productivity with little variability.

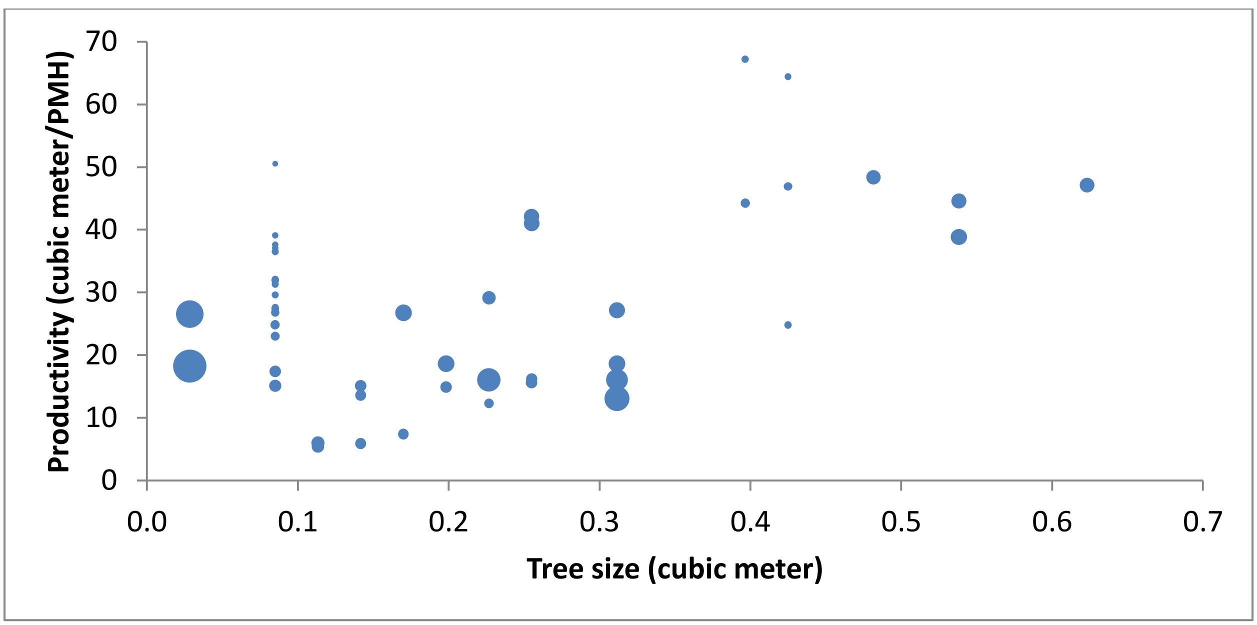


Figure 1. Grapple skidder productivity by tree size. Dot size represents fuel consumption estimate in l m^{-3}.

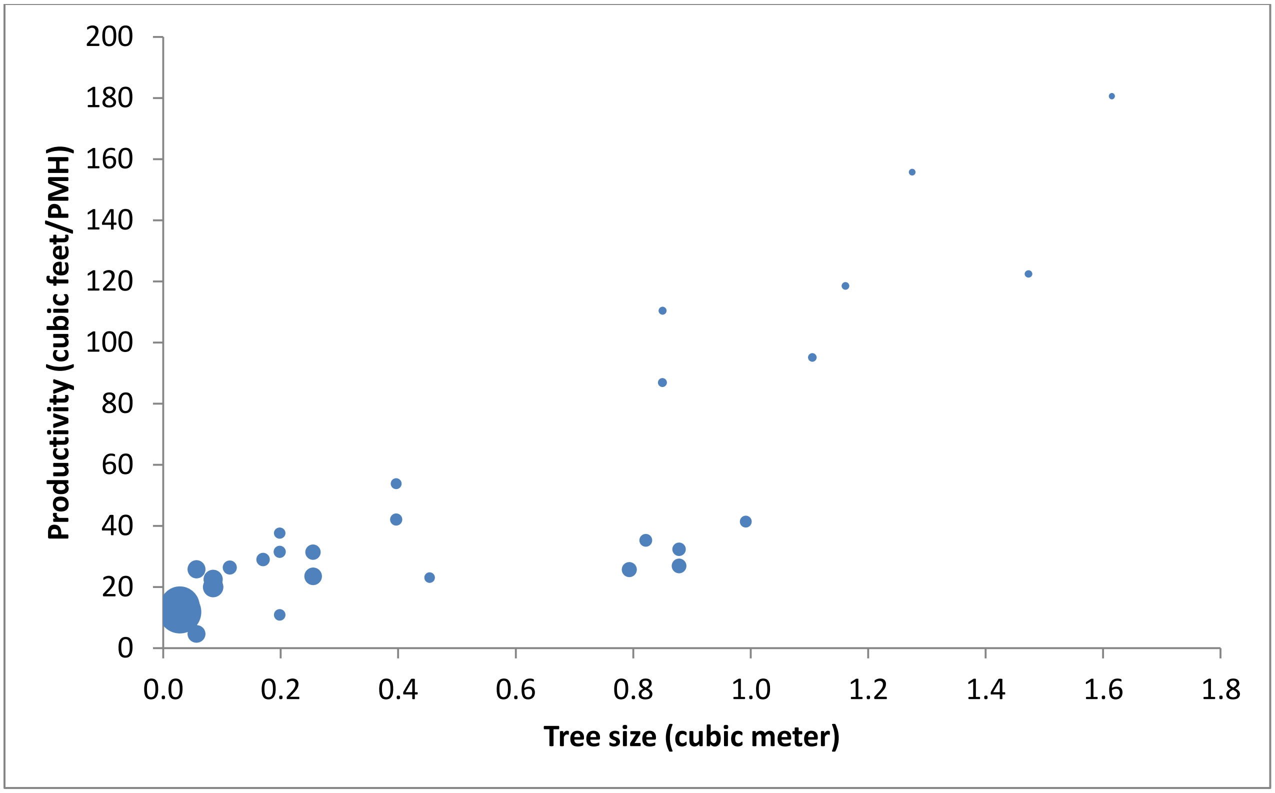


Figure 2. Feller-buncher productivity by tree size. Dot size represents fuel consumption estimate in l m^{-3}.

We developed mean fuel consumption for classes of clearcut and partial cut versus tree size for feller-bunchers and grapple skidders (Table 3). The fuel consumption trend for feller-bunchers in clearcuts appears to be similar to the relationship in Figure 2. Data for small trees in clearcuts were from biomass harvests of very small trees yielding high fuel consumption (l m^{-3}). In partial cuts, tree size had little effect on fuel consumption, although the sample number

Table 3. Fuel consumption (l m^{-3}) for feller-bunchers and grapple skidders for harvest type (clear cut vs. partial cut) and tree size classes. If the data range () is absent, values are from a single data point.

Machine	Harvest	Tree size class			
		< 0.18 m^3	0.18 to 0.51 m^3	0.52 to 0.68 m^3	> 0.68 m^3
Feller - buncher	Clearcut	1.22(0.47-2.75)	0.24(0.17-0.35)	-	0.09(0.05 – 0.12)
	Partial Cut	0.29	0.28(0.19-0.45)	0.16	0.28(0.21-0.35)
Grapple Skidder	Clearcut	0.36(0.08-2.69)	0.51(0.12-1.52)	0.56(0.50-0.64)	-

was limited. For grapple skidders, there were too few data in partial cuts to present an estimate. In clearcuts fuel consumption appeared to increase with tree size, but the data range was quite large with smaller tree size classes. Differences due to terrain and skid distance were important given the small sample size.

Total fuel consumption estimates for the harvesting system have as much or more value than fuel consumption estimates for individual machines. The challenge is that the variability in systems and products are quite large and some components, especially for hardwood harvesting, are represented only to a minor degree in the production studies. Estimates for eight harvesting systems are presented in Figure 3. Six of those are whole tree systems where some degree of processing occurs on the landing. Processing could be delimbing to produce tree length (TL) loads or delimbing and bucking to produce log length (LL) loads. The assumption was that southern yellow pine species were delimbed with the loader and pull-through delimber, and other conifers would require a stroke delimber. The fuel consumption

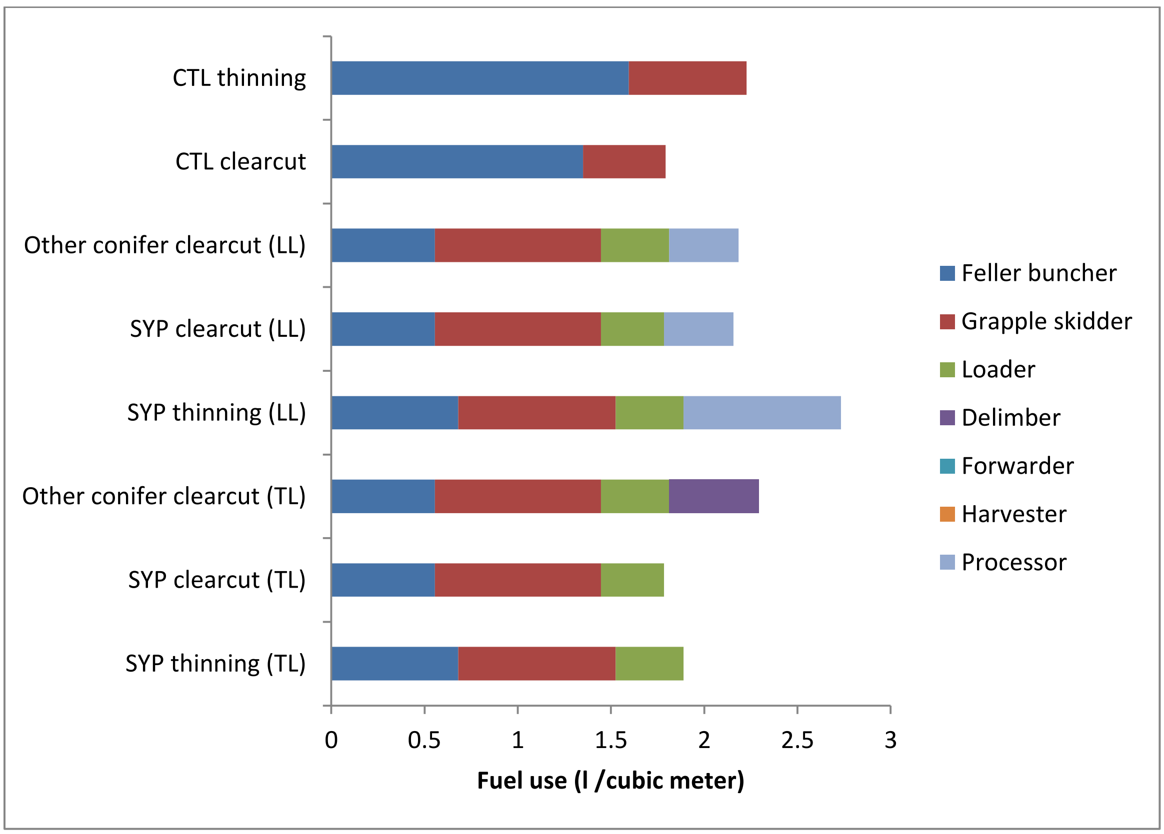


Figure 3. Fuel use by harvest system from machine averages. Wood can be loaded log length (LL) or tree length (TL) from these systems. In southern yellow pine (SYP) delimbing can be done with the loader, but in other conifer a delimber is added. Thinning in SYP includes estimates for felling only trees <0.26 m^3 in partial cuts.

of cut to length systems was estimated for thinning and clearcut harvests. For the processor, we were able to estimate productivity for thinning using small trees (<0.33 m^3) and clearcuts with large trees (>0.33m^3). The estimates in Figure 3 are only the means and reasonable expectations would be that the sum of 90% confidence intervals for each machine could easily sum to 70% or more of the mean of total fuel consumption.

Comparing log length harvests in clearcuts revealed that CTL systems have the lowest fuel consumption. Since both SYP and other conifers required processors, the fuel consumption was nearly the same. Both thinning systems require more fuel per unit than the clearcut systems. The CTL system thinning estimate was only slightly higher than the other log length systems in clearcuts. The two SYP tree length systems (thinning and clearcut) were among the most fuel efficient systems, but were only marginally different from CTL clearcut systems. The addition of the delimber for other conifer increased the fuel consumption above many of the other log length systems. From western Canada, the estimates for most of the similar systems in Figure 3 are similar to these estimates (Sambo, 2002). For CTL in thinning and clearcuts, and full tree clearcuts they estimated just over 2 l m^{-3}. For tree length thinning, the estimate for western Canada was considerably higher at 3.5 l m^{-3}.

Conclusions

While there have been hundreds of production studies over the past few decades, few have documented fuel consumption in their reports. Upon finding and reviewing those reports that did include specific fuel consumption data, variables that may have impacted consumption levels were not always listed (tree size, bunch size, slope, etc). With some interpretation of data, it could be shown that tree size had a considerable impact on fuel consumption for both the grapple skidder and the feller-buncher. The impact of partial cut versus clearcut was less evident. More data may show a better relationship.

Collection of fuel consumption data for new equipment and different system configurations has begun and will continue for the next year or more to determine which variables have significant impact on fuel consumption. While getting logger participation has been challenging, efforts will continue to ensure most of the common logging systems are represented.

Athanassiadis, D., Lidestav, G. &Wasterlund, I. (1999). Fuel, hydraulic oil and lubricant consumption in mechanized harvesting operations, 1996. *Journal of Forest Engineering* 10(1): 59-66.

Brinker, R. W., Kinard, J., Rummer, R. &Lanford, B. L. (2002).Machine rates for selected forest harvesting machines. In *Circular*, 32: Alabama Agricultural Experiment Station.

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

Lindholm, E.-L. &Berg, S. (2005). Energy use in Swedish forestry in 1972 and 1997 *International journal of forest engineering* 16(1): 27-37.

Miyata, E. S. (1980).Determining fixed and operating costs of logging equipment. In *General Technical Report*, 16: USDA, Forest Service, North Central Forest Experiment Station

Sambo, S. M. (2002). Fuel consumption for ground-based harvesting systems in western Canada. *Advantage, FERIC* 3(29): 1-12.

Sundberg, U. &Silversides, C. R. (1996). *Operational Efficiency in Forestry: Volume I: Analysis.* Kluwer.

Sundberg, U. &Svanqvist, N. (1987). Fuel consumption indicator of the economics in mechanization. *Scandinavian Journal of Forest Research* 2: 389-398.

Tufts, R. A. &Hitt, J. A. (1983). FAILURE CAUSE, FREQUENCY, AND REPAIR FOR FOREST HARVESTING EQUIPMENT. *Transactions of the American Society of Agricultural Engineers* 26(6): 1673-1677.

The West Virginia Logging Operation Notification, Inspection, and Enforcement System

Ben Spong[1]

Abstract

The WV Logging Operation Notification, Inspection, and Enforcement System (LONIE) system provides the WV Division of Forestry (WVDOF) a state of the art system to manage the thousands of active logging operations throughout the state. The web-based online database and simple mapping API allows users to submit, track, and enforce logging operation notifications and activities. The new streamlined system facilitates accurate data entry, improves the allocation of limited resources, facilitates the timeliness and accuracy of reporting activities, and provides real time spatial data detailing harvesting activities occurring in the state. Each of these benefits help the WVDOF improve their ability to implement and enforce the Logging Sediment Control Act (LSCA) and minimize nonpoint source pollution from logging and other silvicultural activities. Additionally, the LONIE system provides improved service to landowners, forest operators who can access notifications, inspection reports, and enforcement actions at any time, as well as have improved contact with the state foresters who visit active jobs. Centralized, uniform, and organized data provide the WVDOF new opportunities to analyze harvesting and enforcement data to improve service, identify potential issues, and support departmental programming.

Introduction

The West Virginia forestry community has long known that controlling nonpoint source pollution from silvicultural activities is important to avoid erosion and sedimentation in streams and other waterways. After the Federal Water Pollution Control Act Amendments of 1972 (PL92-500), specifically section 208 of this law, the WV forestry community was mandated to develop a Silvicultural Water Management Plan for West Virginia. An advisory committee, consisting of private and public sector personnel, developed a Best Management Practices (BMP) manual in the late 1970's that was intended to reduce soil erosion due to forestry. In 1992, the West Virginia Legislature passed the Logging Sediment Control Act (LSCA). The LSCA is now regarded as one of the tougher forestry and water quality laws in the United States.

The West Virginia Division of Forestry (WVDOF) currently works with their constituents across the state to protect 12 million acres of forestland from wildfire; train, license and regulate the state's professional loggers; and assist landowners with proper management of the state's privately-owned forests. The WVDOF's responsibilities surrounding logging activities are where they have the largest potential impact on minimizing soil erosion and sedimentation of streams and other waterways. Two of the key provisions that the LSCA introduced were:

- Notification – logging operators must submit a notification form to the WVDOF within three days of starting a new harvesting operation. Loggers must also post the logging job with a sign indicating the company name and license number.

- Inspection and Enforcement – WVDOF personnel are empowered to inspect operations and issue compliance orders to correct problems, and when necessary, can suspend a logging operation until specified corrections are made bringing the operation into compliance.

Each year approximately 3,000 notifications of harvesting activity (covering over 220,000 acres or 89,000 ha) and 10,000 inspection and enforcement reports are processed by the WVDOF on hand-written forms collected at regional WVDOF offices. Following collection, WVDOF personnel manually input the information into an excel file for the supervisor to approve and a hard copy of this file is then sent to a regional office where it is re-entered into a “flat” database file. The existing system does not incorporate current technology tools that help minimize WVDOF staff efforts, the number of mailed forms, and places where data entry errors could be made. In order to address these shortcomings, a new web-based database program was developed to improve the process and provide improved reporting capabilities. The WV Logging Operation Notification, Inspection, and Enforcement (LONIE) program has been in active use since January 2013.

Development

Preliminary meetings between the two primary partners in the project, the WVDOF and the Appalachian Hardwood Center (AHC) at West Virginia University (WVU), helped establish a basic framework and potential funding sources for the development of a new system. A programmer was brought onboard to implement the project. Scaffolding of all the data fields from the WVDOF’s printed notification, inspection, and enforcement forms started the formal development process. Existing non-web based databases of certified loggers and timber license holders were integrated so that basic contact information integrity could be maintained and not have to be inputted manually multiple times. Once the existing data, new data fields, and relationships were established, the user types and user interfaces were incorporated. Mapping and reporting components were added to complete the program.

The LONIE system was developed in the php programming language, using a SQL database and is currently hosted on IIS server.

Implementation

Users

The LONIE system has two primary user types – WVDOF Employees and Timber License Holders. The majority of users (1178 out of 1325 total users) are WV Timber License Holders. These are individuals and companies that are registered with the state to buy and/or sell timber and logs. These users have been set up with basic permissions that allow the license holder to enter timber harvesting notification information and then track inspections and compliance activities on these operations. Currently, only a few license holders have been activated for these activities, as the WVDOF wanted to ensure the system was well tested before they opened LONIE to the full number of potential license holders.

WVDOF employees make up the other primary user group, with a number of subuser types are foresters, supervisors, specialists, and administrators. The most restricted user on the WVDOF's side is the forester. Foresters can view logging operation notification forms that have been assigned to them, enter inspections, and enforcement orders. Supervisors can do these same tasks, but also have the ability to review and approve all the inspections of the foresters that report to them. The specialist has access to everything the supervisor has and has the additional task of assigning new notifications to the most appropriate forester. Of course, the administrator level user has unrestricted access to all areas of the program.

Upon login to the LONIE system, all users will see a customized dashboard that lists all notifications that they own or have been assigned. Notification status is indicated by highlighting in different colors and there is the ability to edit and view the details of each entry from this screen.

The Notification

Most of LONIE is based off of the logging operation notification data that can be entered by the timber license holder or the WVDOF forester. The original paper forms that had been used for many years provide most of the information needed to enter the job into the system. Notification entry starts with the timber license holder's name, which is automatically selected if the timber license holder logged in as themself. Otherwise, the WVDOF employee would select the appropriate license holder and the notification form is auto-populated with the appropriate names and contact information. The user then must enter information about the location, the certified logger in charge, and the timber owner, property owner, and severance tax payer. Once these data are saved, step 2 of the process asks the user to map the harvest unit using a custom mapping application (Figure1). The setup allows the user to use United States Geological Survey (USGS) topographic maps, aerial imagery, or other background data to help them draw the harvest unit boundary and indicate the landing and stream crossing locations. Step 3, automatically calculates out acreage from the drawn boundary in Step 2 and requires the user to assign harvesting methods (even aged, uneven aged, logger's choice, and/or others) to every acre to be harvested. Step 4, allows the user to check off that they will follow the each BMP or specifically describe an alternative practices they will follow. Finally, Step 5 has an optional field to enter the Miss Utility confirmation number and an approval statement that acts as the official signature on the notification.

Once the notification has been submitted it stays in pending status until a WVDOF specialist reviews, approves, and assigns the notification to one of the foresters. Typically, the forester will be assigned all jobs in his or her region, but they may be assigned to others as needed. If a forester is assigned a notification, they will then need to review the submitted information and schedule an inspection of the operation. The original paper inspection forms were mimicked in LONIE, but with most of the required fields being auto-populated and only requiring the forester to check off a few basic options and enter any notes necessary. Similarly, if any enforcement activity must be taken, the forester only has to click a couple of different fields to record these actions. Printing features have been included that allow the forester to generate PDF versions of the notification, inspections, and enforcement orders in a format that exactly resembles the original paper forms.

Reporting

Finally, the reporting components of the system were developed in order to quickly filter and summarize all the data for many different reporting needs. Reports that are needed on a regular basis have been programmed in so that they can be generated with one click, while other reports simply dump large amounts of data for further analysis using external spreadsheet or GIS tools. Each of the reports have date ranges to help generate time period based reports and many of the reports have custom filters to generate reports based on any combination of administrative region, county, forester, or status. Geospatial data from the mapping component are stored in a KML format that is easily exported to other GIS software for more rigorous spatial analysis (figure 2).

Training and Usage

WVDOF employees were trained on the LOINE system in a large face to face meeting and individual site visits to each of the regions. The system was intuitive enough that most users were able to use it without much training, however there were a number of users who had less experience using other web based applications and needed additional one-on-one training. Additionally, a bug/issue reporting system was developed in which 66 issues were submitted over the first six month time period for troubleshooting. Most of these were user error issues that were addressed through additional training. A couple of issues were addressed by the programmer and a number of items were added to a wish list for future improvements.

With six months of use, LONIE has seen 2,037 notification entered into the system and 3,625 inspections. There are 44 WVDOF users and 160 timber license holders registered and actively using the system. All other timber license holders have accounts, but most will not be used before statewide training sessions for these users are completed.

Discussion

Development of the LONIE system turned out to be much more complex than the original scoping of the project had estimated. The sheer number of data types, user types, permissions, complexity of the relationships, the custom mapping and reporting components, and security all required high end programming skills. The entire project was ready for beta testing in November 2012, however difficulty in securing appropriate hosting space pushed back the launch to January 2013 and removed the ability to beta test with a small group of users. Instead, LONIE was launched to all WVDOF users at the same time with the plan that any issues would be addressed as they were identified. This was a risky plan as the tasks that LONIE tracks are critical to the work of the WVDOF and significant issues could have caused huge interruptions to the logging operations around the state and could have possible legal implications in regards to response times and some of the enforcement tasks. Fortunately, only minor issues were encountered and most users found the deployment went smoothly and the use of the system was intuitive and time saving.

When LONIE was initially deployed, the WVDOF users entered notification information for all jobs that were active as of January 1, 2013 and all new jobs submitted after this date. In the first month, 1,139 logging operation notifications and 516 inspection reports were entered into the system by WVDOF foresters (figure 3). While this exercise took considerable effort, it was a beneficial training exercise that allowed the foresters to get extensive experience working with LONIE. Once these notifications were entered, many expired, lost, and other problem notifications became easily identified through different sorting tools and formal reports. Foresters were able to quickly address these operations and either close them out permanently or get them back into their work queues.

With the quick adoption of the LONIE, clean, well formatted data was instantly available in the system for reporting and analysis. Never before had these data all been accessible and related so that someone could look and quickly determine how many jobs or acres were active at a given time. New reports were generated that could look at workloads and productivity of each of the foresters. In the previous system, the notifications and inspections were in separate databases without a common key that allowed them to be related later. In addition to relating these two databases, the certified loggers and timber license databases were also integrated, creating a one stop location to review and analyze all LSCA based activities. With additional experience with the LONIE system, new ways of looking at these data will develop and help the WVDOF report to other state and federal agencies, prepare strategic plans, and justify staffing levels and performance.

The new mapping component provides the biggest set of data that was not digitally available in the previous paper based system. Paper USGS quad maps were supposed to be submitted with the notifications, but often they were difficult to read and didn't have enough detail for the forester to easily locate the harvest area. Additionally, acres were often guessed or generalized to be the entire ownership, rather than just the forested area they were working on. The web mapping component helps improve all of these issues as the user can zoom in and out to see the surrounding area, they can use road maps, topographic maps, or photos to help identify the area, and all of this can be saved and used in many types of GIS analysis. Typically, only landowners with foresters on staff were submitting acreage estimates that had been measured in some manner, so the map area calculations in LONIE are a major data quality improvement. At the completion of 2013, comparisons can be made with annual acreage counts from previous years to provide insight to the scope of the mapping tools impact.

Conclusion

The LONIE system has quickly become the centerpiece of the daily activities of WVDOF's LSCA program. The process to develop LONIE required significant coordination between all project partners and continues to engage the team in second phase development, training, and periodic troubleshooting. The move from a paper and manually re-keyed data entry system has decreased the amount of time required for foresters to record inspection and enforcement data and improves the consistency of the data so analysis and reporting can be completed with much less effort. Built in systems for approvals and checks to ensure notifications do not fall through the cracks also improve WVDOF's service to the forest products industry. Timber license holders can also enter their notifications online with mapping and acreage calculation that are much improved over the manual methods typically used in the previous system. While the move to the LONIE system was a drastic system change, the overwhelming feedback has been very positive from all user groups. With additional data being added daily, news ways to leverage these data will develop to provide additional benefits into the future.

---

[1] West Virginia University, Division of Forestry and Natural Resources email: ben.spong@mail.wvu.edu

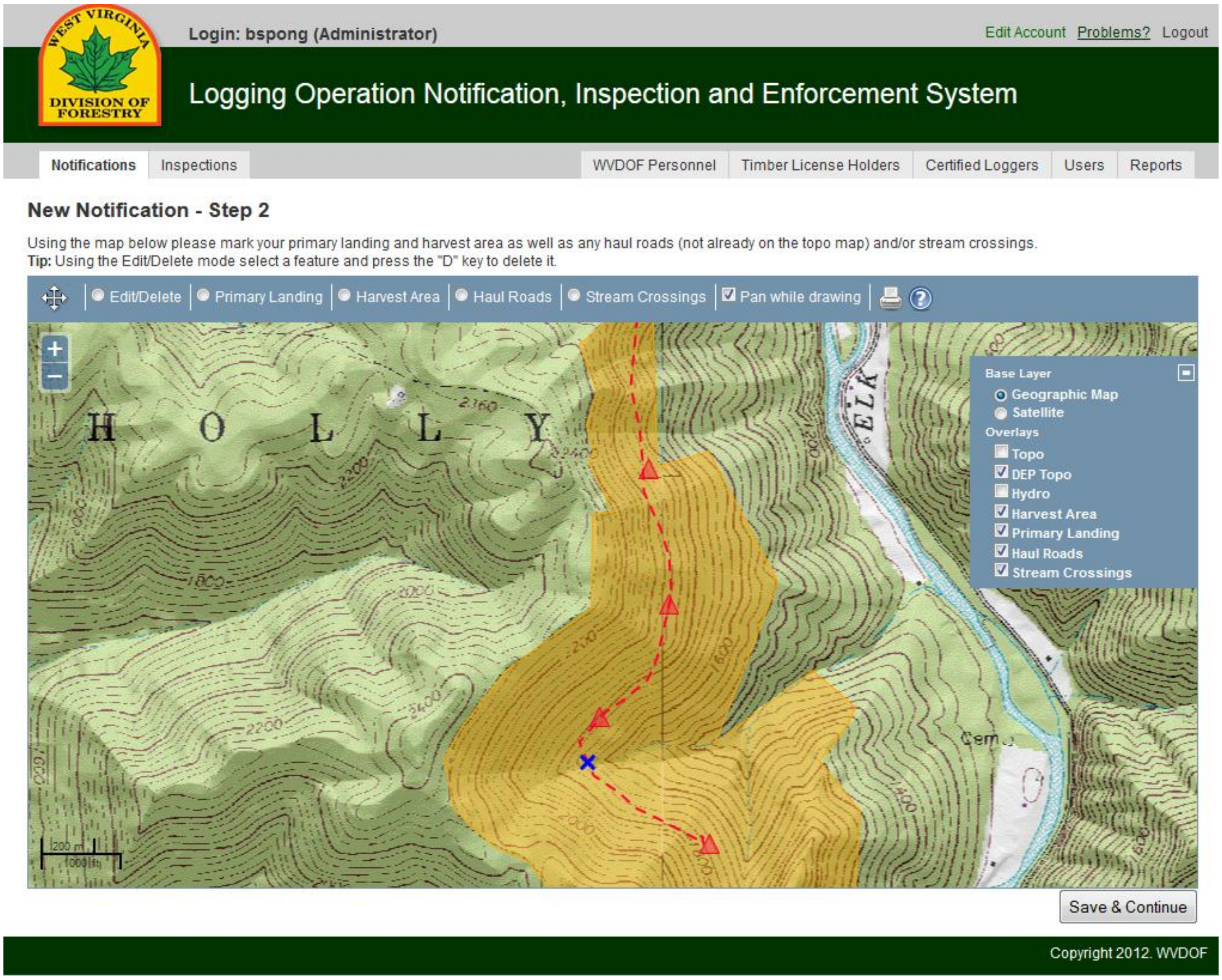


Figure 1. The custom LONIE mapping interface allows users to draw harvest boundaries on a map with different base layers or overlays to help improve the accuracy of harvest area calculations.

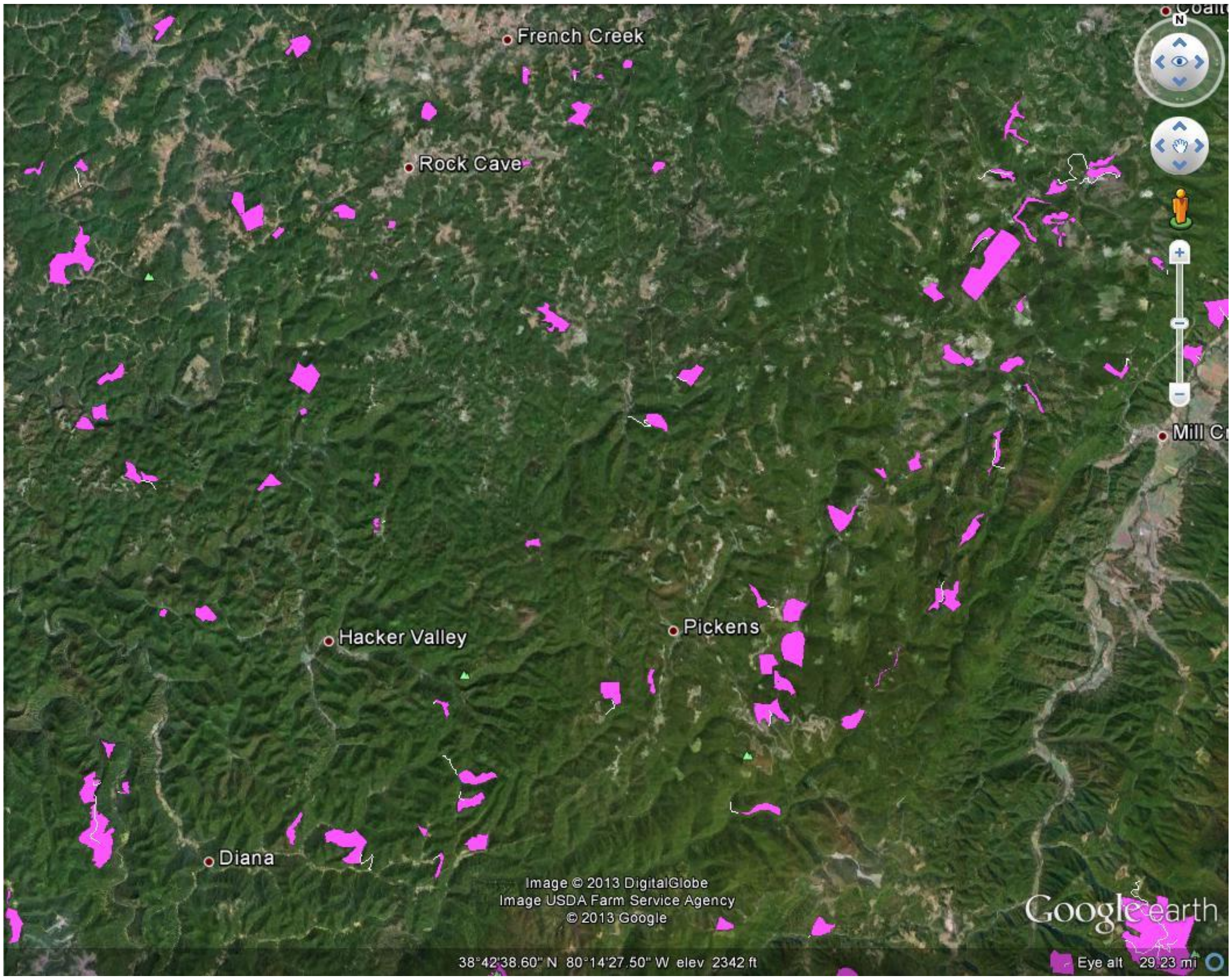


Figure 2. KML export of LONIE geo-spatial data displayed in Google Earth. This screen capture displays an area south of Elkins, WV. The pink polygons denote the individual position and shape of harvest areas as submitted through the notification process.

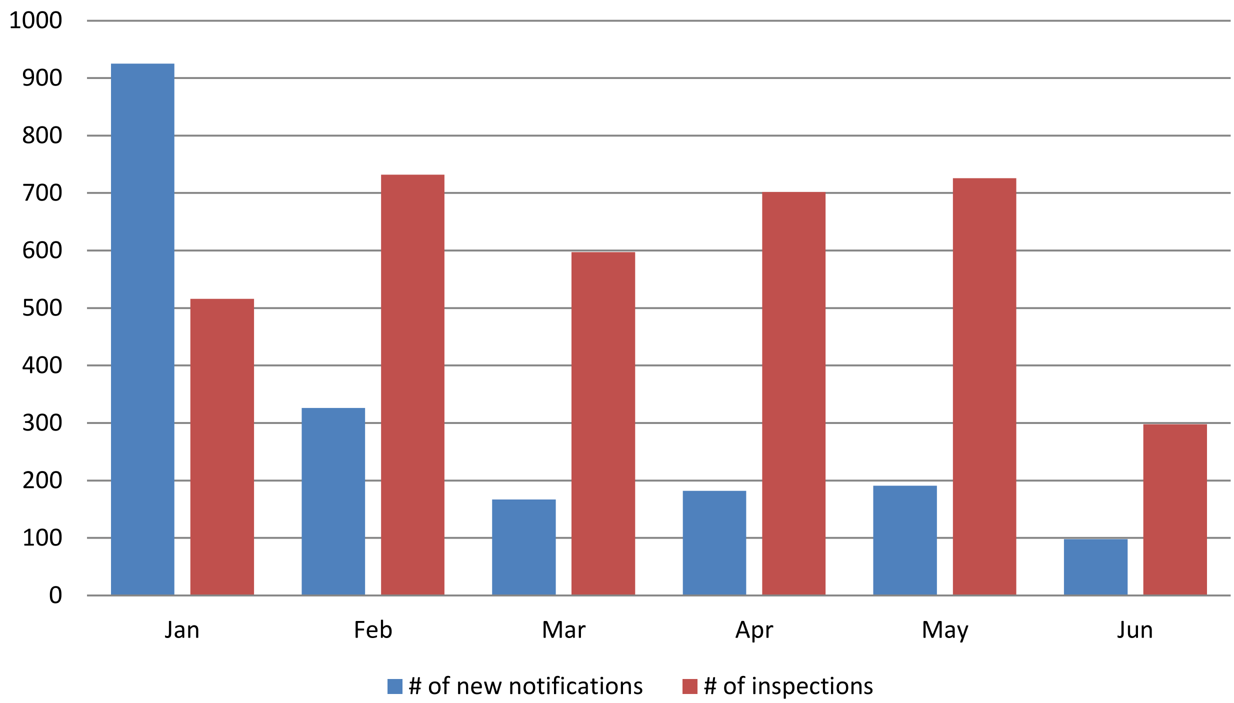


Figure 3. Number of notifications and inspections entered into LONIE by month in 2013. Note June is data is partial data through 6/23/2013.

Production, Cost and Chip Characteristics of In-Woods Microchipping

Jason Thompson[1], Wesley Sprinkle[1]

Abstract

Emerging markets for biomass have increased the interest in producing microchips in the field. As a component of a large United States Department of Energy (DOE) funded project, microchipping has been trialed on a limited scale. The goal of the research was to evaluate the production, cost and chip characteristics of a mobile disc chipper configured to produce microchips. Multiple test loads of Southern Pine were chipped and analyzed during the study. The chipper was modified after each test in an effort to obtain an "ideal" microchip that met a narrowly-defined specification. This paper reports the resulting production rate, cost and chip characteristics.

Introduction

In-woods chipping of trees has been a component of forest harvesting for decades (Stokes et al 1987). These chipping operations produced either clean chips for the pulp and paper industry or whole tree (dirty) chips for energy production. Emerging biomass markets have increased the interest in producing a microchip in the woods. Wood pellet manufacturers as well as woody biomass ethanol and biodiesel startups have expressed interest in in-woods produced microchips.

A microchip has been defined as a chip between 1/4 and 3/8 inches in length (Steiner and Robinson 2011). A traditional pulp and paper chip is generally 1 ¼ inches in length.

Microchips potentially offer several advantages to traditional pulp chips. Steiner and Robinson (2011) list multiple advantages. These include; lower overall total system energy requirements, faster processing times, smaller equipment sizes and fewer processing steps. Whitelaw (2009) also suggests that microchipping can eliminate front end grinding in the pellet process and reduce the horsepower requirement for regrinding after the drying process.

Hein (2011), in an article for Canadian Biomass Magazine, quotes several industry sources, that also contend that microchips may reduce the required mill chipping and grinding capacity and offer better material characteristics. These include less variance (variability?) in moisture content, faster drying and easier chemical conversions.

[1] Forest Operations Research Unit, Southern Research Station, USDA Forest Service, Auburn, AL

Microchips can be produced with either drum chippers or disc chippers (Hein 2011), Steiner and Robinson (2011) and Whitelaw (2009). Drum chippers are more commonly used to produce microchips due to their screening capabilities. Examples of chipper characteristics that may be modified to change chip characteristics include spout angle, knife angle, knife length, number of knives and disc/drum speed (Smith and Javid 1997) Watson and Stevenson (2007).

Methods

A Precision Husky WTC-2675[2] disc chipper was modified in an effort to produce microchips in the field. The chipper was equipped with an 8 knife disc rather than the traditional 3 or 4 knife disc. Over the course of the trial, knife length, knife and counter knife angle, as well as number of chip breakers and paddles were modified in an effort to produce microchips. This paper documents just two of the microchipper trials. For chip comparison, conventional chips were produced with this same chipper and disc, but with only 4 knives installed.

The goal specification was for 90% of chips produced to pass a ½ inch round-hole screen. This specification was set based on conversations with various biomass end users located in the southeastern United States.

Due to a low demand for in-woods pulp chips and whole tree chips during the time of the study, the number of loads produced was small. Each load produced was timed with a stop watch and mill load tickets were used to determine tons produced. Fuel consumption was recorded on a sample of loads. Fuel use was measured by topping the tank before and after individual loads and from the chipper's on-board computer.

Chip samples were taken from the spout of the chipper multiple times (minimum of 11) during each load to produce a sample representative of a whole van load of chips. Chip analysis included particle size analysis, moisture content and bulk density measurements. Particle size was measured by passing the samples through a stack of round-hole sieves.

Results and Discussion

Seventeen loads were sampled. . Table 1 shows the results of producing whole tree conventional chips and two trials of whole tree microchips. The average number of stems per load and average tons per load were similar for conventional chips compared to the first trial of microchips, but the conventional chips averaged approximately 10 tons/Productive Machine Hour (PMH) more than the microchipping. For the second trial

[2] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

of microchipping, the number of stems per load was less and the tons per load was higher, but the microchip production (8.79 tons/PMH) remained lower than the conventional chips. These two trials showed that microchipping production was 12.8% and 11.1% less on average than producing conventional chips with the same chipper.

Table 1: Productivity data for a disc chipper producing whole tree conventional and microchips.

		Conventional Chips		
	Time (min)	**# Stems**	**Tons**	**Tons/PMH**
Min	16.59	278	21.05	76.14
Max	18.47	350	24.86	82.89
Avg.	17.59	320	23.33	79.52
Count	4			
		Micro Chips 1		
Min	15.21	177	19.25	54.77
Max	24.92	425	25.03	84.16
Avg.	19.73	312	22.41	69.37
Count	8			
		Micro Chips 2		
Min	20.65	76	26.68	58.91
Max	27.20	143	29.18	84.78
Avg.	23.96	121	27.81	70.73
Count	5			

Fuel consumption was not measured on every load. Table 2 shows the results for the fuel consumption as measured for the whole tree conventional chipping and the whole tree microchipping. Not enough data was collected to look for statistically significant differences in the results. The data indicates that the fuel consumption for microchipping was higher than that of conventional chipping with the same chipper. A difference of 0.62 tons/gal represents a 14.8% increase in fuel consumption to produce microchips.

Table 2: Fuel consumption for a disc chipper producing whole tree conventional and microchips.

	Conventional Chips	Micro Chips
Gallons	26	39
Tons	108.82	139.07
Gal/ton	0.24	0.28
tons/gal	4.19	3.57
Gal/hr.	18.76	19.53

In terms of chip particle size, the chipper did not meet the goal of 90% passing a ½ inch round-hole screen (actual screen size was 13 mm, which equates to 0.51 inches). Table 3 shows the results of the chip analysis. On average, 74% of the microchips produced passed the ½ inch screen. This compares to 47% of conventional chips passing the ½ inch screen, resulting in a difference of 36.7%. The average moisture content difference between the two chip sizes was 3%.

Table 3: Chip characteristics of whole tree conventional and microchips produced with a disc chipper.

	Conventional Chips	
	MC	**% Passing**
	(WB)	**(13 mm rd.)**
Min	0.44	38.4
Max	0.54	55.8
Avg.	0.47	47.1
Count	5	4
	Microchips	
Min	0.46	68.1
Max	0.56	82.1
Avg.	0.50	74.4
Count	8	7

The machine rate method was used to calculate the owning and operating cost for the chipper (Brinker, et al, 2004). The calculations assumed an off-road diesel cost of $3.50/gallon, 2000 scheduled hours per year and a utilization rate of 50%. The purchase price of the Precision Husky WTC 2675 disc chipper was $490,000. Using the chipping production rates measured during the study, a ton of conventional chips made from whole trees would cost $3.08/SMH ($0.08/ton) to produce at road side. The cost of producing microchips was \$3.82/SMH (\$0.11/ton). A difference of \$0.03/ton was observed. This represents the cost associated only with the chipper.

Conclusions

Results indicate that the disc chipper can produce microchips, but currently cannot meet the narrow specification of 90% passing a ½ inch round-hole screen. On average 74% of the chips produced did meet the required size. Future adjustments to the chipper have the potential to further increase the percent of acceptable microchips produced. The study also indicated that producing microchips with the disc chipper reduced the chipping production rate by 10 tons/PMH an approximately 12% reduction in productivity. This reduction in productivity was also accompanied by an approximately 15% increase in fuel consumption.

The study results show the cost, in lost production and increased fuel consumption, of producing microchips in the field with a disc chipper. These costs may be feasible based on some of the potential advantages of processing cost savings that may be realized by the end-user after delivery of microchips.

References

Hein, T. 2011. *Small is beautiful: microchipping woody biomass*. Canadian Biomass Magazine. November-December. Pgs. 2.

Smith, D., and S. Javid. 1997. Chipper performance improved through analysis of critical angles. In Proc. of conf. on *Pulping Conference*. TAPPI. Peachtree Corners, GA.

Steiner, J. R. and M. Robinson. 2011. *Microchips; comparing wood microchips to conventional wood chips (typical anaylsis)*. Presented at the BioPro Expo & Marketplace, Atlanta, GA. March 14-16, 2011.

Stokes, B.J., W.F. Watson, and D.L. Sirois. 1987. Factors affecting power requirements for chipping whole trees. In Proc. of conf. *American Society of Agricultural Engineers Summer Meeting*, Baltimore, Maryland, June 28-July 1, 1987.

Watson, W. F. and R. Stevenson 2007. The effects of seasonal variation in wood moisture content on chip size and kraft pulping. In Proc. of conf. *Engineering, Pulping, and Environmental Conference*.TAPPI. Peachtree Corners, GA.

Whitelaw, Dave. 2009. CBI; *Continental Biomass Industries, Inc.* Available online at www.pelletheat.org/pdfs/CBI.pdf

Efficiency of Log Vessel Loading Operations: A Loader Configuration Case Study

Rien Visser[2], David Hopper, Josiah T. Simmonds, Matt Wakelin[1], Hunter Harrill.
School of Forestry, University of Canterbury, Christchurch, New Zealand.
[1]C3 , South Island Manager, Nelson, New Zealand
[2]Corresponding Author: rien.visser@canterbury.ac.nz

Abstract

Almost 50% of New Zealand's 23.5 Million m3 harvested volume is exported directly as roundwood (logs). Not only is port cost-effectiveness important in terms of remaining internationally competitive, but capacity and capability of the ports is critical in supporting the expected growth in the industry. In terms of port operations, one important aspect is optimising the delivery of logs to the vessel with the crane loading capability. A detailed time and motion study was completed at the Port of Nelson on both the loaders delivering logs to the bunks alongside the vessel, as well as the four on-board cranes heaving the log bundles during the loading of the 30,000 tonne capacity Rattana Naree vessel. The current log delivery configuration of four-loaders (two large 17 tonne capacity and two 'small' 14 tonne max. capacity) was compared to just two large loaders. The study focussed on cycle times and delays to assess the impact of the loader configurations on both loader and crane efficiency. The average loader cycle time with four loaders was 3.2 minutes, compared to 2.6 minutes with two loaders. Utilisation rates were 69% and 74% respectively. Operational delays were primarily responsible for the difference, with 29% change in operational delays associated with the bunks being full, indicating excess loader capacity. For the cranes, heave rates were 6.4 with four loaders and 9.1 heaves per hour with two loaders. Change in productivity will be significantly less given that the four loader configuration double loaded (one large, one small delivery to each bunk) resulting in larger average payload per heave. However the four loader configuration did reduce crane utilisation by 15%; the larger bunk loads requiring more 'butting', which is the process of a squaring up the all the logs in the bunk prior to heaving the load onto the vessel. Overall, a conclusion can be made that the two-loader configuration was a more efficient option that had no adverse impacts on crane delays.

Introduction

New Zealand currently exports 13 million m3 of roundwood (logs) through 15 ports. As demand for export logs continue to increase there are significant opportunities to increase export earnings, currently NZ third largest (NZFOA 2012). In order to capitalise on the increasing demand, on-port operations will need to increase infrastructure and or improve existing operations to accommodate the expected growth in export of logs. The port environment poses a unique set of difficulties, mainly spatial constraints, to vessel loading operations that restrict the number of feasible solutions to improving productivity. One option is to increase the efficiencies of vessel-loading operations through optimising the current system.

Log delivery is a port operation during vessel loading that retrieves logs from on-port storage and delivers them to bunks on the wharf next to the vessel to be loaded. At this point stevedores operate on-board cranes to load the vessel, with a small excavator based grapple ('digger') operating in the hold to fleet and stow the loaded logs. Vessel have a high daily charge out rate (approx US$20,000 per day) and as such quick and efficient loading is important. It is important to have sufficient loader capacity to ensure no adverse impacts on productivity to stevedore operations. However, there is uncertainty on what the most efficient and cost-effective loading configuration is for loaders when delivering logs to the crane loading area (Figure 1). Both capability and cost-effectiveness of loading log vessels is a sector of the forestry supply chain where few studies have been made. This study seeks to begin to fill the gap of knowledge for this component of the forest supply.

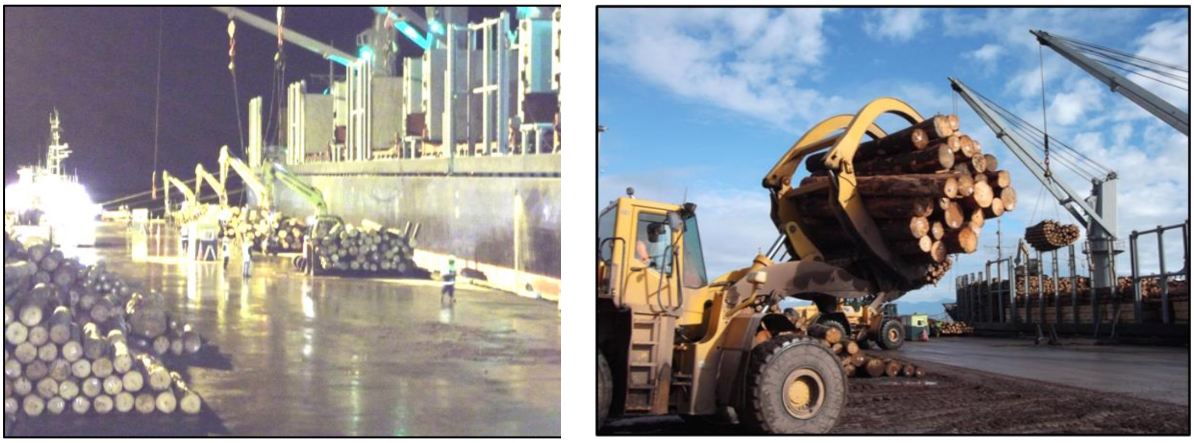


Figure 1: Left – vessels has docked getting ready for loading. The small diggers are lined up to be lifted onboard and the bunks are full ready for the first heave. Right - typical large log-loader (17 tonne max.) delivering logs to ship, with on-board vessel crane in the background heaving bundles from the bunks onto the ship.

C3 Ltd (www.c3.co.nz) is a leading logistics company that includes exporting logs from 15 ports around New Zealand and Australia. Tasman Bay Stevedoring provides stevedoring services at the Port of Nelson, which currently handles 7.2% of the NZ total log export volume. With support of both entities a time study evaluation was initiated to compare two different types of loader system configuration (4 loaders versus 2 loaders –operated by C3) servicing the four vessel cranes (operated by Tasman Bay Stevedores) analysing the types and lengths of delays associated with the two different loader configurations.

Methods

The study observed the loading of 26,500 m3 on to the *'Rattana Naree,'* a bulk carrier vessel at Kingsford Quay, Port of Nelson. Data was recorded in four sessions on the 10th–12th of August, 2012, over 14.5 hours of FourLoader shift and 10.5 hours of day shift; totalling 25 hours – or 40% of the total loading time. A full time and motion study was carried out on both the loaders and on-board cranes to provide both a work rate as well as gaining an understanding of the delays on the overall system. A digital clock displaying to the nearest second was used to record measurements in. Data was recorded in real-time using an excel spreadsheet. GPS units were used on all loaders to also track distance travelled. Time study readings were taken from a two-story high office which gave a clear view of loader activities around the loading area however there were visual limitations associated with tracking loader activities at log stacks located at the back of the storage areas. It was assumed that skill level, motivation, and ergonomic factors were the same for all loader operators and that delivery operations had no significant impacts from the weather conditions.

The loader fleet comprised of:

- **'large'** loaders with 17 tonne (approx. 11-12 m3 log) capacity: Volvo L 22F (VO) and Kawasaki 95ZV (KA), (Figure 2),
- **'medium'** loader with 15/16 tonne capacity, CAT 980G with ¾ grapple (C3q), and
- **'small'** 14 tonne (approx. 7-8 m3) capacity loaders, CAT 980F (Cy) and CAT 966F (Cb).

The C3q loader only operated during the first session (1.5 hours) before being replaced by VO for the remainder of the study. Note that the tonne capacity is the maximum rated; the actual volume is typically considerably less when working with short log sorts.

Figure 2 - Large Loaders used in both Shift Configurations

Loading of vessels is organised into two shifts per day; a day shift (6am to 6pm) and a night shift (6pm to 6am). Teams work the shifts 24 hours per day until the vessel is fully loaded. For this study we were not able to vary the loader configuration during a shift. The vessel had four on-board cranes, and they are referenced by numbers 1 – 4 (starting at the bow). The two configurations were set as a block factor to assess and compare operational performances:

- **FourLoader** (Night shift)**:** VO and Cy worked in tandem to load bunks 1&2 and KA and Cb worked in tandem to load bunks 3&4. One heave consisted of one 'large' load and one 'small' load.
- **TwoLoader** (Day Shift)**:** VA and KA loaded bunks1&2 and bunks3&4 respectively. One heave consisted of one 'large' load.

For the loader, the cycle time was defined as the time it took for the loader to deliver a load to the bunks, with a new cycle beginning once the loader completed unloading the previous load. The heaving process for the cranes was defined as the load of logs being lifted from the bunks up onto the vessel for the diggers to then distribute, and then the empty strops being dropped back down to the bunks in preparation for the next heave. For both loaders and cranes delays were categorised into mechanical, operational, and social delays. Delays were recorded to the nearest second with delays over 30 seconds deemed significant. Mechanical delays are defined by machine mechanical unavailability. Social delays include both scheduled breaks and other personal breaks. Operational delays, which were the focus of the study, were defined as:

Operations delays / Loader:

1. **Waiting** in front of full bunk
2. **Machine congestion**
3. **Non-productive tasks**: e.g. preloading the berth, and adjusting or retrieving logs at the bunk.
4. **Management delay**: e.g. receiving instructions, foreman interaction
5. **All other** operational delays

Figure 3: Left, a loader 'squares' up the logs in a bunk, whereas on the right the scanners are recording the bar codes on each individual log for accurate inventory. Both work activities are recorded as operational delays as they can affect both the loader and the crane productivity.

Operations delays / Cranes:

1. **Bunk not full/ready**: including scanning delays and extended periods needed to strop up.
2. **Butting**: butting was completed using a loader with a large flat plate. It makes the fleeting process for the digger onboard the vessel easier.
3. **Digger Delays**: any crane delay caused by on-board diggers that stow the logs in the hold.
4. **Digger lifts**: all four diggers were lifted off the vessel in order to be serviced at the end of each shift, and lifted back on the vessel again ready for the next shift (Figure 4).
5. **Closing of the Hatches**: the hatches are closed so loading could continue on the deck of the vessel.
6. **Mark Off**: paint is used to identify parcels of wood, whereby the crane hoists a specific cage which was lifted onto the vessel (Figure 4).
7. **Management delay**: any delay where the crane had to stop its operations either for confirmation of instructions relating to the specific operation of the crane.

Figure 4: Examples of Operational Delays: On the left, logs in the hold being 'marked-off' to identify separation between parcels; on the right the digger is lifted into the hold to aid the stowage of logs.

With respect to analysing the data, the operational delays were kept separate to the social delays as the primary focus of the study was based on operational delays during working time. Due to the nature of the study structure with capturing the start, middle and ends of the shifts at different times, it was deemed to be biased if social delays were also included.

Results

LOADERS

The average cycle time for the loaders was 3.0 minutes (Table 1). The FourLoader shift had a longer average cycle time of 3.2 minutes compared to 2.6 minutes for the TwoLoader shift.

Table 1 –Average loader cycle time, by loader and configuration.

Loader				Shift		Total
Code	Average	Min	Max	Configuration	Average	Average
VO	**3.3**	*1*	*9*	FOURLOADER	**3.2**	**3.0**
Cy	**3.4**	*1*	*7*			
C3q*	**4.2**	*2*	*6*			
KA	**2.8**	*0*	*8*			
Cb	**3.2**	*1*	*8*			
VO	**2.7**	*1*	*7*	TWOLOADER	**2.6**	
KA	**2.4**	*0*	*5*			

*Note: *C3q loader only operated during session one before being replaced by VO for the remainder of the study.*

The GPS data showed a correlation between cycle time and distance to the log stack in the storage area, however the loader typically completed a circular track (one way loader movement to avoid the risk of incidents) and as such the correlation between distance and cycle time was not strong. The primary reason for the difference between the two configurations is the level of operational delay associated with operating four loaders.

The TwoLoader shift had a higher operational utilisation of 74.3% compared to 69.2% for the FourLoader shift (Table 2). During the FourLoader shift, the two large loaders, KA and VO, both had higher operational utilisations compared to the accompanying loaders, Cb and Cy. The utilisation of VO and KA were found to be similar during the TwoLoader shift.

Table 2 - Utilisation of Loaders (Excluding Social Delays)

Loader		Bunk ID		Shift		Total
Code	Utilisation	Code	Utilisation	Code	Utilisation	Utilisation
VO	**80.0%**	[1&2]	**76.8%**	FOURLOADER	**69.2%**	**70.5%**
Cy	**77.2%**					
C3q*	**50.6%**					
KA	**66.6%**	[3&4]	**61.8%**			
Cb	**57.0%**					
VO	**74.4%**	[1&2]	**74.4%**	TWOLOADER	**74.3%**	
KA	**74.2%**	[3&4]	**74.2%**			

**C3q loader only operated during session one before being replaced by VO for the remainder of the study.*

Operational delays were significantly longer during the FourLoader shift, 29% greater than total percentage delay during the TwoLoader. A breakdown of the types of operational delays is presented in Figure 5. No mechanical delays were observed over the study sessions. Loader C3q was omitted from delays analysis as this loader was only used during the first 1.5 hours of the study.

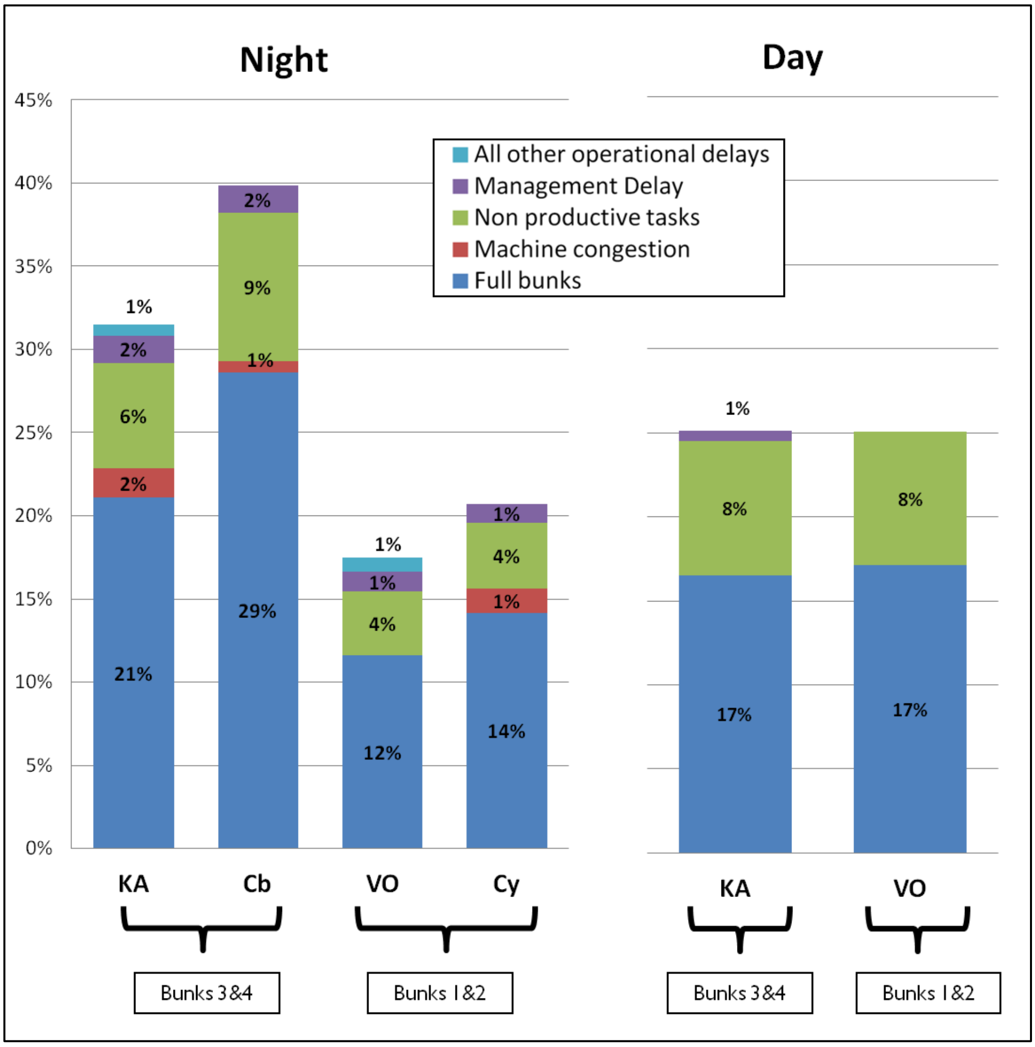


Figure 5 - Operational Delays for Each loader for TwoLoader and FourLoader Shift Configurations

The majority of operational delays came from being held up due the bunk being full. It can be seen that the distribution of operational delay types is very similar for both loaders (VA and KA) during the TwoLoader shift, however there is a noticeable difference in operational delays for loaders servicing bunks 1&2 compared to loaders servicing bunks 3&4 during the FourLoader shift. Cb and KA, which worked in tandem to fill bunks 3&4 had the longest amount of delays for the FourLoader shift. The high duration of non-productive task delays for Cb can be attributed to the role it had of being the designated 'sweeper', which is a work related task of associated with cleaning up the accumulated bark around the loading area.

ON-BOARD CRANES

The heave rate is defined as the number of completed crane cycles in an hour. Although this measure is a good indicator of efficiency, it does not consider the size of the heave. Table 3 shows the heave rates recorded for each crane, as well as the average, for the two loader configurations.

Table 3: Heave Rates of the four cranes

Heaves per Hour	Crane #				
Shift:	1	2	3	4	Average
TwoLoader	8.2	7.9	9.3	10.9	9.1
FourLoader	6.1	6.8	6.2	6.5	6.4

There is a distinct difference in heave rates, with the smaller average loads associated with the TwoLoader configuration being clearly faster. However, with both a large and small loader delivering logs to each bunk in the FourLoader configurations, larger volume heaves were made relative to TwoLoader. Each heave volume varies not just the number of deliveries to it, but also the length of log sorts will heavily influence total heave volume. Heave rates also varied by crane, for example the TwoLoader crane averages ranged from 7.9 heaves/hour to 10.9. This variation was also evident visually during the study as crane 4 had less delays from both onboard the vessel and from the butting procedures. Crane 2 had the lowest heave rate on the TwoLoader shift as there was a Mechanical Delay associated with a hydraulic hose failure with the diggers on the vessel. These heave rates were also evident in the utilisations (Table 4), being the percentage of productive time for the machine relative to the total shift time (excluding Social Delays).

Table 4: Cranes Utilisation rates

Utilisation	Crane #				
Shift:	1	2	3	4	Average
TwoLoader	85%	79%	96%	86%	86%
FourLoader	71%	75%	71%	69%	72%
Overall Total	76%	77%	80%	76%	77%

Consistent with the heaves rate results, there is a distinct drop in utilisation associated with the FourLoader shift associated. Crane 3 has the highest utilisation yet does not have the highest heave rate during the delay; this is due to an increased average cycle time.

Delays were broken down into several categories to obtain a better understanding of the types of delays that occurred during operation of both shifts (Figure 6). Delays were calculated by taking the total duration of each delay dividing by the actual working time (i.e. total study time minus social delay duration).

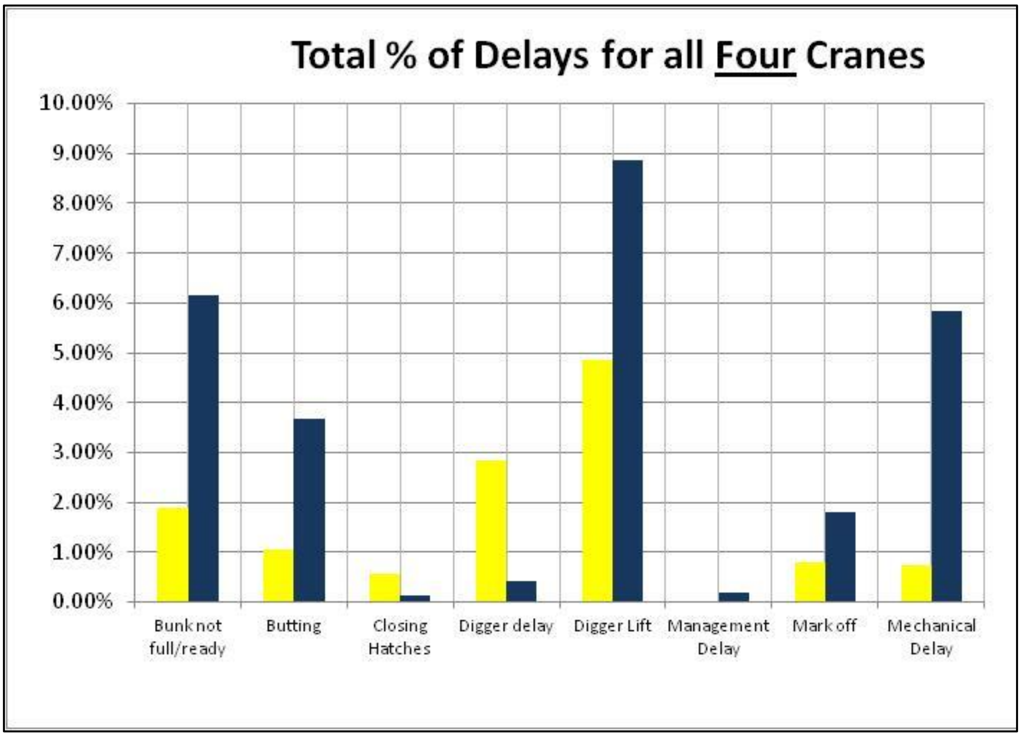


Figure 6: Graphic of delays for all four cranes, with the yellow bars representing the TwoLoader, and the blue bars the FourLoader configurations.

Digger lifts were the most significant delay occurring during the TwoLoader and this was due to the duration of each lift being over 4 minutes long. Butting and bunk delays are clearly higher for the FourLoader configuration. Along with a higher percentage of both butting and bunk delays occurring during the FourLoader shift, the duration of butting delays has also increased by approximately one minute on average. The demand for butting increased as the loader was needing to spend more time on each bunk due to the larger load being placed in the bunk relative to the TwoLoader shift load sizes. There was an attempt to minimise mark-off delays by completing the task within a social break. The high level of mechanical delay associated with the FourLoader occurred due to a failure of the generators on-board the vessel. During this time only one crane was able to operate.

Discussion

The shorter cycle times and less operational delays for the TwoLoader shift configuration suggest a more efficient alternative to FourLoader. The primary reason was the increase in operational delays that were found to be 29% larger during the FourLoader shift. It suggests excessive capacity for the four-loader configuration. Including heave size as a factor into future studies would allow a full productivity comparison.

This study does have limitations in accurately estimating long-term trends and large delays are not adequately sampled. The study assumes that the effects on cycle time and delays are associated with different loader configurations. However, the true and full effect of TwoLoader / FourLoader on basic operations is not known. The ship vessel was loaded primarily over the weekend. The increased interaction with log trucks that need to be unloaded can be expected to affect delays during the normal work week days. The range of loading conditions is also limited due to the short duration of the study. Variation associated with unmeasured effects could have an impact on quantifying average cycle times and delay analysis. For example, it was noted that wet weather conditions are likely to have an impact on the loading.

The two configuration compared not only changed the number of loader from four to two, but also the way the bunks were loaded. Going from putting two scoops (one large, one small) into a bunk to just one large scoop simplified the operation resulting in both lower loader cycle time and faster heave rates. However, there were other benefits noted, including that more extensive butting was required and that scanning became more problematic with the fuller bunks. Such issues could also be compounded, for example at times two or more cranes would become synchronised with their cycles, meaning that butting would be required on several bunks at once. This would result increased delays in waiting for the loader to butt up a bunk. A replicate study that also recorded the actual heave volume would establish actual productivity difference.

Using the data as well as visual observations, an opportunity for improvement was also identified in the operational procedures of the diggers. The Diggers were lifted on to the vessel at the start of each shift and lifted off at the end. Although diggers due need to be lifted off occasionally, for example so that the hatches can be shut and the need to refuel, consideration could be given to lowering just the personnel without the digger.

Conclusion

Improving port capacity and capability for servicing the log export business will be critical for New Zealand to successfully accommodate the expected increases. With ports typically very spatially constrained, the initial focus is on improving current delivery systems. After completing a total of 25 hours of elemental time study on the Rattana Naree between the 10th-12th of August 2012, a simple conclusion can be made that the current shift structure containing four loaders incurs more operational delays for both the loaders and the on-board cranes. The most common type of delay was butting and bunk delays.

References

New Zealand Plantation Forest Industry. (2010/2011). Facts and Figures. Retrieved August 2012, from Forest Owner Association: http://www.nzfoa.org.nz/images/stories/pdfs/fandf2011web.pdf

Olsen, E. D., Hossain, M. M., & Miller, M. E. (1998). Statistical comparison of methods used in harvesting work studies. Corvallis: Oregon State University.

Hopper, David. 2012. An elemental time study on the cranes of the Rattana Naree. Final Year Engineering Project Report. University of Canterbury, Christchurch, New Zealand.

Simmonds, Josiah. 2012. A Log Delivery Case Study at the Port of Nelson. Final Year Engineering Project Report. University of Canterbury, Christchurch, New Zealand.

Experimental framework to increase wood mobilisation in fragmented private forests in Auvergne (France): lessons learnt after 2 years

Morgan Vuillermoz, Maryse Bigot, FCBA
10 avenue de Saint Mandé, F-75012 Paris, FRANCE
Contact: morgan.vuillermoz@fcba.fr

French National Forest Policy calls for an increase of wood mobilisation to maintain a competitive forest-based industry in rural areas and meet the national objectives regarding energy. The challenge lies in forest areas with technical and economical constraints, or lack of interest from private forest owners.
In this context, 2 national institutions have launched an experimentation to test, in a given perimeter and in respect to sustainable management principles, measures to increase the supply of wood to the different value chains.

In 2010, FCBA was entitled to study the feasibility of such an experimental framework. The two major outputs were the selection of the region (Auvergne) and the choice of the main target, around which collective actions would be initiated. Expectations were high towards innovative organisations and tools within the chain of actors, namely owners of small and fragmented forests, industries and local public-funded forest councillors who act as an interface between the former populations.

The paper describes the methodology used to steer the forest community (professionals, non professionals and institutions) into launching collaborative projects and willingly contribute to the experimentation. Many motivations and barriers were balanced before any concrete action could start. After more than 2 years, first results are now being delivered to the local population of forest owners and professional operators, as knowledge or as a service.

In parallel, FCBA has also set up a strategy to facilitate the transfer of the lessons learnt in Auvergne to the other French regions where organisational-innovation would favour wood mobilisation.

1. Context and objectives

Wood mobilisation is a traditional topic for controversial discussions in the French forest-based sector. Under-exploitation of the resource is seen by some parties as a potential for additional harvest while others remind the former of the numerous barriers which create this situation. On the one hand, vast and diversified forests cover one third of the metropolitan land. They are mainly private-owned and fragmented in the hands of millions of un-professional individuals with a full range of socio-cultural expectations, or lack of expectations, towards their forest. About 40 million cubic meters are harvested and commercialized yearly from the 82 millions of annual increment[1]. On the other hand, the French national forest policy calls for an increase of wood mobilisation to maintain a resilient and competitive forest-based industry in rural areas and meet the national objectives regarding the European Energy Policy. There is an increasing demand for softwood from the traditional forest-based industries (sawmills, pulp & paper mills and panel companies) and a raising interest for wood as a raw material from energy producers.

The challenge lies in increasing mobilisation in forest areas with technical and economical constraints, or lack of interest from private forest owners. In this context, 2 national institutions (ADEME[2] and Ministry for Agriculture & Forests) decided in 2010 to launch a so-called experimentation to test, in a given perimeter and in respect to sustainable management principles, measures to increase the supply of wood to the different value chains.

The chosen scope is to experiment mechanisms and organisation schemes with direct impact on wood mobilisation, namely the triggering factors leading to a logging operation and the actual harvest. Structural instruments such as legislation or taxation leverages or downstream conditions such as market developments are considered out of focus and therefore not included in the experimentation.

Since June 2010, FCBA is entitled by ADEME and the Ministry for Agriculture & Forests, later referred to as “national sponsors”, to play a facilitation role in the design and the implementation of the experimental framework. This could be understood as the role of a catalyst, from the very beginning of the process and through out all the chain of reactions.

2. Designing the experimental framework to increase wood mobilisation

2.1. *The role of the supervisor and facilitator*

Expectations towards the facilitator (FCBA) in the experimentation could be described as follows:

- Provide methodology to support decision making;
- Feed the discussions with facts and expertise on any necessary topic or context (France and Europe);
- Facilitate dialogue between the different stakeholders at all geographical and sector-wise levels;

[1] 2010 data from the Ministry of Agriculture and forests “Enquête annuelle de branche”

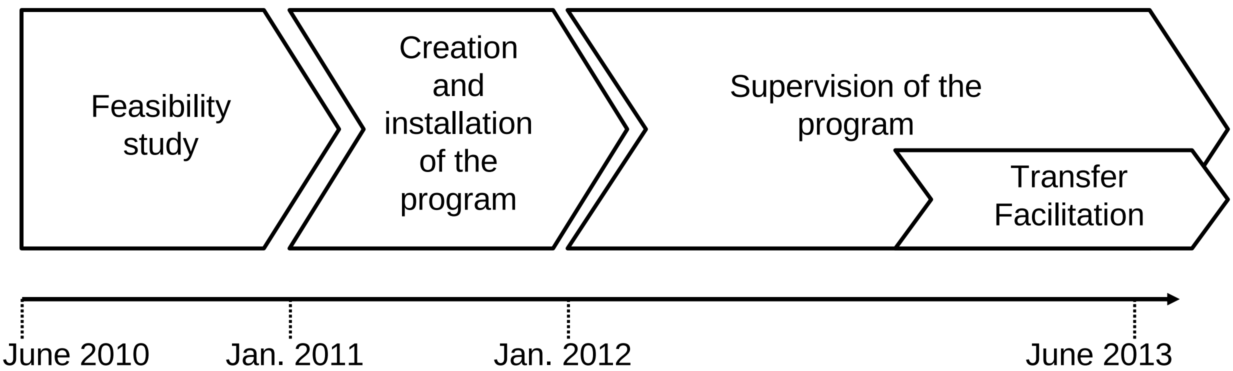
[2] French Environment and Energy Management Agency (ADEME) is a public agency active in the implementation of public policy in the areas of the environment, energy and sustainable development.

- Listen and act as a mediator to contribute to overcome difficulties, e.g. socio-cultural, technical or administrative difficulties faced by the participants (professionals, non-professionals, institutions…);
- Review progressive results to ensure quality management and steer dissemination and transfer towards the target groups of the experimentation: owners of small and fragmented forests, industries and local public-funded forest councillors who act as an interface between the former populations.

2.2. Life cycle of the experimental framework

FCBA's mission as project facilitator started in June 2010 and has continued since through successive steps (see figure 1). At first, a national feasibility study (Bigot et al. 2011) enabled the translation of the initial objectives announced by the national sponsors into a targeted experimental framework to be tested and implemented in a chosen area. This definition acted as a milestone enabling the start of the next phase: the creation and the funding of a program of coordinated experimental actions proposed by the local players in response to the national suggestions. From then, FCBA acted as a supervisor for each of the supported actions and ensured the balance of the program as whole while preparing the future transfer of results.

Figure 1 : Process steps in the creation and supervision of the experimental framework to increase forest mobilisation



2.3. French stakeholders at work in wood mobilisation and in the experimentation in particular

In France, professional forest-based stakeholders (forest experts, forest cooperatives, the state forest service, independent wood suppliers or industry-integrated ones, logging contractors…) can be characterized by their diversity in terms of size, organisation or range of interventions (Lebel & Bigot 200x). This numerous options for wood mobilisation highlight two important aspects with direct impact on the design of the experimentation:

- The presence of multiple competing service providers whose offerings are often presented to the forest owner in different and not so comparable ways (due to diverse levels of integration);
- The complexity of un-professional forest owners who only occasionally have to decide on forest-related issues.

In addition to this diversity, social aspects need to be taken into account as they contribute to stratifying the forest owner population in groups of unmotivated forest actors, for sentimental, ecological, organisation-wise or economical reasons.

Finally, it should be noted that France is a centralised country, as much through its institutions as in the structure of professional organizations. Therefore, in any experimental project initiated on the national level, it is mandatory to involve national representatives even if the goal is to act on a limited geographical perimeter.

Therefore, in the design and management of the experimental framework, FCBA had to interact with a large panel of forest-related stakeholders:

- Institutions: both on national and local level;
- Multiple professional representatives (individual federation and associations);
- Public-funded organisations.

3. Material and Methods

FCBA has called upon diverse materials and methods to run the experimentation along the different process steps but was always driven by three common denominators, namely the willingness to steer collective and consensual actions, the anticipation of results transferability and the openness necessary for iterative evolution of the experimental framework. Applied methods and exploited material are hereafter described in chronological order in each of the process steps.

3.1. Feasibility study

The main objective of the feasibility study was to translate the initial ambition of the national sponsors into an experimental framework which could be implemented in a given forest area, for a given period of time and with a specific target related to additional forest mobilisation. In the area to-be-selected, forest stakeholders would participate in the experimentation and national sponsors would build partnerships with local institutions to support such endeavour.

For the purpose of the feasibility study, national and regional statistics were compiled, mainly forest resource inventories under technical and economical constraints (logging practices and materials, terrain, wood species…). A literature review (about 60 French references) browsed the recent bibliography available on wood mobilisation and experimentation towards an increase of the annual harvest. Reports and results from 2010 regional consultations by the Ministry of agriculture and forests were taken into account and special attention was dedicated to the few socio-cultural studies of French private forest owners (Valenzisi et al. 2008; Roussel et al. 2010).
In parallel, FCBA consulted national stakeholders directly concerned with wood mobilisation and several meetings were organised with two main purposes: gather information and feedback but mostly involve federations and representative from the start to find a balance between their expectations and willingness to change and the experimental concept proposed by the national sponsors.

Considering the organisation of French forest-based sector and its corresponding institution, regional level was judged as the most relevant scale of reasonning. A set of 7 of indicators was designed to ensure that all relevant aspects would be taken into account:

1. Availability of resource for additional harvest (minimum threshold set to 500 000 m3/year in at least 2 of the 4 wood categories (solid-wood or industry & energy, hardwood or softwood) from biomass inventory (Rantien 2009))
2. Non limiting logging infrastructure e.g. forest road network

3. Non limiting logging material and resources
4. Demand from the markets (solid wood, pulp, panel, energy)
5. Significant share of private-owned forest
6. Ability of the local players to work together on wood mobilisation
7. Past collective projects or initiatives to build upon

Except from the first, all indicators were rated on qualitative estimation based on experts' opinion and available studies.

A benchmark based on the set of indicators led to the **pre-selection of 5 potential regions** among which national sponsors were suggested to choose the experimentation area. Finally, a SWOT analysis was performed on existing scheme dedicated to forest owners' activation. Priorities and relevant targets to overcome gaps were highlighted, hence leading to the **specifications and the focus of an experimental program-to-be**.

3.2. Creation of the regional program

In 2011, during the actual creation of the program in the chosen regional, the two main objectives were to design and finance actions with appointed leaders and co-funding parties to the national sponsors.

Regional documentation was collected and analysed in the experimentation area but the main material FCBA had to work with was the local population of forest-based stakeholders and their behaviours in regard to the proposed approach. Results from the feasibility study were of course taken as input but the new material brought in by the actors was the source of most of the work to find a suitable match between regional and national interests.
The local consultation was organised through collective meetings and a call for contributions was released at early stage to invite participating organization to propose project ideas in relation to the experimental focus. Collaborative ideas were encouraged and transparent selection process was set up to ensure that the iterative creation of the program would be understood and acknowledged by all participants.
In parallel, support was provided to the local institutions who usually subsidize wood mobilisation and related projects. The goal was to create a favourable context in which they would agree on a shared strategy with the national sponsors and therefore become active financing bodies for the program under creation.

3.3. Supervision of the program

By the end of 2011, actions funded under the umbrella of the experimental program had been clarified enough to be launched and become the dynamic material needing supervision.
Inspired by project management spirit, the method consisted in reviewing the progress of each action on regular basis with the action leader. An encouraging attitude was adopted, even when methods or preliminary results were questioned by FCBA. Tools were created for supervision purposes, for the action leaders and the supporting institutions, in both cases to keep track of questions and recommendations in regard to technical content, organisation, deliverables or interaction with the other actions in the program.

Dialogue with the stakeholders was organised differently than in the earlier program creation phase. Three types of formal meetings were organised on regular basis:

- Dialogue between action leader and supervisor (face to face or by phone), on a by-monthly basis;
- Discussions between action leader, supervisor and local representatives of the national sponsors, three times a year;
- Collective meeting between action leaders, supervisor and representatives of all financing bodies, at least once a year.

FCBA also valued action contributors as feedback providers and collected information on the experimentation's progress through this informal channel.

4. Results

Since 2010 and the initial need for an experimental framework was specified by the two national sponsors, FCBA's mission and the participation of local stakeholders have led to the delivery of a series of results.

By January 2011, the administrative region "Auvergne" was chosen to host the experimentation. The forest covers 700,000 ha of the total 26,000 km^2 area, with about 210,000 individual registered as forest owners (84% of the forest cover). Most of the softwood resource (spruce and silver fir) is located in sub-mountainous areas called "Livradois Forez" where many small private-owned fir stands are overstocked, over-aged and threatened by decay, because of limited silvicultural activities for decades. Specific approaches both on the human and technical sides are needed to (re)activate owners, forest management and harvesting operations. Historically, the region has hosted many initiatives trying to enhance forest operations by involving individual private owners, industrials and forest-sensible institutions (communes). 15 forest charters[3] provide a county-wise dynamic while over 20 forest development scheme (PDM)[4] have helped in the installation of neutral forest councilors who can assist forest owners in the understanding of their role and status in the local mobilization chain. In 2010, a realistic target of additional harvested volume was agreed on by the local stakeholders of the forest-based sector: plus 1 million of m^3/year by 2020. This is stimulated by recent investments in the local sawmilling industry, hence calling for an increased need for softwood in primary processing. It was decided to create the experimental program, later called PPMBA[5], in Auvergne to build on this favorable context and experience and push further existing initiatives through innovation.

The program is organised in 3 complementary branches directly inspired by the structure specified at the end of the feasibility study.

1. The chosen target, and central branch of the experimentation, is innovative organisations and tools within the chain of actors, namely owners of small and fragmented forests, industries and local public-funded forest councillors who act as an interface between the former populations.
2. Additionally, shared culture is encouraged through collaborative actions and the development of collective tools.
3. Finally, support is provided to technical and human resources which are necessary to wood mobilisation.

---

[3] in French : « Chartes forestières de Territoire »
[4] in French « Plan de développement de massif »
[5] in French « Projet Pilote de Mobilisation des Bois en Auvergne (PPMBA) », meaning pilote project to increase wood mobilisation in Auvergne

The engineering and the funding of the program was finalised in December 2011. It connects together 8 actions including 5 collaborative ones. All themes were suggested by the local stakeholders but very few remained unchanged after the long consultation that followed the call for proposals in February. From the 27 proposals, adjustments, prioritization or mergers were suggested while less than 10 proposals were rejected due to irrelevance to the chosen target. In the end, three organisations took the lead of the selected actions:

- Auvergne Promobois the regional association which federates all forest-based professions implemented in its geographical area;
- CRPF Auvergne, the public-funded regional forest centre is in charge of private forest-owners activation through different channels: counselling, training, dissemination…;
- URFA, the regional union of private and public forest owners and related organisations.

The budget of the program amounts to 675 000 Euros with high public support from the regional, trans-regional, sub-regional and local financing institutions as well as the national sponsors. This very coordination between the supporting organisations is an achievement of the program in itself as it is a result of mutual understanding and agreement on a shared strategy to support innovation through experimentation in the chain of actors.

Since 2013, some results are being delivered from the supported actions. New methods, tools or reports are hence made available to the stakeholders, such as:

- A future tool kit for the councillor based on :
    - Report on consolidated methods to activate forest owners (best practices handbook for the councillor);
    - Technical report on property exchange service and the dedicated software used by the councillor.
- Cost-effective and trustworthy method to evaluate the impact of forest owner activation by the forest councillor;
- Experimental protocol to test alternate organization schemes in the chain of actors : Forest Owners - Councillors - Forest companies;
- Detailed specifications of a IT-platform to support information exchange between the regional forest-stakeholders;

The first results are delivered as knowledge but the program will also provide new services, such as two alternate interventions by the forest councillor or the provision of new IT-based services thanks to the collective information platform.

On a more qualitative level, an evolution of the social network towards increased cooperation and trust in one another is observed in Auvergne since 2011 and as a result of consultations and collaborative work undergone through the program.

5. Lessons learnt after 2 years and conclusion

From the supervisor point of view, several lessons can be learnt from the experimental framework. Collaborative behaviour is not an instinct and it is difficult to inspire to individuals or organisations who are used to being quite independent or in a 1 to 1 relationship with their public sponsor. Therefore, change management is a real challenge in such experimentation, which very purpose is to test something new without threatening to enforce long term implementation of the innovative measure. But willingness to look beyond the usual comfort zone is a rare quality in the target population and even such clarification doesn't easily counter-balance reluctances because trust issues and competition between professional actors remain strong.

From an external point of view, one of the main criticisms directed towards the whole process is the lack of immediate results for the individual stakeholder from the first year of the project. But the truth is that evolution needs and takes time especially when multi-stakeholder dialogue is involved. Moreover, in a public-private initiative such as this one, institutions are slowed down by the fluctuations of internal and external political decisions, and project management can suffer from human resource turn over in organisations.

But despite the difficulties, the PPMBA program is proving operative and more and more results will emerge as the actions' progression continue.

In parallel, FCBA is also facilitating the transfer of the lessons learnt in Auvergne to the other French regions where organisational-innovation would favour wood mobilisation. Feedback and transfer to the national level has been initiated and inter-regional exchanges are progressively crossing the regional borders, through institutional and professional channels. Such dialogues are important to maximize the value created from local experiences but also to prepare a potential reproduction of the experimental framework in another context.

For the national sponsors, the regional experimentation provides field-proven experience and material to feed the national considerations on the creation of a national plan and fund dedicated to increase mobilisation.

PPMBA as a program will live at least until 2015 as many actions are still running and won't deliver their final results before tested methods and mechanisms are evaluated and approved by the involved participants.

References:

BIGOT M., VUILLERMOZ M., MONCHAUX P. 2011. Etude de cadrage d'une expérimentation de mobilisation de bois. Rapport final public, FCBA, janvier 2011, 53 p.

LEBEL L., BIGOT M. 2010. « L'entrepreneur forestier du Québec, véritable propriétaire dirigeant de PME ». PREfoRT, Université Laval, 2010, 303 p.

RANTIEN C. et al., 2009. Biomasse forestière, populicole et bocagère disponible pour l'énergie à l'horizon 2020. ADEME / FCBA / IFN / Solagro, novembre 2009, 105p.

ROUSSEL C. et al., 2010. Feuillus : Quelle ressource disponible pour de nouveaux usages en bourgogne ? APROVALBOIS / CRPF Bourgogne / FCBA, mars 2010, 70p.

VALENZISI M. et al, 2008. Projet ECOBIOM « Une approche socio-économique et environnementale de l'offre de biomasse ligno-cellulosique » Projet ANR-05-PNRB-BIOE-18 – Volet 2 « Condition d'une mobilisation accrue de la ressource forestière ». Livrable n°13-3 «Etude des motivations et blocages à la mise en vente de bois des propriétaires forestiers ». ABS Conseil, Janvier 2008, 50p.

A Remote Sensing Approach to Estimating Forest Treatment Residue for Alternative Operational Configurations on the Uncompahgre Plateau, Colorado, USA

Lucas Wells[1], Nathaniel Anderson[2], Woodam Chung[3]

Abstract

In the Northeastern United States, as in many places around the country, interest has developed in the increased use of renewable resources for the production of energy. While regions such as the Southwest and central have focused on the development of solar and wind technologies; these technologies have limitations on their effectiveness. In the Northeast, biomass derived from forests and short rotation woody crops (SRWC), may hold the key for renewable energy production in the region. While woody biomass is a potential feedstock for a diverse set of energy development options, little emphasis has been placed on developing supply chains to efficiently deliver the resource to the end user. Developing efficient supply chains is predicated on identifying configurations that will optimize the harvest, extraction, transport, storage and preprocessing of the woody biomass resources to provide the lowest possible delivered price. The characteristics of woody biomass, such as spatial distribution and low bulk density, tend to make collection and transport difficult as compared to traditional energy sources. These factors, as well as others, have an adverse effect on the cost of the feedstock. The objective of this research is to identify potential supply chain alternatives, through the use of mathematical modeling and computer simulations, that will potentially be able to provide sufficient quantities of biomass resources that can be utilized in the production of renewable energy at an economical price.

[1] Graduate Research Assistant, University of Montana
[2] Rocky Mountain Research Station
[3] Associate Professor, College of Forestry and Conservation, University of Montana

RENO: A Computerized Solution Procedure and Decision Support System for Forest Biomass Recovery Operations

Rene Zamora-Cristales[1] and John Sessions[2]

Abstract

A computerized decision support system, Residue Evaluation and Network Optimization (RENO) is presented to estimate the optimal mix of methods and equipment for conducting forest biomass recovery operations given a harvest residue assortment, road and landing access and product deliverables. The model was developed using the JAVA platform is able to read spatial data (vector) and simulate the dynamics of the productive system. The problem to be solved is classified as a special case of the multi-commodities, multi-facilities problem. The computerized model uses spatial information of the road network and residue pile locations in order to determine travel distances and calculate costs. The solution procedure represents the problem as a network and creates the routes for each residue pile and their processing and transportation costs. At each point of comminution, equipment of different sizes can be used, with different mobilization costs and production costs. Similarly not all trailers types can reach all forest residue locations. In some operations the processing of forest biomass is closely coupled to transportation and others are not. RENO incorporates the use of geographic information systems (GIS), mathematical optimization (mixed integer programming and ant colony heuristics), simulation and economics to support decisions of land owners and forestry managers at the operational level. The simulation model provides support to calculate cost accounting for truck-machine interactions expressed as waiting times.

Key Words: Forest biomass, economics, optimization, simulation.

1. Introduction

In forest biomass recovery operations from forest harvest residues, an important task for forest managers, land owners and contractors is to select the most cost-effective equipment given the spatial distribution of the residues, road access and available machinery. In-field operations require the use of expensive machinery with high fixed cost to reduce the particle size in order to facilitate handling and transportation. Transportation is required to haul the processed residues to a bioenergy facility but is affected by road characteristics such as horizontal and vertical curve geometry, road grade and road standard that limit the type of the truck-trailer configuration that can be used for an operation (Sessions et al. 2010). Additionally, forest biomass from residues

[1] Faculty Research Assistant, Department of Forest Engineering Resources, and Management, Oregon State University, rene.zamora@oregonstate.edu .

[2] University Distinguish Professor, Strachan Chair in Forest Operations, Department of Forest Engineering Resources, and Management, Oregon State University, john.sessions@oregonstate.edu.

is considered a low value product in the forest although forest harvest residues have few competing uses.

The literature provides significant contributions related to this problem at the tactical and strategic level. Spinelli and Magagmotti (2010) developed a model to estimate productivity and cost of decentralized wood chipping. The authors developed a Microsoft Excel workbook where different equations were developed to calculate costs and productivity. The model was validated comparing the model results with real data. The model presented the long term performance of a given machine rather than the operational individual performance. Frombo et al. (2009) developed a decision support system (DSS) for long term planning for biomass-based energy production. The model includes a graphical user interface capable of reading spatial data. The model calculates optimal woody biomass sources and potential plant locations that minimize cost at the strategic level. Flisberg et al. 2012 developed a decision support system for forest fuel logistics. The model takes into account different processing machines and different transportation systems. Their linear programing model maximizes profit.. The model was developed and validated at the tactical level and provided considerable savings when compared with actual operations in Sweden. Although different decision support systems have been developed for forest recovery operations, most of them were developed at the tactical or strategic level. At the operational level, road accessibility can greatly affect productivity especially on steep terrain forest where in-forest road distance can reduce productivity by limiting the access of high capacity trucks and increasing the round-trip times. Road characteristics can also affect machine waiting times by limiting the number of trucks that can reach a processing site on time. Given the reduced actual marginal income of this operation an efficient cost management is required. The operational level improvement target is to ensure the long term success of this emerging supply chain in the United States.

The main objective of this paper is to develop a decision support system to minimize cost of processing and transport of forest biomass from harvest residues at the operational level. Specific objectives are to develop a friendly graphical user interface that enables the forest managers, land owners and contractors to analyze their operations and to decide which sites and residue piles are the most profitable to process and transport. It will also help analysts to decide the optimal location of processing sites such as centralized landings (within the forest) or centralized yards (located in nearby locations out of the forest unit). The main scope of the study is for steep terrain regions where road access is often difficult, but it can be applied in other less constrained operations in terms of access

2. Description of the Problem

Forest biomass processing and transportation from residues involves different machinery, truck-trailer configurations and systems. In the U.S. Pacific Northwest residues are usually processed following harvesting operations using a stationary grinder that is located adjacent to the residue pile. Residues are fed with an excavator. The processed material is directly conveyor fed into chip vans. Chip vans consist of a tractor (truck) and a trailer of different lengths. Trailers are usually light and open in the top to maximize hauling capacity. They may also contain an extension in the bottom known as the drop center. Grinders reduce the particle size of the residues by hammering the material. The particle reduction process requires the use of large engines (700-1200 hp) that consume considerable amounts of fuel per hour. As an alternative to stationary grinders, mobile chippers (Figure 1) are also used in recovery operations. Mobile chippers are capable of reaching more residue piles but are greatly affected by the type and cleanness of the material. Residues with high contents of dirt and stone negatively reduce productivity causing excessive wear of the cutting knives.

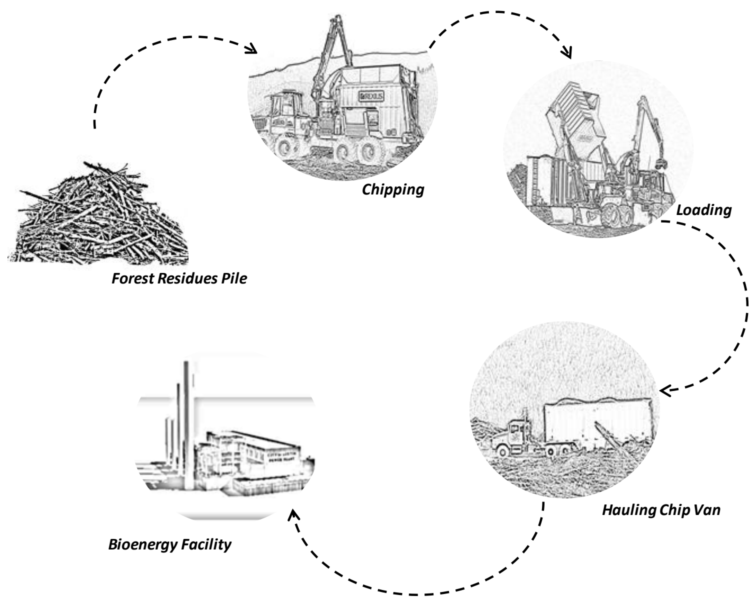


Figure 1. Chipping of forest residues at road side with a mobile drum chipper and transporting the chips to a bioenergy facility.

3. Material and Methods

The DSS is composed of a graphical user interface (GUI), capable to read spatial data (vector), a simulation model to account for the system dynamics of forest biomass recovery operations, and a mixed integer programming (MIP) solver. It also includes an ant colony heuristic (Dorigo 1996). The ant colony heuristic was primarily developed to make the program available for users who do not have a linear programming solver. It also provides the lower bound for the objective function to decrease the MIP solver solution times.

3.1 Program architecture

The program was developed using the JAVA platform. JAVA was selected as the programming language because it is well supported, and is capable of running on different operating systems. JAVA also provides access to different libraries that improve and facilitate the design of certain processes (Figure 2). The GIS component of the program is based on the Geotools JAVA code library (2012). Geotools library enables the program to read ESRI shapefiles. The simulation model was developed based on a simulation JAVA library for process-based discrete-event simulation developed by Helsgaun (2000). The program also makes the use of JFreeChart (Gilbert and Morgner, 2012), to produce the graphical representation of the results. Additionally lp_solve package (Berkelaar et al. 2004) is used as the MIP solver engine.

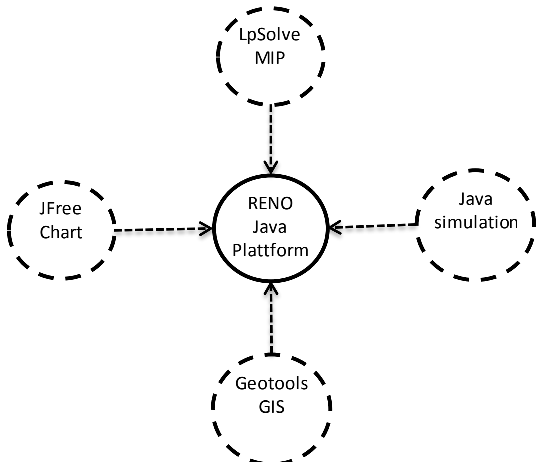


Figure 2. RENO components with different JAVA code libraries

3.2 Graphical user interface

RENO's GUI is composed by several dialog windows that allow the analyst to choose different processing and transportation options and also to access to different menus that provide information to the user (Figure 3). Menus are complemented by tool bars that give access to different modules. Available modules include a shapefile reader to input the road network, road features such as available turn-out and turnaround and pile location into the system.

Transportation options are divided in first and second stage transport. First stage transport is related to the use of bin trucks or hook lift trucks. Second stage transport comprised different conventional trailers with payloads ranging from 17 to 31 tons. Non-conventional trailers are also available to be selected. RENO includes the option for a 48 ft long, rear-steered axle trailer with a capacity of 25 tons. A 42 ft long stinger steered trailer can be also selected from the dialog window.

4. Application of results

The model was applied to a harvest unit located 15 miles northwest of the city of Sutherlin. The forest in characterized by a mix of Douglas-fir and white fir. The actual operation used a mobile chipper to process the residues and two double trailer trucks to transport the material to a bioenergy facility located 32 miles south of the harvest unit. Actual results were compared to model outputs under the same conditions. Fifteen forest residue piles at roadside were located and the road network identified. It was estimated that a total of 1100 green tons of forest residues were available in the forest unit.

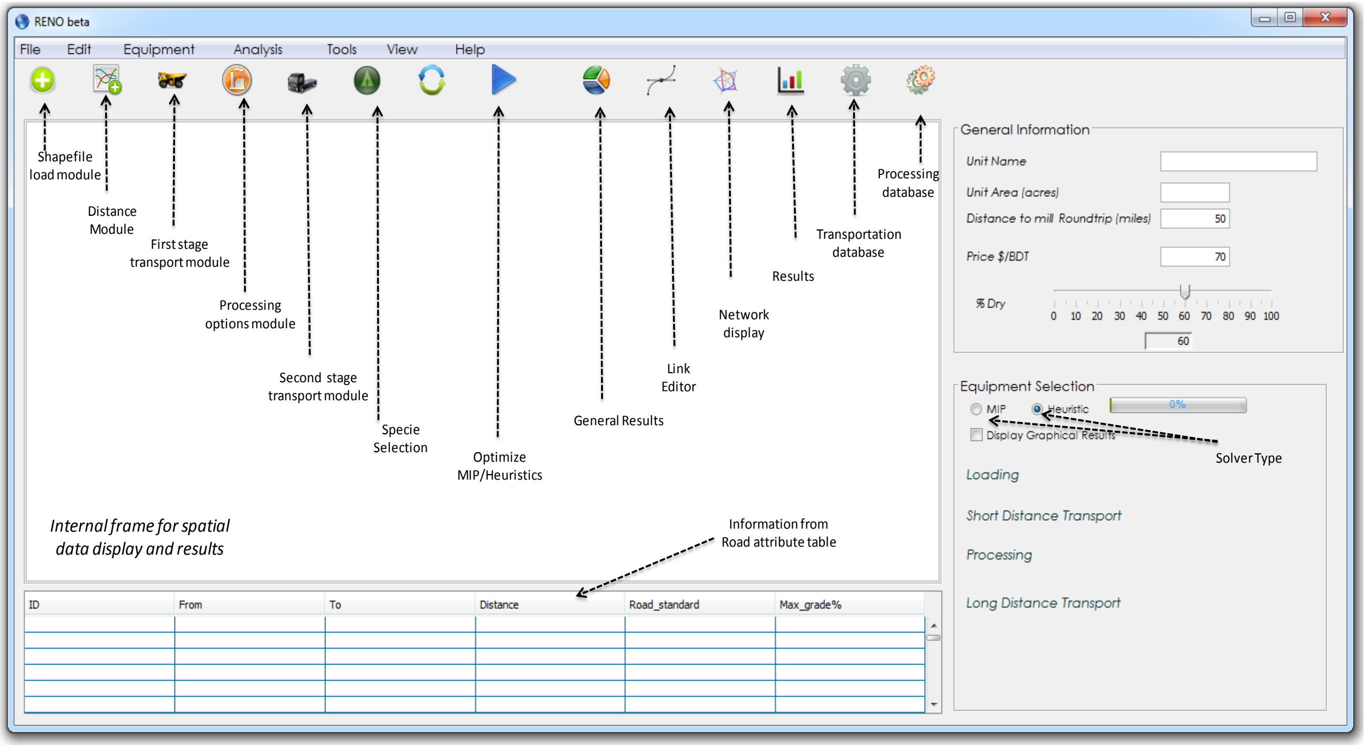


Figure 3. RENO graphical user interface

Available processing options were: (i) a 750 hp horizontal grinder (H-750) with an average productivity of 50 green tons (GT) per productive hour; (ii) a 1000 hp horizontal grinder H-1000), with an average productivity of 60 GT per productive hour; (iii) a 1000 hp tub grinder with an average productivity of 32 GT per productive hour; and (iv) a mobile drum chipper with an average productivity of 15 GT per productive hour. Available transportation configurations were: (i) two 6x4 trucks hauling two double 32 ft long trailers with a capacity of 30 tons; (ii) two 6x4 trucks hauling a single 32 ft long trailer with a capacity of 17 tons and (iii) two 6x6 trucks hauling a rear steer axle 48 ft long trailer with a capacity of 24 tons.

The optimal solution indicates that the best option to process the material was to use the H-1000 grinder (Figure 4). The most cost effective transportation option was the use of two double trailers, with an average of six loads per day. For transportation, the available number of trucks was the limiting factor. We performed a new analysis increasing the number of potential available trucks to 9 per day. The optimal solution suggests that depending on the location, from 4 to 6 double trailer trucks must be used to minimize total cost. Total cost decreases 13% because grinder utilization rate is maximized and truck-chipper interaction minimized.

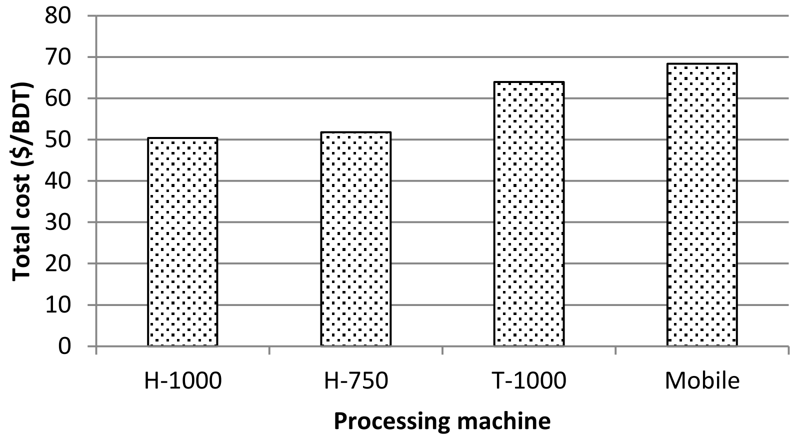


Figure 4. Total cost in dollars per bone dry ton for available processing machinery.

Although using the double trailer configuration implies spending more time in the forest (to hook and unhook the trailers), the hauling capacity under this option (30 green tons) compensates for the increase in round-trip time. The use of the mobile chipper reduces the truck dependence and decreases the waiting time for the truck, however this saving does not compensate the high cost and low productivity of the mobile chipper. However if a premium price exist for chips, rather than grindings, then a cost benefit of each option must be carried out.

RENO also reports the processing and transportation cost associated for each pile (Figure 5). Costs per pile vary because their location is different and their access can be constrained depending on where the closest and feasible turn-around and turn-outs are located. Costs associated to pile 1 were higher than the others because the high fixed cost associated with machine mobilization and site preparation at this location. Hook-lift trucks are assigned to this pile because it is chipper to transport the material to an adjacent pile (pile 2) than process the material in situ.

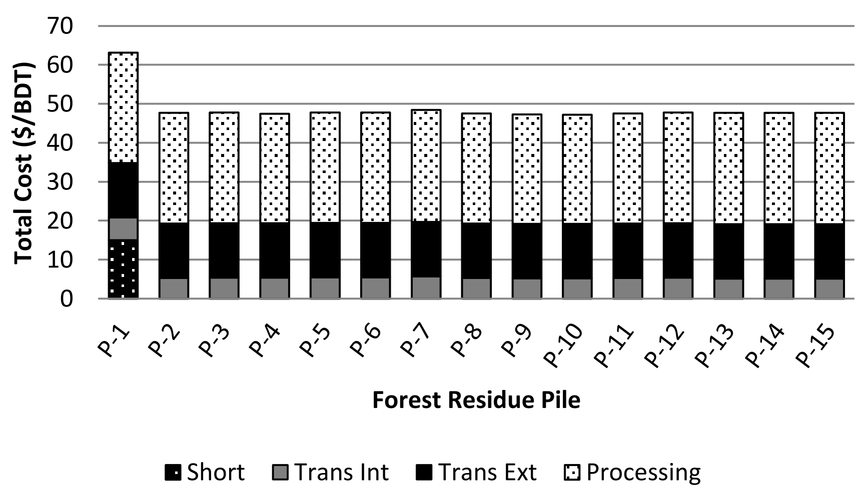


Figure 5. Processing and transportation cost per forest residue pile**.**

5. Conclusions

The decision support system, RENO, can provide decision support to forest managers and landowners at the operational level. RENO combines the use of GIS, mathematical optimization and simulation in order to provide the most cost effective processing and transportation options given the residue pile location, road access and technology available. Considerable savings can be obtained from its implementation as we were able to test the model by comparing their results to actual operations using the same parameters. Future research can be focused in the estimation of truck scheduling programs that can use the RENO solution to schedule trucks based on the available volume at each pile.

6. Acknowledgments

This Research was funded by the Northwest Renewables Alliance (NARA). NARA is supported by the Agriculture and Food Research Initiative Competitive Grant 2011-68005-30416 from the US Department of Agriculture, National Institute of Food and Agriculture.

7. Literature cited

Dorigo M., V. Maniezzo & A. Colorni (1996). Ant System: Optimization by a Colony of Cooperating Agents. IEEE Transactions on Systems, Man, and Cybernetics–Part B, 26 (1): 29–41.

Berkelaar, M., Eikland K., Notebaert P. 2004. lp_solve 5.0.0. Open source (Mixed-Integer) Linear Programming system.

Frombo F., Minciardi R., Robba M., Sacile R. 2009. A decision support system for planning biomass-based energy production. Energy 34 (3): 363-369.

Flisberg P. Frisk M., Ronnquvist M., 2012. FuelOpt: a decision support system for forest fuel logistics. Journal of the Operational Research Society 63: 1600-1612.

Gilbert D. and Morgnet T. 2012. JFreeChart 1.0.14 Java code library available from http://www.jfree.org/index.html [Accessed on June 2012].

Geotools Java code library. 2012. Geotools 8.0 avaialble from http://www.geotools.org/. [Accessed on June 2012].

Helsgaun, K. 2000. Discrete event simulation in Java. DATALOGISKE SKRIFTER (Writings on computer science), Roskilde University, Denmark, 64pp.

Sessions J., Wimer J., Costales F., Wing M. 2010. Engineering considerations in road assessment for biomass operations in steep terrain. Western Journal of Applied Forestry 25(5): 144-154.

Spinelli R., Magagnotti N. 2010. A tools for productivity and cost forecasting of decentralized wood chipping. Forest Policy Economics 12:194-198.