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June 22-25. Francis Marion Hotel, Charleston, South Carolina

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Seasonal Effects on Moisture Loss of Loblolly Pine

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ABSTRACT: Ten loblolly pine *(Pinus taeda)* trees from a plantation were felled during April 2007 and left in the woods to dry. Five trees were randomly selected to be delimbed and topped at 2 inches, while the remaining five trees were left whole. All trees including limbs and tops from delimbed trees were weighed weekly thru mid-September to determine moisture loss. Climatological conditions were obtained daily throughout the study period from a local weather station. Two additional sets of five trees were felled during October 2007 and January 2008 transported whole-tree to the G.W. Andrews lab and placed separately in A-frame stands for drying. Trees were weighed daily during the week to monitor moisture loss during the Fall and Winter seasons. Climatological conditions were monitored daily from a weather station placed on site. During summer drying, whole-trees lost a maximum of 37.2 percent of their initial weight, compared to 33.2 percent for the delimbed trees. Initial weight loss of whole-trees occurred at a higher rate compared to delimbed trees. For fall drying, trees averaged a 27.7 percent loss in weight over a 104 day drying period. Winter trees lost 21.6 percent of their total weight over a 63 day drying period.

Introduction

Utilization of woody biomass as a fuel source for generating power is becoming a very attractive option for replacing fossil fuels as oil prices rise and the oil market continues to fluctuate. This woody biomass is most valuable as a fuel source when moisture content is at a minimum. A very inexpensive way to dry this material is to leave it in the woods and let it air dry. This has been called "transpirational drying" or "sour felling". The general concept is that foliage left on felled trees continues to transpire, pulling moisture from the stem. Previous studies have documented drying curves for hardwoods and softwoods in southern conditions. Several studies have compared delimbed and undelimbed drying curves. However, the existing work has several methodological limitations. Most of the studies are single cohorts documenting drying curves for one set of weather conditions. Most of the delimbed vs. undelimbed studies confound moisture loss in foliage with moisture loss from stemwood.

This study had two primary objectives: 1) compare drying of delimbed and undelimbed stems with consideration of total moisture, foliage moisture and stemwood moisture; and 2) compare drying rates of seasonal cohorts through an entire year. This report describes initial results of field drying tests. There is an additional laboratory drying study that will provide more detailed information on drying parameters. The eventual outcome will be a model of field drying rates for loblolly pine that can be used to optimize harvesting and utilization processes.

Methods

All trees were randomly selected from a 16-yr-old loblolly pine plantation growing on a coastal plain site in east-central Alabama. The first cohort of 10 trees was felled in April 2007. Additional cohorts (5 trees each) were felled in October 2007, January 2008, and April 2008. All trees were selected to be between 4.5 and 6.5 inches in diameter breast height (Dbh).

The first group of trees (summer) were used to compare delimbed and undelimbed drying rates. Five trees were randomly selected, delimbed and topped at 2 inches. Limbs and tops were placed on plastic netting to facilitate weighing with minimal disturbance. At weekly intervals, the total biomass of each tree was weighed using a Chatillon hanging scale. At the end of the 5-month drying period (Sept 2007) disk samples were taken from Dbh, mid-stem, and top for gravimetric determination of moisture content.

The remaining groups of trees were suspended from frames for continuous weighing (Figure 1). All of these trees were left intact throughout the drying period. A Watchdog Model 900 ET weather station located near the trees recorded climate data at 30-minute intervals. Data included temperature, relative humidity, precipitation, wind speed, wind direction, wind gust, dewpoint, and solar radiation. At the end of each drying period, detailed measurements of volume and size were taken on each tree. Disk samples were taken from Dbh, mid-stem, and top for gravimetric determination of moisture content.

Figure 1. Tree attached to scale in A-frame.

Results

Trees for summer drying were observed for 140 days from April thru September. Limbs from one of the delimbed trees were accidentally pushed and scattered by a crawler tractor after day 50. Trees for fall drying were observed for 104 days from October 10th, 2007 thru January 22nd, 2008. Trees during the winter were observed for 63 days from January 28th thru March 31st, 2008. A summary of mensuration data is shown in Table 1. Volumes shown are total stem.

Table 1. Elemental statistics for mensuration data of study trees.

Variable	Summer Trees					Fall Trees					Winter Trees				
	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
Dbh (in)	10	5.7	0.18	5.5	6.0	5	5.6	0.22	5.3	5.8	5	5.3	0.51	4.7	6.1
Ht. 1st limb (ft)	10	22.0	6.66	8.1	34.0	5	26.0	4.64	18.8	29.3	5	30.3	3.23	25.8	34.7
Total ht. (ft)	10	45.2	3.08	41.3	52.1	5	47.0	3.66	43.1	50.9	5	50.3	4.15	45.4	55.6
LCR	10	51.5	13.22	34.7	82.2	5	45.1	7.03	37.4	56.4	5	39.5	7.65	30.2	45.8
Volume (ft^3)	9	3.8	0.21	3.6	4.2	5	3.8	0.54	3.3	4.7	5	3.9	0.70	3.2	4.9

Figure 2 illustrates the drying trends of the study trees for the seasons observed and is expressed as percent of initial weight. Summer whole-trees decreased to 62.8 percent of their initial weight over the 140 day period. Over 68 percent of this loss occurred after only 30 days. Delimbed trees (stem only) dried to 66.8 percent of their initial weight. Only 13 percent of this loss occurred after 30 days. Combining moisture loss of the stem and limbs and top of each delimbed tree showed total tree biomass dried to 64.4 percent of the initial weight. Summer whole-trees lost an average of 0.65 pounds of water per day (Table 2), compared to 0.57 pounds per day for delimbed trees.

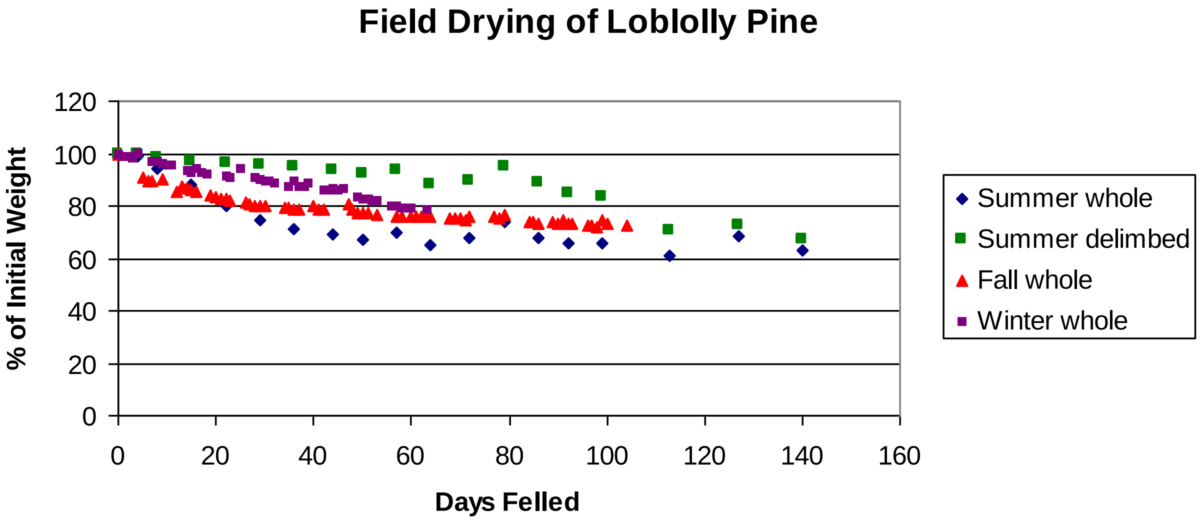

Figure 2. Tree weights as a percentage of initial weight by season.

Over the 104 day fall drying period trees dried to 72.3 percent of their initial weight. Over 73 percent of this loss occurred at the end of the first 30 days. Winter trees decreased to 78.4 percent of their initial weight over 63 day period where approximately 50 percent of this loss occurred after 30 days. For fall drying, trees lost an average of 0.71 pounds of water per day. Winter trees had the highest weight loss per day as compared to summer and fall trees at 0.91 pounds per day. This is most likely attributed to the shorter observation period for the winter test. Cumulative water loss for each season observed is displayed in Figure 3.

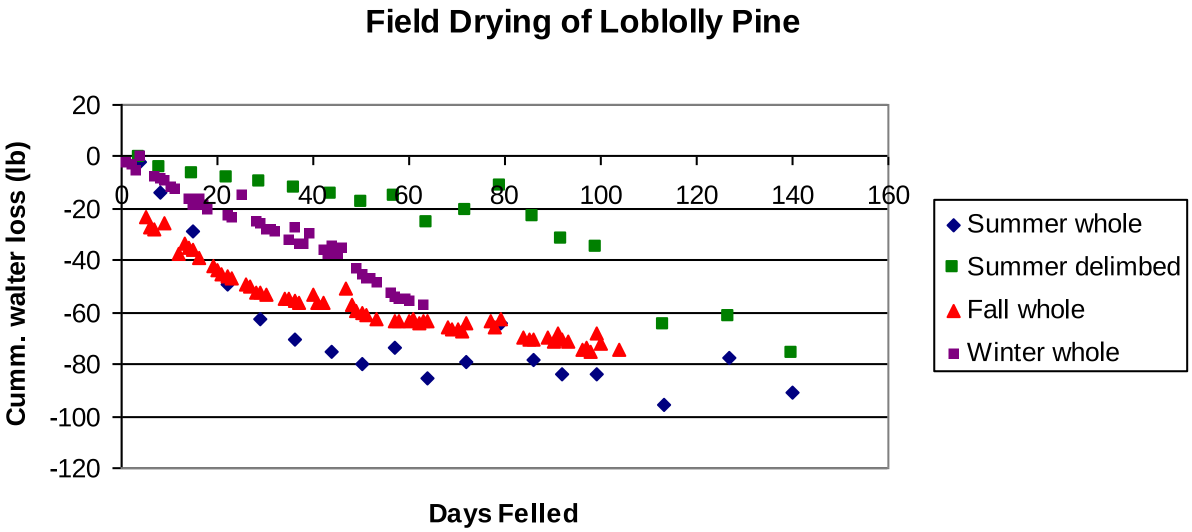

Figure 3. Cumulative water loss for total days felled for each season.

Table 2. Summary of drying rates for each season observed.

Season	*Days Felled*	*Weighing interval (days)*	*Weight loss per day (lbs)*	*Total weight loss (lbs)*	*Final weight relative to initial weight (%)*
Summer whole-tree	140	7.8	0.65	90.8	62.8
Summer delimbed	140	7.8	0.57	80.1	66.8
Fall whole-tree	104	1.7	0.71	74.2	72.3
Winter whole-tree	63	1.4	0.91	57.1	78.4

Percent reductions in moisture content for each season observed are summarized in Table 3. Summer whole-trees had a 55.3 percent reduction in moisture content and dried to 23.1 percent. Summer delimbed trees had a 43.8 percent reduction in moisture content and dried to 29.9 percent. Trees during the Fall season had a much lower reduction in moisture content. This is probably attributed to milder temperatures and more rainfall during the fall (Table 4). Also, Fall trees had a drying period that was 36 days shorter than Summer trees. Winter trees had nearly the same percent reduction in moisture content as Fall trees, even though Winter drying time was 41 days shorter. The Winter drying period also had the lowest percent relative humidity as compared to the other periods.

Since drying times were different for each season, a moisture content reduction rate per day was determined for a common period of the first 57 days. Summer whole-trees had moisture content losses at a rate of 0.36 percent per day, compared to 0.22 percent for fall drying and 0.23 percent for winter drying. Summer delimbed stems lost approximately 0.06 percent per day, compared to 0.14 percent per day for total biomass (stem and limbs) for delimbed trees. Trends of percent moisture content loss (wet-basis) for each drying period are shown in Figure 4.

Table 3. Mean percent moisture contents for each season observed.

Season	*Days Felled*	*Initial MC (wet-basis)*	*Final MC (wet-basis)*	*MC Reduction (%)*
Summer whole-tree	140	51.7	23.1	55.3
Summer delimbed	140	53.2	29.9	43.8
Fall whole-tree	104	56.7	40.1	29.4
Fall stemwood	104	57.7	41.5	28.2
Winter whole-tree	63	48.9	34.8	29.0
Winter stemwood	63	49.6	35.7	28.2

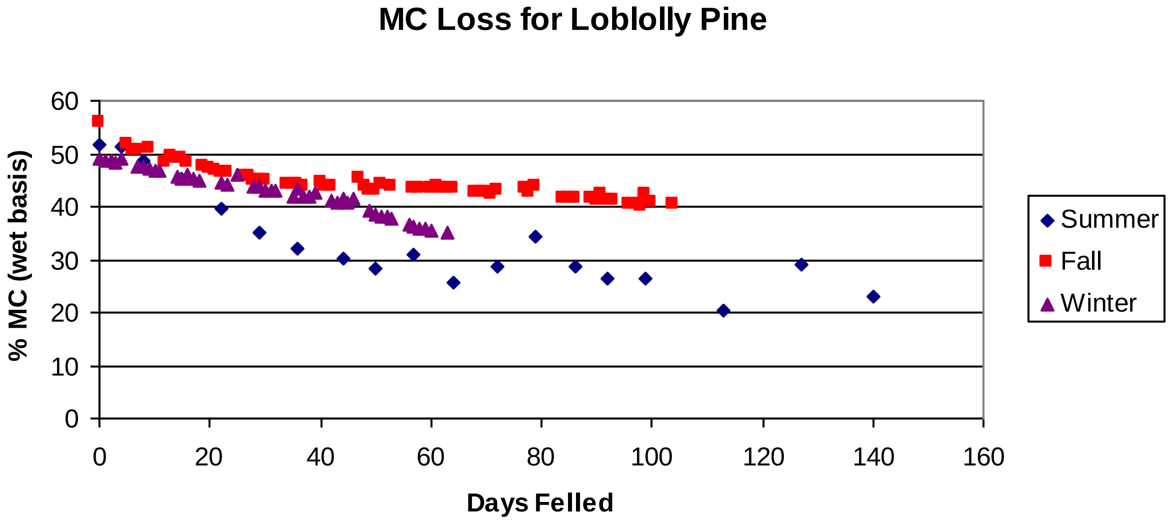

Figure 4. Loss in percent moisture content by season and days felled for whole-trees.

Table 4. Summary of climatological data by season observed.

Season	***Air temperature (°F)***	***Relative Humidity (%)***	***Total Rainfall (in)***	***Wind gust (mph)***	***Solar radiation (watt-hr/m^2)***
Summer	78.0	94.1	6.13	17.8	6087.6
Fall	53.6	69.9	14.71	10.1	129.0
Winter	51.0	57.9	10.27	12.8	173.0

Heat Content

Rising oil prices over the last few years have led industry to explore the need to increase the use of wood as a fuel source. Both wood and bark from southern pine trees are good fuel sources and have been highly utilized to generate heat, steam, and electrical power in the pine mills in the South (Koch, 1972). To estimate the fuel potential of a substance, its net heat value (NHV) can be calculated. This value accounts for the loss of energy required to drive off the moisture in the fuel (Rogers, 1981). Ince (1979) reported the amount of recoverable heat energy after accounting for losses due to moisture, hydrogen, dry gas and excess air, and conventional heat loss. This method for calculating recoverable heat energy was used in this paper. Several assumptions must be made for use as input data in the equations. These assumptions included a temperature of 500°F for stack gases past heat recovery devices, 40 percent excess air, and a 4 percent heat loss factor (Ince, 1979). A temperature of 80°F was assumed for the temperature of air and fuel before entering the boiler.

Higher heat value (HHV), or heat of combustion, is defined as the total amount of heat obtainable from oven dry material, allowing no deductions for heat losses (Koch, 1972). Since wood and bark both are included in the analysis and bark has a slightly higher HHV than wood alone, a HHV of 8,600 Btu/lb was used. Using moisture contents from Table 3 yielded results (Table 5) for initial and final NHV for the study trees.

Table 5. Increase in net heat value for loblolly pine by season and tree component.

Season/tree portion	***Days Felled***	***Initial***	***Final***	***Percentage increase***	***Btu's/lb per day***
			Btu's/lb		
Summer/whole-tree	140	2595	4859	87.3	16.2
Summer/delimbed	140	2472	4320	74.8	13.2
Fall/whole-tree	104	2198	3514	59.9	12.7
Fall/stemwood	104	2118	3404	60.7	12.4
Winter/whole-tree	63	2854	3980	39.4	17.9
Winter/stemwood	63	2798	3908	39.7	17.6

Comparing increases in whole-tree Btu's/lb per day for the first 30 days for each season resulted in rates of 44.0, 28.9, and 14.5 lb per day for summer, fall, and winter, respectively. Due to varying drying times among seasons, a rate of increase in Btu's/lb per day was calculated. Whole-trees and stemwood both had similar percent increases in Btu's/lb per day for all seasons observed except for the Summer season, where whole-trees were higher as compared to Summer stemwood. Trends in the increase in net heat value over time for the study trees are illustrated in Figure 5.

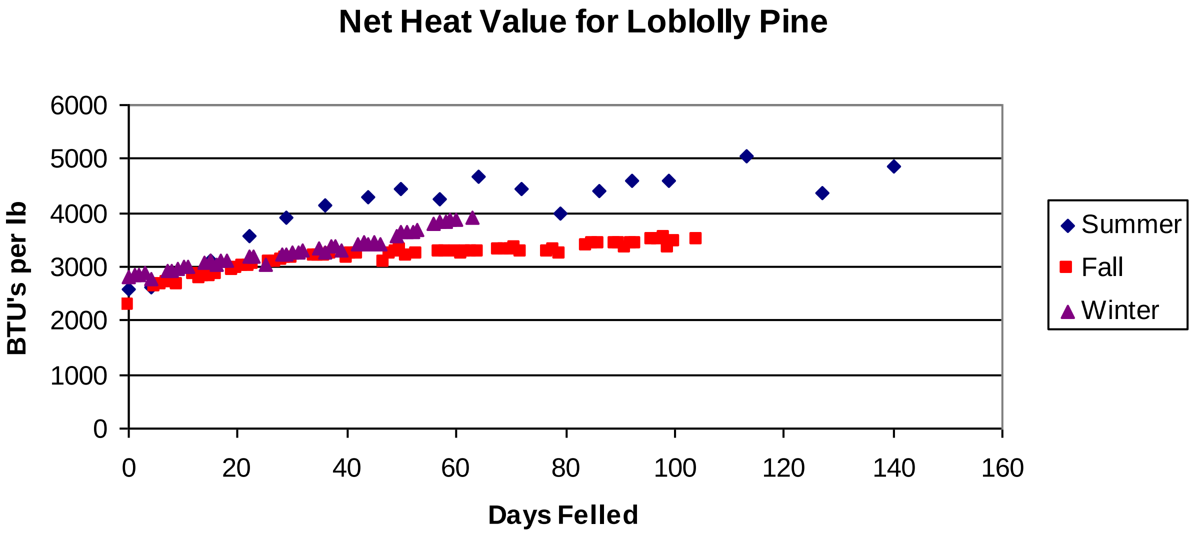

Figure 5. Net heat value of whole-tree loblolly pine for each season observed.

The advantage of letting trees dry in the field before delivery for use as a fuel source can be better illustrated by considering the gain in total MMBTU's (million Btu's) for a truck load of wood (Table 6). Percent increases are with respect to the initial MMBTU content on day zero when trees were felled. Gains in MMBTU's per day are with respect to the previous period shown. Negative amounts are due to rainfall events that occurred during the study period. As Table 6 illustrates, substantial gains in MMBTU content can be realized from field drying for all seasons observed. Summer drying for 50 days could possibly yield a gain of 93 MMBTU's, or a

71 percent increase, for a 25-ton load. Fall and winter drying after 50 days could result in gains of 50 and 41 MMBTU’s, respectively. Figure 6 illustrates gains in MMBTU content for a truck load over time for each season observed.

Table 6. Increase in MMBTU content for a 25-ton load of wood.

Days Felled	***MMBTU’s***			***Percent Increase***			***Gain in MMBTU’s Per day***		
	Summer	**Fall**	**Winter**	**Summer**	**Fall**	**Winter**	**Summer**	**Fall**	**Winter**
0	130	114	140	0	0	0	0	0	0
7	141	134	146	9	18	4	1.6	2.9	0.9
15	156	141	155	20	24	11	1.9	0.9	1.1
30	196	157	164	51	39	17	2.7	1.1	0.6
50	223	164	181	71	45	30	1.4	0.4	0.9
63	234	163	195	80	44	40	0.8	-0.1	1.1
72	221	164		70	44		-1.4	0.1	
92	230	171		77	51		0.5	0.4	
104		175			54			0.3	
140	243			87			0.4		

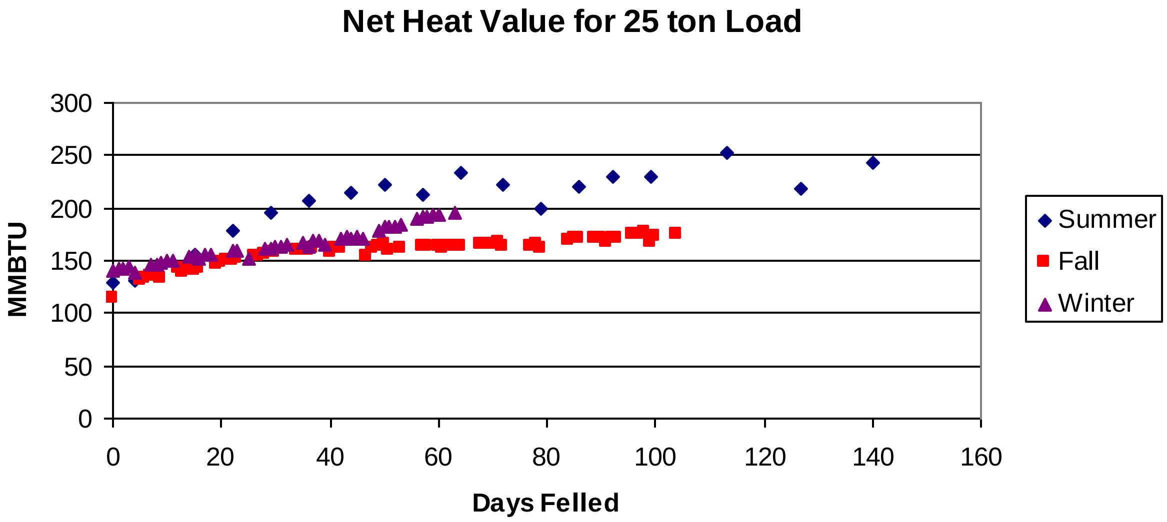

Figure 6. Net MMBTU content for a truck load of wood by season and days felled for whole trees.

Conclusions

Field drying trees resulted in moisture content reduction and substantial gains in recoverable heat energy for summer, fall, and winter seasons. Summer drying of whole-trees resulted in the highest reduction in moisture content (55.3 percent) but had the longest drying period. Leaving limbs and needles intact appeared to enhance the drying process. The period during summer drying was a very dry time with only slightly over 6 inches of rainfall recorded from the end of

April thru mid-September. Fall and winter drying resulted in almost the same reduction in moisture content (29.4 and 29.0 percent, respectively). Fall trees had a higher initial moisture content as compared to Summer and Winter trees. Also, Winter trees had the shortest drying period. Further statistical analysis will be conducted to address the effect of different drying periods.

Substantial gains in MMBTU content were realized after only 30 days of field drying for each season. Higher heat values would be beneficial to both the supplier and the consumer. For the supplier, delivering a product with more MMBTU's could translate to a higher economic return. For the consumer, using a drier fuel source results in less heat loss due to moisture and more efficient burning.

There was some overlap in seasons which would have been nice to avoid. The Summer drying period started near the end of April, so it includes some of the Spring season. Fall trees dried from October thru part of January and the Winter drying period occurred from the end of January thru March. Allowing the Winter drying period to run from December thru February would have been more desirable.

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Roll-Off Containers: A Solution to Transporting Woody Biomass?

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Abstract

Mechanized harvesting of trees and reducing stand density has been shown to be an effective means of treating severe wildfire hazard. However, harvest operations always entail costs. To offset this cost, managers must harvest in an economically effective manner. When thinning small diameter trees, however, and treating slash and other woody biomass, difficulties arise in meeting harvesting costs or producing any profit. A system of forest machines equipped with hook-lifts and the use of roll-on/off containers has been developed to help reduce costs and transport woody biomass. Past studies (Han 2008) have shown that this process can be economically viable under certain situations with the use of a similar roll-on/off container system. However, current time and motion studies are being conducted to expand on the feasibility of this process. The results of these studies will indicate how applicable this system is under a wide array of silvicultural prescriptions as well as other economic and environmental factors. So far, significant reductions in time and costs of handling processed material as well as a 1:17.6 ratio of diesel BTUs to green slash BTUs has been found.

Introduction

Throughout the past two decades, increasing wildland fire hazard and risk have led government policymakers to recognize the need for forest thinning of overcrowded stands (Atkins *et al.* 2007). Densely stocked stands can provide an environment in which fires can quickly become severe due to fuel build up and ladder fuels. To remove this material, managers must find a way to conduct harvesting operations economically. This is often done by harvesting larger, more valuable trees within harvest areas to offset costs. However, it is still difficult to treat small diameter trees and biomass as this material has little market value and considerable time, resources, and money can be wasted. Because of this, a means of reducing the costs associated with harvesting and handling small woody biomass needs to be developed. One potential method is the use of hook-lift equipped trucks and harvester-forwarders (or combi-machines) in combination with roll-off/on containers. "Roll-off" refers to a system incorporating straight frame trucks in which modular containers are "rolled" onto, and off of, the straight frame truck by use of a hydraulic hook-lift (Han 2008).

This project will conduct case studies at four harvest areas. The three major areas are located in West Yellowstone, Eureka, and Red Lodge, MT, accompanied with a fourth area in Council, ID where the bins and trucks will be used without the use of the combi-machine. The hook-lift and roll-off design is being implemented at these sites by Cky-Ber Enterprises, Inc. The projects are being supported with funding by the United States Forest Service, State and Private Forestry, Montana Community Development Corporation, and The University of Montana.

The advantage to this system is its ability to allow access to remote landings, which are not accessible by highway container trucks, and a reduction in time and money spent in transferring materials (Atkins *et al.* 2007). A detailed time and motion study format will be used to precisely describe and categorize each process involved in the harvesting system into basic elements. Such a study will specify how each system functions, how it can be improved, what rates of production can be expected, which arrangement of systems is most efficient, and associated costs. In addition to the motion and time study, shift-level data will be supplied by the contractor for further detail on time spent on processes over the length of the harvest and fuel consumption.

At the end of this project, the use of the hook-lift equipped trucks and combi-machines with roll-off/on bins will be fully assessed and determined whether they are cost effective for treating forest biomass and residues as well as merchantable timber. Large scale comparisons will also be made between removing slash for product and more traditional methods of slash treatments in the woods. Such knowledge will help forest managers treat biomass build up and ladder fuels in forests while reducing the risk of losing money. The outcome of this study has application for all facets of forestry including national forest land, wildland-urban interface (WUI) areas, and private land as well as furthering an emerging field of renewable forest biofuels.

Harvesting/Biomass System: Hook-lift and Roll-off Bunks and Bins

To conduct the harvesting in the proposed study areas, a combi-machine with a multi-attachment capable boom will be used. By using such a device, the number of machines needed to conduct the harvesting is reduced. Typically, when using a forwarder, it must be used in conjunction with a harvester or feller-buncher. The combi-machine will be capable of cutting trees using a hot saw attachment, returning to the trees with a processing (dangle-head) attachment, and then make one final trip with a grapple attachment to load the trees into a log bunk or load slash into roll-on/off containers. Several other combinations of processes will be studied as well such as using the dangle-head processing attached to cut and process all trees, using a rubber tire skidder to skid whole trees, process trees at the landing, and a sawyer to fell non-merchantable timber prior to mechanical harvest.

The combi-machine has been fitted for custom built roll-on/roll-off containers and log bunks and a hook lift system for loading and unloading bins. Roll-off log bunks differ from standard log bunks in two distinct ways. The roll-off log bunks are shorter than traditional bunks and they are taller when using extender bars on the side beams. They are also built with an eye-hook that provides an attachment point for the hydraulic hook-lift. Other equipment that will be necessary for this project is the use of a mobile or stationary chipper and haul trucks for the transportation of containers from the woods to the processing area and bunks from the woods to the timber mills.

Methods

While this system may look very enticing on paper, testing is needed to identify strengths and weaknesses. To gather data on how well this system functions, sites have been chosen in Montana and Idaho in which Cky-Ber Enterprises, Inc. is scheduled to operate. To date, there are four study areas located on Forest Service land: Hebgen Lake area, West Yellowstone, MT; Lower Pinkham area, Eureka, MT; Parkside, Greenough, and Limber Pine campgrounds, Red Lodge, MT; and Council, ID. The Lower Pinkham and Red Lodge area field work is nearly complete and the remaining two are scheduled to be completed in the late summer to fall of 2008. At each of these sites, a time and motion study will be conducted to record the movement and timing of the system in its entirety, shift-level study data will be collected, and a MultiDAT will record GPS positions and machine functions. Additionally, at each site combinations of combi-machine attachments, mechanized harvesting, and hand felling will be studied to determine the most efficient arrangement.

Using a time and motion study to determine the most efficient process for this system was a logical choice. Time and motion studies are systematic studies with the purpose of developing the preferred system and method, standardizing the system and method, determining the time required by a qualified and properly trained person working at a normal pace to do a specific task or operation, and assisting in training the worker in the preferred method (Barnes 1968). In the past, time and motion studies have mainly been used for direct factory labor such as automobile manufacturing lines. However, principles of time and motion studies are universal and may be equally effective wherever men or women and machines are employed (Barnes 1968).

Each system process will be broken into basic time elements followed by timing each element with a decimal stop-watch. Being the most common method of measuring work, the stop-watch study finds a representative time value for each element, and then adds the times together to obtain the total selected time for performing the operation (Barnes 1968). However, prior to starting the time and motion study, watching the system and observing its components is necessary before determining how to categorize it into elements. The advantage of using an elemental design is that specific records are gathered which will indicate where the most time is spent and what elements require the most attention. As stated earlier, several arrangements of equipment and operations will be studied. By doing so, the most efficient method can be determined. Additionally, testing various arrangements in the initial study area in Eureka, MT, will allow better direction for later study areas within Montana and Idaho.

The study near Eureka, MT, is testing four arrangements of processes and slash treatments. Two arrangements are extracting the slash to be sold to market while the other two arrangements are more traditional and will leave the slash in the woods in piles. In detail, each arrangement is as follows:

- Arrangement 1: Hotsaw merch and non-merch, process in the woods, skid forward all material out on bunks.
- Arrangement 2: Hotsaw merch and non-merch, ground grapple skid whole-trees to the landing, process at landing, pile slash with skidder at landing during processing.

- Arrangement 3: Hand fell non-merch, use processor to harvest merch saw and non-sawlog trees and process in the woods, skid forward saw merch material out on bunks, pile slash in the woods with grapple on forwarder.
- Arrangement 4: Use processor to fell merch and non-merch trees, skid products out on bunks, pile slash in the woods.

Preliminary Results

After analyzing the time and motion data for the Lower Pinkham study, some small conclusions can be made that will help direct efforts for the remaining study locations.

- Process Times:
  - See appendix for hourly breakdowns and production rates by process.
- Time Per Ton: 0.07 hours
- Cost Per Ton:
  - Arrangement 1: $22.98
  - Arrangement 2: $14.10
  - Arrangement 3: $14.31
  - Arrangement 4: $13.25
- Time Saved in Unloading Pulp Logs:
  - 4.52 minutes for traditional method
    – 2.56 minutes for roll-off method
    1.96 minutes saved
- Time Saved in Unloading Sawlogs:
  - 5.3 minutes for traditional method
    – 2.56 minutes for roll-off method
    2.74 minutes saved
- Time Saved in Loading Haul Truck with Pulp Logs:
  - 40.25 minutes for traditional method
    – 21.34 minutes for roll-off method
    18.9 minutes saved
- Estimated cost savings of $161.90 for every truck load of pulp material.
- Diesel Gallons/Green Ton Brush: 3.6
- Ratio of diesel BTUs to green slash BTUs: 1:17.6
- Sawyers can fell non-merchantable timber at a faster rate (265.5 trees/hour) and for a much lower hourly cost ($95.00/hour) than the combi-machine with the hotsaw attachment (203.9 trees/hour at $267.00/hour).

Lessons Learned and Possible Improvements

Following the completion of the Lower Pinkham and Red Lodge study areas, patterns in delays, performance, and production were identified. Each of these patterns has room for improvement or redesign to increase production, lower costs, and advance machine and worker performance.

When the combi-machine uses the bins for brush or chipped biomass material the operator has difficulty seeing when traveling in reverse and runs the risk of hitting residual trees.

Decreased visibility occurs due to the tall, solid steel walls of the bin. As a result, the operator may be forced to use the bins in open areas where the hazard of hitting trees or other equipment is reduced. Redesigning the bins may be necessary. One possible solution is to cut portions out of the sides of the bins and install wire mesh that would be capable of holding the load and increase visibility.

Another problem that was encountered occurred at the timber mill when unloading the logs. The mill operator attempted to unload the roll-off bunks with a front end loader with a log loader attachment as is typically done with haul trucks. However, the bunks were built with a smaller clearance than normally found on log bunks between the bottom of the logs and the support rail of the bunks. The loader did not have enough room to slide the arms under the load for removal. To unload the logs, the operator had to use a log loader to unload the logs two to three at a time. This resulted in a 40 minute unload time at the log yard which equates to a total of $98.33. To improve this time the bunks will need to be modified to increase the clearance.

Loading the pup trailer with the log bunks was another difficult task because of the heavy snow fall in which the equipment was operating. To load the pup trailer with a bunk the combi-machine or the truck cab has to load a full load onto itself first and then transfer this bunk to the trailer since the trailer does not have a hook-lift of its own. Since the trailer was sitting unassisted as the operators tried to load it, the trailer kept sliding because of the slick conditions at the landing and the force being created from loading the full bunk. After two failed attempts of loading the pup trailer, the workers had to brace the trailer with the truck cab to keep it from sliding as the combi-machine loaded it. This is far from ideal since the truck could not load the trailer by itself. This caused the combi-machine to be at the landing and not producing more logs in the woods. This could be improved by keeping an area continuously plowed of snow or dedicating a tree near the landing to serve as a brace for the trailer.

Conclusion

The work that has been completed in the Lower Pinkham area and Red Lodge has shown that this system can be competitive to traditional slash treatments and can save money, resources and time. Arrangement two did cost less than one of the traditional treatments. Additionally, prescribed burning costs have not been added yet nor has hauling costs been added as slash piles are currently in the drying process and these processes have not yet been observed. Also, there have also been examples of slowed production and higher costs with some aspects of the system. The system and the operators are benefiting overall because as these problem areas are identified they can be improved or removed to streamline the operation. Also, please note that these results are preliminary. As additional components are completed they will be added to the study and further refinement of results will be done.

The Hebgen Lake area will be the study area with the most potential for determining the ultimate usability of the hook-lift and roll-on/off bin system. Since a staging area will be used for unchipped biomass there will be several examples of the bin transfer from combi-machine to truck and the subsequent travel of the bin to the holding area.

Figure 1.1 – Hebgen Lake Study Site

Harvest Area shown in pink. Travel Route shown in blue (7 miles).
Map generated using Google Maps.

This distance of seven miles to the transfer station followed by additional travel to market will provide a great case study of how far the trucks can travel and stay competitive with traditional methods. Additionally, arrangements of equipment will be further studied and implemented to build a larger comparison and build confidence in the preferred method of using this system. With additional study and some modification, the hook-lift and roll-on/off container system may prove to be the missing link between forest biomass and its potential utilization for energy or other economic gains.

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Hebgen Lake Study Site. Scale unknown; generated by Aaron Kash; using Google Maps. <http://maps.google.com/maps?tab=wl>

Appendix

Hotsaw:

	Travel	Time Spent Cutting and Felling	Delays
Hours:	0.1322	0.66015	0.20765
Minutes:	7.932	39.609	12.459

# of Trees Cut Per Hour:	78.296626
# of Trees Cut Per Productive Hour:	98.9144892

# of Sawlog Trees Cut Per Hour:	15.73	*
# of Pulp Trees Cut Per Hour:	29.5	*
# of Non Merch Trees Cut Per Hour:	46.2	*

# of Trees Cut Per Acre:	392.641725
# of Trees Cut Per Productive Acre:	496.036134

Hotsaw Acres/Hour:	0.19940985
Tons/Hour:	10.863

Dangle-Head Processor:

	Travel	Searching for Merchantable Tree	Processing	Delays
Hours:	0.1134	0.2658	0.2785	0.3423
Minutes:	6.804	15.948	16.71	20.538

# of Trees Processed Per Hour:	57.7617329
# of Trees Cut Per Productive Hour:	87.8193996

# of Trees Processed Per Acre:	162.081642
# of Trees Processed Per Productive Acre:	246.42461

# of Logs Recovered Per Hour:	78.1986171
# of Logs Recovered Per Productive Hour:	118.891094

# of Sawlogs recovered Per Hour:	33.28	*
# of Pulp logs recovered Per Hour:	69.8	*

# of Logs Recovered Per Acre:	219.428325
# of Logs Recovered Per Productive Acre:	333.612978

Processor Acres/Hour:	0.35637431
Tons/Hour:	6.77

Forwarding:

	Travel	Brush Loading	Brush Unloading	Sawlog Loading	Sawlog Unloading	Pulp Loading	Pulp Unloading	Loading Truck With Pulp Logs	Delays
Hours:	0.4981	0.1264	0.0441	0.0173	0.0096	0.0632	0.0249	0.1006	0.1158
Minutes:	29.886	7.584	2.646	1.038	0.576	3.792	1.494	6.036	6.948

# of Brush Loads Per Hour:	0.76211214
# of Brush Loads Per Productive Hour:	0.86176862

# of Pulp Loads Per Hour:	0.43549265
# of Pulp Loads Per Productive Hour:	0.49243921

# of Sawlog Loads Per Hour:	0.10887316
# of Sawlog Loads Per Productive Hour:	0.1231098

# of Tons per Load (estimated):	7.5

# of Tons produced per hour of Brush Forwarding:	5.71584105
# of Tons produced per hour of Brush Forwarding:	6.46326465

Forwarding Acres/Hour:	0.21445783
Tons/Hour:	15.432

Brush Only:

	Travel	Brush Loading	Brush Unloading	Delays
Hours:	0.6375	0.2413	0.0841	0.0372
Minutes	38.25	14.478	5.046	2.232

# of Brush Loads Per Hour:	1.45460591
# of Brush Loads Per Productive Hour:	1.51073702

# of Tons produced per hour of Brush Forwarding:	10.9095443
# of Tons produced per hour of Brush Forwarding:	11.3305277

Pulp Only:

	Travel	Pulp Loading	Pulp Unloading	Delays
Hours:	0.4239	0.3263	0.1287	0.1211
Minutes	25.434	19.578	7.722	7.266

# of Pulp Loads Per Hour:	1.12470125
# of Pulp Loads Per Productive Hour:	1.8818216

Sawlog Only:

	Travel	Sawlog Loading	Sawlog Unloading	Delays
Hours:	0.6156	0.2473	0.1371	0
Minutes	36.936	14.838	8.226	0

# of Sawlog Loads Hour:	1.55199975
# of Sawlog Loads Per Productive Hour:	*No dealys during this trial.*

Process at Landing:

	Selecting Tree From Pile	Pcrocessing	Delays
Hours:	0.2273	0.4897	0.283
Minutes:	13.638	29.382	16.98

# of Logs Recovered Per Hour:	202.577372
# of Logs Recovered Per Productive Hour:	282.530554

# of Logs Recovered Per Acre:	568.097412
# of Logs Recovered Per Productive Acre:	792.313944

Processing at the Landing Acre/Hour:	1.48062016
Tons/Hour:	43.53

Sawyer:

	Cutting Non-Merch Trees	Delays
Hours:	0.7332	0.2668
Minutes:	43.992	16.008

# of Non-Merch Trees Cut Per Hour:	265.596333
# of Non-Merch Trees Cut Per Productive Hour:	362.259906

# of Non-Merch Trees Cut Per Acre:	491.895249
# of Non-Merch Trees Cut Per Productive Acre:	670.920131

Sawyer Acre/Hour:	0.5399449
Tons/Hour:	2.706

Processor Head Harvesting in Pre-Sawyer Unit:

	Travel	Searching for Merchantable Tree	Cutting and Processing	Delays
Hours:	0.1564	0.0995	0.4746	0.2695
Minutes:	9.384	5.97	28.476	16.17

# of Logs Recovered Per Hour:	82.0557491
# of Logs Recovered Per Productive Hour:	112.312395

# of Logs Recovered Per Acre:	240.306122
# of Logs Recovered Per Productive Acre:	328.914872

Processor head in Sawyer Unit Acre/Hour:	0.34146341
Tons/Hour:	22.926

Processor Head Harvesting:

	Travel	Cutting Non-Merch Trees	Searching for Merch Trees	Cutting and Processing Tree	Delays
Hours:	0.097	0.1744	0.1553	0.3886	0.1848
Minutes:	5.82	10.464	9.318	23.316	11.088

# of Non Merch Trees Cut Per Hour:	62.3156342
# of Non Merch Trees Cut Per Productive Hour:	76.4360018

# of Non Merch Trees Cut Per Acre:	368.475055
# of Non Merch Trees Cut Per Productive Acre:	451.969402

# of Logs Recovered Per Hour:	104.351032
# of Logs Recovered Per Productive Hour:	127.996382

# of Logs Recovered Per Acre:	617.032192
# of Logs Recovered Per Productive Acre:	756.84817

Processor Harvesting Acre/Hour:	0.16911765
Tons/Hour:	24.94

Brush Piling:

	Travel	Piling Brush	Delays
Hours:	0.2206	0.6618	0.1176
Minutes:	13.236	39.708	7.056

# of Piles Made Per Hour:	7.61307658
# of Piles Made Per Productive Hour:	8.6281277

# of Piles Made Per Acre:	7.01535569
# of Piles Made Per Productive Acre:	7.95071271

Brush Piling Acre/Hour:	1.08520179
Tons/Hour:	28.517

<u>Delay Breakdown:</u>

Warming up:	19.16%
Idling:	3.39%
Repairs/Inspect:	18.80%
Discussions:	9.97%
Changing Attach.:	11.25%
Clearing Stumps:	2.04%
Breaks:	8.33%
Refuel/Service:	5.53%
Repositioning:	3.86%
Other:	17.67%

** Data taken from video tapes. Accounts for any differences in other rates*

Biomass Baling into Large Square Bales for Efficient Transport, Storage, and Handling

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Abstract

Forest Concepts is working under a federal contract from the USDA CSREES SBIR program to develop better methods to collect and transport woody biomass collected from small-scale fuels reduction projects (ranging from residential lots to 20 acre parcels) in the true wildland-urban intermix zone (WUI). Our specific objective is to enable more of the material to be delivered to value-added uses including energy, biorefineries, and engineered wood products. A secondary objective is to enable diversion of urban greenwood from landfills and compost facilities. Our solution to the problem is to develop baling equipment and technology that enable woody biomass to be baled for transport on standard flatbed trucks, rail, and barge. The driving assumption behind our project is that baled biomass a) preserves user values as compared to on-site chipping, and b) facilitates delivery to more distant users than can be economically reached by chip vans or bulk bins. Another consideration for urban and suburban sources is that baling within residential areas produces lower noise, lower dust (and aerosols), and is potentially safer than chipping. We have designed and tested a baler that is a mid-size unit to demonstrate the concepts for equipment, on-site operations, and baled-material distribution logistics. Smaller and larger balers will be defined as appropriate for other markets.

Introduction

Forest Concepts is working to develop better methods to collect and transport woody biomass collected from urban and suburban areas. Our objective is to develop technological solutions to the problem of collecting woody biomass from community wildfire protection projects in the wildland-urban intermix, and to efficiently transport the resulting material to bioenergy and biobased products manufacturers. There are two facets to the problem. Most of the work is done in urban and suburban residential neighborhoods, presenting safety, noise and operational challenges for conventional forest equipment systems. The customers for urban-source biomass are often hundreds of miles away, making high-density transport solutions a necessity. The current situation of on-site chipping with landscape chippers and disposal or land application of the resulting chips is generally acknowledged as costly and inefficient. If more appropriate equipment and logistics systems were available, many of the organizations, governmental entities, and contractors involved in the quest of wildfire protection would adopt the better technical solution.

Our Solution to the Problem of Biomass Handling

Our solution to the problem was to develop equipment and knowledge that enable woody biomass to be baled for transport on standard flatbed trucks, rail, and barge. The driving assumption behind our project was that baled biomass a) preserves user values as compared to on-site chipping, and b) facilitates delivery to more distant users than can be economically reached by chip vans or bulk bins. A secondary consideration, particularly for urban and suburban sources, was that baling within residential areas produces lower noise, lower dust (and aerosols), and is potentially safer than chipping. The baler that we are developing and testing is a mid-size unit to demonstrate the concepts for equipment, on-site operations, and baled-material distribution logistics. Smaller and larger balers will be defined as appropriate for other markets.

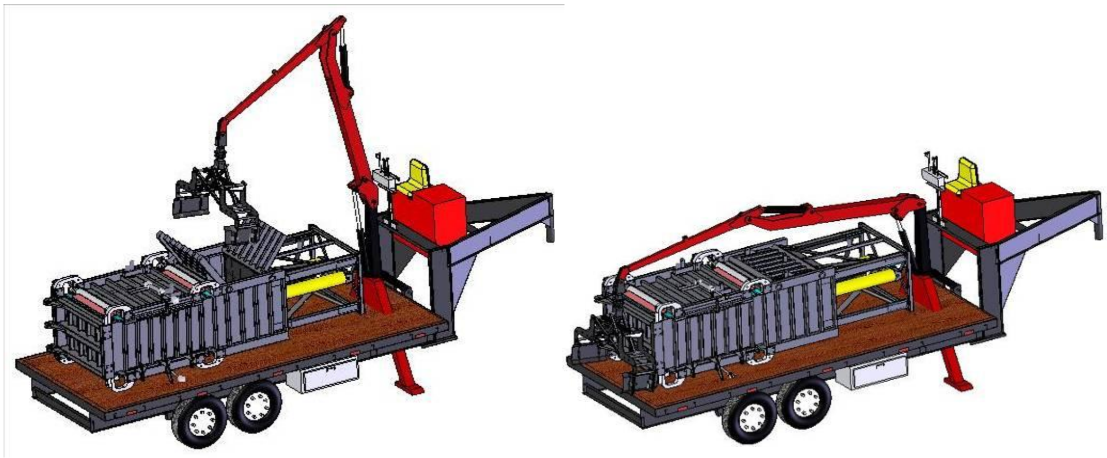
To a large extent, we achieved our research and development objectives. We demonstrated that woody biomass of the type removed from wildland urban interface fire protection projects and urban greenwood can be effectively baled into large square bales and transported on conventional flatbed trucks. We produced several truckloads of baled woody biomass and delivered the bales to distant users in Washington and Oregon. Bale integrity was good during long-haul highway transport on flatbed trucks with tarped loads. Receivers had no problems processing the baled biomass through their existing grinders and chippers. In fact, all receivers observed that the ease of handling bales would likely result in lower processing cost and increased throughput in their grinders. Thus, we validated our hypotheses that baled woody biomass should enable long-distance transport and should reduce the cost of handling and processing by receivers.

Commercial implementation of the project results will require design and manufacture of a new "biomass class" of balers – either by existing industrial or agricultural baler makers or by biomass processing equipment makers as a product line extension. Receivers of woody biomass bales demonstrated that they can handle and process the material with existing equipment. However, addition of bale squeezes, bale busters and infeed conveyors is expected to substantially reduce handling and processing costs. Investment by biomass handlers in such equipment, all of which exists on the market today, will not be made until sufficient quantity of baled woody biomass is available to justify the capital investment.

Many of the project activities were conducted with full participation of others in the profession, industry and public. One major public demonstration was held in Medford, Oregon and another was held in the Seattle, Washington area. Industry field demonstrations were held in Hoquiam and Kettle Falls, Washington. In all, presentations were made at eleven events and conferences to-date, and at least three more are scheduled later in 2008.

The first year of the project (SBIR Phase I) focused on problem definition and development of operational specifications for baling systems. During that phase, more than 60 interviews and site visits were conducted across four western states. The development phase began with a year-long science and fundamental engineering effort to extend the existing knowledge base – primarily from research conducted by Stokes, Stuart and others in the late 1970s. Major advancements in knowledge included 1) the development of compression vs. bale density relationships, 2) woody biomass shear bar design and performance data, 3) Poisson's ratio for baling woody biomass, and 4) methods to classify woody biomass physical parameters. Select results have been or will be reported in conference proceedings, posters and other outreach events. A number of patent applications are in process in preparation of licensing the technologies, and certain results are being held as trade secrets.

The project culminated with the design, fabrication and testing of a custom woody biomass baler for use in urban and suburban areas as a substitute for arborist-type chippers. Beginning in July 2007, our engineering team of Dave Lanning, Chris Lanning, Taneka Aristidou, and Jim Fridley began the process of designing a prototype biomass baler. The design is fully documented in proprietary design reports, computerized analyses, and detailed drawings. Fabrication began in October 2007 and was completed in March 2008. The baler was designed to be integrated with our existing smallwood trailer and self-loader as shown in the computer models below.



a **b**

Figures 1a, 1b. Computer model of self-loader trailer with prototype baler and specially designed grapple as engineered in November 2007.

a **b**

Figures 2a, 2b. Fully assembled self-loader trailer with prototype baler and grapple during initial testing in April 2008.

Fabrication and debugging of the baler was completed at the Forest Concepts shop in Auburn, WA. Machined components and flat steel waterjet and laser cutting were outsourced. Our team did all the welding, hydraulic circuitry, electronics, wiring and assembly. Two features of the design are particularly notable. The baler hydraulic system is entirely “fly by wire, under automated sequencing of a programmable logic controller (PLC). This enables automatic sequencing of bale compression chamber cycles and bale ejection positioning. This frees the loader operator to concentrate mostly on loading and handling biomass. The hydraulic power unit runs on a small 30 horsepower engine that provides power to both the baler and loader. Two pumps are used. One is a high flow low pressure gear pump and the other is as low flow high pressure pump. The PLC controller allocates flow from each pump and an attached accumulator to maximize cylinder speeds while minimizing horsepower consumed.

Figure 3. Field trial of prototype biomass baler at BRC Inc. yard waste facility in Auburn, WA.

The photos above show how the loader picks up biomass from the ground and places it into a top-loading infeed section. During bale compression the two finger-grates close to pack biomass into the chamber and form the top surface of the baler. Completed bales are ejected out the curb side of the baler to facilitate tying and lifting by the loader. Finished bales can be lifted onto companion haul trailers or trucks, or set on the roadside for later collection.

Figure 4. Bales of woody biomass produced by the prototype and research balers.

We conducted bale processing experiments with biomass processors in Washington and Oregon.

- Rainier Wood Recyclers – Auburn, WA – 6 miles
- Cedar Grove Compost – Maple Valley, WA – 19 miles
- Grays Harbor Paper and Cogeneration – Hoquiam, WA – 94 miles
- Vaagen Brothers Lumber / Avista Power – Colville, WA – 353 miles
- Biomass One – Medford, OR – 426 miles

a b c

Figures 5a, 5b, 5c. Woody biomass bales being processed by cooperators. a) Vaagen Brothers processing with Peterson horizontal axis grinder, b) Rainier Wood Recyclers dropping onto infeed conveyor to large fixed Universal Grinder, c) Grays Harbor Paper & Cogeneration feeding into large tub grinder.

All materials for the field trials were baled and then palletized for handling and shipment. Depending on the type of material in each bale, the bales were either stacked two or three high for trucking. The five biomass users in Washington and Oregon who processed prototype bales all commented that baled biomass would be easier and less costly to handle and process than bulk biomass. The processing demonstration held in Medford, Oregon at the Biomass One cogeneration plant was attended by more than twenty observers from the forest products industry, local agencies and the Bureau of Land Management. All other user trials were restricted to company employees due to safety concerns by the cooperators. However, photos, video and sample materials were obtained for use in off-site public presentations.

Conclusions

Research and development activities conducted under USDA CSREES SBIR Phase II funding provide important science, engineering, and performance knowledge that enable design of specialized balers for woody biomass and specification of handling systems at centralized collection points or end users.

We demonstrated the technical and economic viability of baling woody biomass and delivery to distant users as an alternative to chipping for local waste disposal. New scientific and engineering knowledge was developed to a) characterize woody biomass in the context of preserving value and enabling baling; b) shearing and compression properties of both individual biomass pieces and bulk material; and c) handling and transportation characteristics of baled woody biomass. Design data was developed that will reduce the time and risk for licensees to bring commercial biomass balers to market.

Acknowledgements

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Parcelization at the Wildland-Urban Interface: Effects on Forest Operations[1]

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ABSTRACT – One of the most prevalent issues facing the forest industry today concerns the expanding Wildland-Urban Interface (WUI). As urban centers sprawl, what were once large tracts of managed forestland are being divided and sold – a process known as parcelization. As these parcels divide, the amount of land once under the management regime of a single landowner suddenly belongs to multiple independent owners, which presents several challenges. The increase in the number of property owners typically implies a land use change. Parcelization is known to have an effect on wildfire outbreak, habitat fragmentation, groundwater quality; and is ultimately the cause of heat islands, uplighting, point-source pollution, and other factors associated with growth and development. Property division also leads to smaller tract sizes available to forestry practices, and past research has shown that there are few consistent methods available for profitably extracting low-valued timber products from these smaller tracts. Parcelization also increases loggers' moving and related costs by requiring more frequent equipment relocation. Therefore, the objective of this paper is to explore the effects of parcelization on South Carolina's timber products industry, specifically the logistics of forest operations. Through a review of relevant literature, the effect of parcelization at the WUI on forest operations is explored, and a methodological survey designed to collect data from the members of the South Carolina logging community will be developed.

INTRODUCTION

Threat of development and associated urban sprawl has significantly affected forest management in the southern United States. Increasing human populations encourage the lateral growth of communities and cities, and in this process large, relatively unbroken tracts of managed land at the urban edge are divided into smaller parcels. When individual parcels are purchased, and some forest landowners resist pressure from developers, it may lead to a fragmentation of timber resources. This reduces the likelihood that those forested properties will later be managed or harvested (Barlow et al. 1998). Many forested landscapes are dissected by road networks, housing subdivisions, commercial strips, or by varied ownership values (Egan et al. 2000), and

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population density has been shown to have an inverse effect on probability of harvest (Sampson and DeCoster 2000, Wear et al. 1999). High productivity harvesting systems struggle to operate efficiently on smaller tracts, and there are minimum tract sizes (with various qualities of timber) that a logger may agree to operate on (Kittredge 1996). Reduced tract size may have severe consequences for the logger, whose productivity, and therefore profitability, relies on the principles of economies of scale (Row 1978, Cubbage 1982). Because of parcelization, firms dependent on Non-Industrial Private Forests (NIPFs) will need to adapt their harvesting systems in order to maximize productivity on smaller tracts, and to minimize their fixed costs.

BACKGROUND

The 2001 Federal Register (USDA and USDI 2001) divides the Wildland-Urban Interface (WUI) into two levels. The area where housing abuts vegetation is called the "interface"; where housing is dispersed throughout the wildland is called the "intermix". Both these designations are generally referred to as the WUI, and many view it as a single entity. This is the area where the parcelization of contiguous tracts occurs – a process contributing to urban sprawl, habitat fragmentation, and reduced economic yield of managed resources, including forest products.

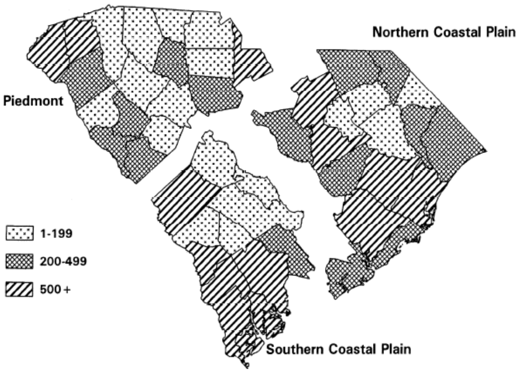

Figure 1. Average tract size for NIPF land by county in South Carolina, 1993 (Thompson 1997).

Though industrial forestland is being subdivided and sold for residential and recreational uses (Best 2002), the vast majority of privately owned forests in the U.S. are in the form of Non-Industrial Private Forests (NIPFs). NIPFs account for about 363 million acres of forestland in the U.S., owned by 10.3 million owners (Blinn et al. 2007), and average NIPF size is 24 acres (LaPierre and Germain 2005). According to Best (2002), 10 million acres of this land was lost to development between 1982 and 1997, with 70 percent more lost between 1992 and 1997 than from 1982 to 1991. Between 1978 and 1994, two million acres in NIPFs was divided into parcels less than 100 acres, and 8 percent of private forest area is in parcels less than 20 acres (Best 2002). The probability that these parcels will be managed is about 75 percent where population density is 19 people per square mile (Sampson and DeCoster 2000). Management is unlikely to occur where population density is 150 per square mile (Wear et al. 1999). Age is also a concern in NIPF ownership, in that 40 percent of owners are retired and will eventually sell their property (Macie and Hermansen 2003), putting the land at increased risk for development.

NIPFs are a major source of timber resources for loggers in the South. Metropolitan area in the southern U.S. increased from 9.8 percent in 1960, to 23.2 percent in 1990 (Barlow et al. 1998), and recent data would likely show a continued increase. Of the area considered forestland, 26 percent is in counties with more than 250,000 people, occupying about 28 million acres; 43 percent of which is unmanageable for timber resources (Barlow et al. 1998).

About 70 percent of forestland in the South is in NIPFs. In Alabama, 67 percent of forests are controlled by 432,000 NIPF owners; two-thirds of whom own less than 10 acres (Pan et al. 2007). Twelve percent of those owning more than 50 acres control approximately 85 percent of the state's private forestland (Pan et al. 2007). In Georgia, Atlanta sprawl consumed about 355,500 acres between 1982 and 1997 (Best 2002). And, from 1982 to 1989, parcels less than 10 acres in size increased almost 7 percent, while parcels greater than 200 acres decreased about 18 percent (Greene et al. 1997). Since 1987, Georgia loggers have increased their weekly production by 83 percent, and production per man hour has increased more than 50 percent (Baker and Greene 2008). The number of fully mechanized crews has increased by about 15 percent, while logging companies have seen a decreased return on investment over the last 20 years (Baker and Greene 2008). Baker and Greene (2008) also found that clearcutting in Georgia has decreased from 80 percent to 32 percent during this time, implying that loggers are needing to harvest more tracts per year to meet production levels; facing an increased number of moves per year.

South Carolina's NIPFs accounts for 74 percent of the state's 12.3 million acres of timberland (Thompson 1997). Sixteen percent (1.5 million acres) of NIPFs are in tracts greater than 500 acres; 31 percent (2.8 million acres) are in tracts between 101 and 500 acres, and 10 percent (0.9 million acres) are in tracts 10 acres or less. The dominant size category is between 11 and 100 acres, accounting for 43 percent (3.9 million acres) of NIPFs. Figure 1 shows average NIPF size distributions for South Carolina counties based on 1993 forest statistics.

CONCERN FOR PROFITABILITY

Economies of scale are negatively impacted by reduced parcel size. Row (1978) found economies of scale for minimized harvest cost to be effective between 20 and 40 acres. Likewise, Cubbage (1982) found that the economies of scale for a highly mechanized harvesting system in the South to effective at just less than 40 acres. In Georgia, harvesting costs increase rapidly on tracts less than 50 acres, while there is little motivation for harvesting tracts less than 20 acres (Greene et al. 1997). The advantages of larger tract size include, but are not limited to reduced transaction costs, standard or interchangeable parts, more efficient power source or automatic equipment, and specialized workers and equipment (Row 1978).

Parcelization and changing land use implies a reduced number of timber sales, while capital costs for loggers are increasing (fuel, machinery, hauling, and labor). Therefore, timber may be less available (with greater distance between tracts), with loggers incurring greater productivity losses from time spent moving. Depending on the mechanization level of the harvesting system (i.e. semi-mechanized shortwood vs. highly mechanized tree-length) small parcels may be suitable for harvesting. Many harvesting systems in South Carolina are highly mechanized. Comparable to South Carolina, Baker and Greene (2008) found that about 90 percent of Georgia loggers surveyed operate a conventional highly mechanized feller-buncher/skidder system.

According to Cubbage (1982), moving costs should consider costs for transporting equipment between sites, wages paid to unproductive employees, fixed costs for idle equipment, and the value of timber not being actively harvested. Small systems cost less to move, and require less time to move than highly mechanized systems. A small partially-mechanized system may cost between $400 and $1,100 per move, while a highly mechanized system may cost between $2,200 and $5,400 per move (Cubbage 1982, adjusted to 2008 dollars).

Potential solutions for mitigating the increased costs associated with smaller tract size might consider land-use planning, conservation easements, forest landowner co-operatives, and appropriately-scaled harvesting systems. The first three are consolidatory methods – either planning for, setting aside, or establishing personal relationships that encourage, contiguous networks of timber resources. The last, appropriately-scaled harvesting systems, will be important as the process of parcelization continues, and demand for timber increases.

METHODOLOGY

In response to the potential threats of parcelization, a study has been designed to determine whether logging companies in the state of South Carolina have noticed an overall reduction in tract size harvested. If they have noticed a difference, this study will highlight what modifications they have made to their operation to minimize the effects of reduced parcel size. Members of the South Carolina Timber Producers Association and companies with employees certified as Timber Operations Professionals (TOP) will be contacted.

Employing a survey methodology modeled after Dillman (2000), the companies will be mailed a prenotice letter, a questionnaire with accompanying cover letter, a thank you postcard/reminder, and where additional response is sought, a replacement questionnaire and an additional final contact. Loggers responding to the survey will be informed of its importance in the prenotice letter and the survey cover letter. Dillman (2000) encourages the establishment of trust with the respondent for an increased response rate. This may be accomplished by use of a respondent-friendly questionnaire, first class mail, real first-class stamps, personalized correspondence, and a financial incentive (typically cash) (Dillman 2000). These methods follow Dillman's Tailored Design Method (Dillman 2000). Some research following his original Total Design Method (1978) yielded response rates as high as 77 percent when all five modes of contact were incorporated (Dillman 2000).

Studies investigating similar topics have also used surveys as a tool for judging loggers' reactions to population growth and/or NIPF dependency (e.g. Rickenbach and Steele 2006, Baker and Greene 2008). Baker and Greene (2008) assessed changes in production levels, workforce, land ownership patterns, system mechanization, and other important indicators in the Georgia timber production industry. They have developed a time series analysis, surveying loggers every five years for the last 20 years. Using a single survey mailing for a sample population of 878 loggers, their most recent questionnaire had a response rate of 24 percent, or 211 loggers. Similarly, Rickenbach and Steele (2006) surveyed loggers in northern Wisconsin and Michigan to assess their NIPF dependency, as related to production and profitability levels, worker safety, and other issues. They used a "multi-wave" approach with their survey, consisting of a full mailing including a $2 financial incentive, a postcard follow-up, and two additional mailings to nonrespondents. Distributing 1,063 11-page surveys, the authors received a usable response of 513 out of 921 firms, yielding a response rate of about 56 percent (Rickenbach and Steele 2006).

For this study of South Carolina logging firms, a response rate of 24 percent as in Baker and Greene (2008) would be acceptable. However, implementation of the Dillman (2000) approach intends to produce a response rate closer to 50 percent, approximately that of Rickenbach and Steele (2006). A higher response rate would provide more confident relationships between responses to different survey questions. For example, the questions "What is your average moving distance between tracts?" and "How much time do you usually spend moving between tracts?" may be correlated. Examples of questions included in the survey are:

7. How many loads does each crew average per day?
( ) <1 load ( ) 2-4 loads ( ) 5-6 loads ( ) 7-8 loads ( ) >8 loads

8. What is the minimum number of loads / acre required to make harvesting a tract worthwhile?
( ) <1 load ( ) 1 loads ( ) 2 loads ( ) 3 loads ( ) >3 loads

15. How much time do you usually spend moving between tracts?
( ) <2 hours ( ) 2-4 hours ( ) 4-6 hours ( ) 6-8 hours ( ) >8 hours

16. What is your average moving distance between tracts?
( ) <20 mi. ( ) 20-40 mi. ( ) 40-60 mi. ( ) 60-80 mi. ( ) >80 mi.

CONCLUSION

Two issues are presented in the preceding literature review. Generally, NIPF size in the United States is decreasing due to population growth and development, and, changing resident values are influencing the way timber is harvested. To maintain production levels and business viability it can be assumed that logging companies are harvesting a greater number of tracts through increasingly selective measures. Regionally comparable studies have shown that loggers are increasing the mechanization level of their operation. With rising fixed costs and more frequent movement between tracts, harvesting operations will need to modify the scale of their operation to more appropriately address tract size and management restrictions. Soon, harvesting systems may economically suffocate logging companies, as many believe that maximizing productivity by use of highly mechanized, multiple-machine systems is the most efficient method. Conversely, if smaller systems, requiring fewer pieces of equipment, fewer crew members, less moving expense, and less moving time were utilized, the logger may find his or her system to align better with the demands imposed by expanding urban growth and increasing human populations.

This study will be conducted to determine the effects of urban growth and population increase on the logging industry in the state of South Carolina. Firms are largely dependent on their harvesting of NIPFs, and NIPF subdivision may be forcing them to modify their operation. A methodological survey will be mailed to a group of South Carolina logging companies, intending to learn whether parcelization has impacted their harvesting operation, and how or if they have modified their operation to increase efficiency on smaller tracts.

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Public Perceptions of Wildfire Risk and Controlled Burning in the Wildland/Urban Interface of the Louisiana Florida Parishes

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ABSTRACT

To reverse the effects of long-term fire suppression in the Florida Parishes of Louisiana, a three-tiered approach is being initiated: assessment, education and demonstration. A survey to assess the current level of public knowledge has been developed and is being distributed. Educational materials will be developed based on the results of the survey. Finally, a series of workshops will be offered to the public to demonstrate the need, suitability and safety of prescribed burning or mechanical fuel removal to reduce the chance of catastrophic wildfire in the Wildland/Urban Interface.

INTRODUCTION

A combination of wildfire suppression and suburban sprawl has created a potentially volatile situation in the land beyond the suburbs known as the Wildland/Urban Interface (WUI). In southeastern Louisiana, fire has been a natural part of the ecosystems for hundreds, if not thousands, of years. As civilization encroached on these forests, grasslands and marshes, the natural cycle of fire was interrupted. Over the past few hundred years, fire suppression has become not only the societal norm; it has also become an increasingly unveiled threat. The occurrence and intensity of wildfire in the WUI of southeastern Louisiana has come to the forefront of society's notice, with massive burns such as the Okefenokee Swamp wildfire of 2007 in southern Georgia and the spectacular San Diego fires in recent years clamoring for media attention. For example, an Internet search of the Google Images search engine conducted on May 29th, 2008 resulted in approximately 81,900 images using the words "San Diego wildfires". A similar search using the words "Georgia swamp wildfire" yielded approximately 22,800 images.

Clearly, there is significant public interest in these wildfires. These unfortunate events can be viewed as fortuitous, for as public awareness of large fires increases, the threat of wildfire at home seems more real and urgent. The public is ripe, perhaps for the first time in a long time, to learn about, understand and embrace the use of prescribed fire as a forest management tool. It's not a difficult concept to grasp that fire is not "bad" but indeed a natural and necessary tool to prevent such catastrophes from occurring in outlying areas of our cities.

For the purposes of this study, we are concentrating on an area of southeast Louisiana known as the Florida Parishes. The population growth in this area is burgeoning, particularly since Hurricanes Katrina and Rita ravaged the southern part of the state in 2005. Fear of future catastrophic hurricanes, economic uncertainty in the hardest hit areas, employment opportunity north of Interstate 10 and sharply rising insurance rates south of Interstate 10 have all combined to influence our citizens to move into these parishes and away from the coast. Rapidly developing suburban areas are encroaching into vast timberlands and pine/grassland savannahs, and have created a more urgent need to educate our citizens about wildfire risk, prevention, and smoke management. Further complicating the issue is the presence of downed timber that resulted from high winds during Hurricane Katrina. There remains a swath of blown down timber from the coast of Louisiana inland to north of Hattiesburg, Mississippi. This additional fuel adds opportunity and risk.

METHODS

The first step in educating the public about wildfire risk and prevention is to understand current perceptions and attitudes about the risk of wildfire and the use of prescribed burning to aid in diminishing that risk. We created a survey instrument that will be mailed to a random sample of people residing in our study area. In order to obtain the mailing list, we contacted the tax assessor's office in each of the eight parishes to obtain records of landowners possessing more than 5 acres of land. We chose these criteria to preclude sending surveys to inappropriate recipients, such as those with urban addresses (the target is those citizens residing in the WUI). We are in the process of creating a database, using data from the tax assessor's office, the U.S. Census Bureau and other sources. Once compiled, this database will allow us to create mailing lists, record responses and begin our statistical analysis and identification of trends in the populations.

We found that creating a survey instrument is a delicate balance of word-smithing and tact. It is extremely difficult to write questions that are unbiased, don't attempt to educate, are statistically-relevant and will result in data that are informative and truly reflective of current attitudes and perceptions of wildfire and prescribed burning. Dillman's Tailored Design Method (2000) has been extremely helpful throughout the survey creation process. We will send out a pre-mailing postcard, the survey, a post-mailing postcard and a second survey (if necessary). We have also taken this opportunity to gather some basic demographic data and to give the respondents the opportunity to show interest in learning about wildfire risk, prevention, prescribed burning and smoke management.

RESULTS

A 25% response rate is possible in this study. That may be ambitious, but we are operating under the assumption that the public is ripe for knowledge and understanding and will respond accordingly. Based on the response to the offer of education, we are planning to offer a number of different avenues for learning, such as a website, brochures, videos, workshops, etc. We will ultimately offer whichever medium that generated the most interest as the preferred method of learning. In our efforts to not reinvent the wheel, we are learning from the likes of Firewise Communities (www.firewise.org) and similar studies such as those produced by the collaborative effort of Resources for the Future (RFF). We intend to involve community leaders as much as possible, as well as the local fire districts and natural resource professionals. If we decide that a demonstration burn is appropriate, we will coordinate with LSU's School of Renewable Natural Resources 1200-acre Lee Memorial Forest in Franklinton, La as well as the State Office of Forestry.

CONCLUSIONS

It is our goal to increase the public's awareness, education, and acceptance and ultimately, begin to reverse the long-accepted policy of wildfire suppression. The south Louisiana ecosystems are naturally fire-driven systems, and in order to retain their vitality, they must return to a more "original" state. The goal is to find the balance between allowing nature to proceed un-impeded and protecting our citizens who live within these ecosystems.

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Economic analysis of forest harvest residues biomass storage in Northwestern Ontario

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Abstract

Wildfire burnt forest biomass can potentially be salvaged as feedstock for power generating stations. Although there is a great potential availability of such forest biomass in northwestern Ontario, its procurement has been generally considered uneconomic. There is no study that has looked into the cost of harvesting, processing, and transporting the burnt salvaged material for bioenergy production in northwestern Ontario. The Ontario Government is committed to eliminate the use of lignite coal as feedstock for power generating stations by 2014 and potentially replace it with renewable biomass. As part of a feasibility study for efficient utilization of salvaged forest biomass from burnt areas for power generating stations, a standard costing model is utilized for the cost analysis, as opposed to actual costs. The model is applied to assess the costs involved in salvaging biomass with a Full-Tree to Roadside, Roadside Crusher System from a wildfire burnt area of the Hogarth Plantations near Thunder Bay, Ontario. The cost per tonne of forest biomass and per kWh of energy production is assessed. The change in total cost is also predicted with change in fuel prices and haulage distance.

1. Introduction

In spite of ratifying the Kyoto protocol on December 17, 2002 and agreeing to reduce its Green House Gas (GHG) emissions to 6% below 1990 level by 2012, the emissions in Canada had risen to 27% above 1990 levels by 2004 (Wood and Layzell 2003). The fossil fuel based power generating plants have significantly contributed to these emissions. The white paper for a community strategy and action plan considered bioenergy as a clean and cost-effective source of renewable energy (EC 1997). However, in Canada only 6 to 9% of electricity is generated using biomass feedstock (Bradley 2006), whereas in Austria, Finland and Sweden this renewable source accounts for 12%, 23% and 18% of primary energy supply, respectively (EC 1997). The Ontario Government is taking initiatives to reduce GHG emissions most notably through plans to phase out coal fired generating stations by 2014. One option being investigated is to replace lignite coal as a feedstock with renewable biomass to keep the power generating stations operational. Two of these power generating stations are centrally located to many forestry operations. These operations produce sizeable amount of forest residue that are not utilized and have the potential to be utilized as biomass for electricity generation (Ride 1999).

Biomass resources are generally low in energy content, bulk density and high in moisture content as compared to fossil fuels. Therefore, procurement and transportation of biomass feedstock for power generation can quickly become uneconomical unless efficient methods are used to optimize the logistics involved (Hemelinck *et al*. 2003). The higher share of bioenergy use in European countries is not a coincidence but a result of in depth research into all aspects of utilization (EC 1997). With the developing bioeconomy sector in northwestern Ontario, there is a need to explore more efficient and cost effective procurement methods for surplus biomass feedstock (Ride 2008).

One of the efficient and cost effective ways to utilize the forest biomass is to salvage the wildfire burnt forest areas. Fire is a frequent and a natural occurrence in the boreal forest. On average, over 10,000 ha of forest area or over 1 million m^3 of wood that is part of the harvest schedule is consumed by wildfire every year in Ontario (OMNR 2008). This results in huge losses to the forest companies, although silviculture costs to regenerate these sites in most cases can be claimed from the Ontario Forest Futures Trust. The forest companies in many cases lose their investments on roads and administration costs in spite of predetermined contingency plans. If the burnt areas are salvaged to obtain wood biomass for energy production the losses to the forest companies can be greatly reduced, as well as locally grown bioenergy and economic benefits generated.

As part of the feasibility assessment, an economic analysis of the different procurement methods needs be carried out. There are various combinations of methods to transport and process the feedstock. One such method is to fell and bunch the biomass, skid it to roadside as full trees, crush it at roadside and transport it on a chip truck to the power generating station. The objective of this paper is to utilize a standard costing model to perform a cost analysis on a Full-Tree to Roadside, Roadside Crusher to Mill (FTR-RCM) System, as opposed to using actual costs. This system was used to harvest a wildfire burnt area of the Hogarth Plantations near Thunder Bay, Ontario. The total cost of harvesting, procurement and transportation is also analyzed as a function of fuel price and hauling distance.

Section 2 deals with theoretical models used for cost estimation, and volume, mass, and energy estimation of the forest biomass feedstock from a wildfire burnt area using the FTR-RCM system. Section 3 describes the methodology used to collect data for use in the theoretical models. Section 4 presents the results and section 5 concludes with policy implications for biomass power generation in northwestern Ontario.

2. Theoretical Model

2.1 Cost Estimation

The supply costs of the crushed material consist of harvesting costs and hauling costs. The harvesting cost is the operating cost of the machines and equipment and was calculated according to (Pulkki 2001) as detailed below:

$$C_o = \frac{C_c}{SMH/year} + C_e \times PMH/year + C_l \times SMH/year + C_i + C_r \qquad (1)$$

Where, C_o is the annual operating cost, C_c is the annual capital cost, C_e is energy, oil and lubricant cost in $/ Productive Machine Hours (PMH), C_l is operator cost including all employment expenses in $/ Scheduled Machine Hours (SMH), C_i is the annual insurance and licence cost, and C_r is the annual repair and maintenance cost. SMH per year is defined as the number of scheduled machine hours per year, whereas PMH per year is the product of SMH per year and the percentage of machine utilization. C_c and C_i constitute fixed costs and C_e , C_l , and C_r constitute variable costs. These costs are calculated as:

$$C_c = (P - PSV) \times \left[\frac{i}{1 - \frac{1}{(1+i)^T}} \right] \quad (2)$$

Where, P is the purchase price of the machine, PSV is its present salvage value, i is the rate of interest, and T is the expected useful life of the machine.

$$C_i = P \times i_c + L_c \quad (3)$$

Where, i_c is the percentage rate for insurance of purchase price and L_c is the annual licence cost.

$$C_e = (F \times F_c) + (O \times O_c) + (H \times H_c) \quad (4)$$

Where, F is the fuel consumption, F_c is the fuel cost, O is the oil consumption, O_c is the oil cost, H is the hydraulic oil consumption, and H_c is the hydraulic oil cost.

$$C_l = w \times n \quad (5)$$

Where, w is the operator wage including fringe benefits and n is the number of operators.

$$C_r = P \times r \quad (6)$$

Where, r is the percentage of purchase price for repairs and maintenance.

The transportation cost is the amount involved in hauling the crushed chips from roadside to the mill in trucks, and is expressed as:

$$C_t = \frac{R \times (2T_d + T_w)}{W} \quad (7)$$

Where, C_t is the transportation cost in $ per tonne, R is the hourly rate of transportation, T_d is the time taken for hauling the material from roadside to mill, and T_w is the waiting time for loading, unloading and other unavoidable delays, and W is the weight in tonnes per load. The equation assumes the driving time empty is equivalent to the driving time loaded.

2.2 Volume, Mass, and Energy Estimation

The forest biomass from the plantation was divided into three components - stem, branches and foliage - and volume, mass and energy of each component was estimated. The volumes of the stems for each of the three species - red pine (Pr), jack pine (Pj) and poplar (Po) - were estimated using standard volume tables (Honers 1967). The stem volume of each species was converted into mass using their standard densities at 35% moisture content. The crown (branches and needles) mass of jack pine was estimated using the following equations (Green and Grigal 1978):

$$M_b = 0.0094 \times D^{2.493} \qquad (8)$$

$$M_n = 0.0471 \times D^{1.664} \qquad (9)$$

Where, M_b is the mass of branches in kg, M_n is the mass of needles in kg, and D is the diameter of the tree at breast height in cm. The mass of branches of red pine and poplar was estimated using the equations given by Young et al. (1980) as follows:

$$M_b = 0.0098 \times D^{2.5011} \text{ for red pine} \qquad (10)$$

$$M_b = 0.011 \times D^{2.0766} \text{ for poplar} \qquad (11)$$

The mass of needles of red pine was estimated using the following equation (Perala and Alban 1994):

$$M_n = 0.0007 \times D^{3.1222} \qquad (12)$$

The energy content of each component of the forest biomass was estimated by using the FERIC energy calculator.

3. Methodology

The study was conducted in the Hogarth Plantations, located to the southwest of the city of Thunder Bay, Ontario. The plantation is owned and managed by the Faculty of Forestry and the Forest Environment of Lakehead University and covers an area of 44 hectares. Major species found in the area include red pine, jack pine and poplar. A devastating fire engulfed an area of about 15.6 hectares in this plantation on April 29, 2007. The Ontario Ministry of Natural Resources (OMNR) attributed the cause of fire to a smoldering slash pile that was burnt in the previous year. About 72% of the burnt area was a 35-year-old mixedwood stand and the rest was part of a 60-year-old red pine stand. The Lakehead University signed a contract with Abitibi-Bowater Inc., to harvest the burnt 35-year-old mixedwood stand (about 11.2 ha) and utilize the crushed forest residue as fuel for electricity and steam generation. The Abitibi-Bowater pulp and paper mill is located at a distance of about 7 km from the plantation.

Aerial photographs were taken to facilitate an assessment of the intensity of fire. Fig. 1 shows the burnt area delineated on one of these aerial photographs. The intensity of the fire ranged from low to high, from ground fire to crown fire at various locations of the stand. An inventory of the post fire stand was conducted to estimate the mass of potential hog fuel available on the site, by surveying five circular plots of radius of 11.28m (each having an area of 400 m^2) for species, diameter at breast height, and average tree height.

The site was harvested using a Madill 2250B feller buncher and Caterpillar 525 wheeled skidder. A Caterpillar 325 DL with loading boom was used to feed the material into a Pacific Peterson HC 5400 grinder at roadside. The grinder was equipped with a rotor 160 cm in width, 105 cm in diameter and with 28 fixed hammers having two sided replaceable cutting bits. The

575 hp grinder had an output capacity of 86 metric tonnes per hour. The 150 cm x 100 cm feed throat of the grinder was continuously fed by a chain conveyer and the crushed material was discharged at a height of 4.42m by a 146cm wide conveyer belt. The crushed material was directly loaded into chip vans by the grinder and hauled to the Abitibi-Bowater mill. The weight of each load was recorded and a time study was performed on the grinder to determine the time to fill each van. The harvesting and transportation costs were estimated using the equations (1) and (7) developed in section 2.

Fig 1. Aerial photograph showing 11.2 ha study area delineated.

4. Results and Discussion

The volume and mass of each of the three components of forest biomass are estimated using equations (8) to (12). The results of estimation are illustrated in Table 1. The results indicate that red pine had the highest volume and mass for each of the three components. It could be due to the dominance of species in the Hogarth Plantations. However, pure patches of these species are required to make a comparison of available biomass from stands of these species. The total biomass obtained from 11.2 ha salvage area was estimated to be about 1,695 green tonnes (Gt) with 35% moisture content, the long interval between wildfire and harvest led to such low moisture content. The estimation was very close to the yielded value of 1696.3 Gt, recorded at the mill during the study. Therefore, the model used to assess the biomass is very accurate and can be used to predict the availability of biomass from wildfire burnt areas.

Table 1. Volume and mass estimates for the wildfire burnt area in the Hogarth Plantations.

Source	Species	Volume per ha (m^3/ha)	Volume (m^3)	Mass per ha (Gt/ha)	Mass (Gt)
Stem	Pr	90	1,013	67	745
	Pj	62	698	48	533
	Po	25	269	16	179
Branches	Pr	12	133	9	96
	Pj	8	87	6	63
	Po	1	13	1	9
Foliage	Pr	5	58	4	42
	Pj	4	39	3	28
	Po	0	0	0	0
Total			2,310		1,695

The energy estimates, using FERIC energy calculator, for each species in the wildfire burnt area is shown in Table 2. Results of the energy estimate show that red pine provides the highest energy yield per ha. The total energy yield from the 11.2 ha burnt area was estimated to be 22,100 GJ. Using the total biomass available from the plantation, it is estimated that 13 GJ of energy was recovered per green tonne of biomass.

The harvesting and processing costs of the wildfire burnt area at the Hogarth plantation were estimated using the equations (1) to (6). Standard costs used at the Faculty for the feller buncher, grapple skidder and loader were used (See Appendix). The costs for the Pacific Peterson HC5400 grinder were obtained from the dealer. The calculated fixed costs, variable costs, total costs and costs per tonne for each machine are presented in Table 3. It was found that out of the total harvesting and processing cost of $16.64/Gt only 23% was attributable to the grinder. A similar study by Desrochers (1998) using a smaller grinder (Maxigrind 425) found the grinding cost to be over 40% of the $20.63/ODt for harvesting and processing. A lower percentage of the grinder cost is due to the more efficient grinder with a larger engine having greater output per unit time. Moreover, the Maxigrind was not equipped with a conveyer belt to self load the material into the chip trucks. The self loading conveyer belt reduced the grinder's running time.

Table 2. Energy estimate of available biomass from burnt area in Hogarth plantation.

Source	Species	Energy per ha (GJ/ha)	Energy (GJ)
Stem	Pr	902	10,097
	Pj	556	6,226
	Po	221	2,480
Braches	Pr	119	1,331
	Pj	78	868
	Po	10	116
Foliage	Pr	53	590
	Pj	35	392
	Po	0	0
Total			22,100

Table 3. Operating Costs for harvesting and processing at Hogarth Plantations.

Operating Costs		**Feller Buncher**	**Grapple Skidder**	**Loader**	**Grinder**
Fixed Costs	C_c($)	116,324.24	85,615.67	113,950.27	130,568.02
	$/SMH	30.04	22.11	29.43	33.72
	Insurance ($)	15,680.00	14,482.40	15,360.00	17,600.00
Variable Costs	C_e ($/PMH)	26.60	21.60	16.60	76.60
	C_r($)	114,800.00	73,750.00	86,400.00	90,000.00
	C_l($)	31.35	31.35	31.35	0.00
Total Cost	C_o($)	335,290.04	24,4792.88	270,622.12	487,305.96
	Hourly operating cost ($/hour)	86.59	63.22	69.89	125.85
Production	Volume (m^3/SMH)	22.10	22.80	25.01	45.28
	Volume (m^3/PMH)	26.00	27.14	29.77	53.90
	Mass (Tonnes /SMH)	16.29	16.81	18.44	33.38
Cost per green tonne	$/Gt	5.31	3.76	3.79	3.77
Total Cost, $/Gt					16.64

The transportation costs were estimated using equation (7). The hauling distance consists of about 2 km of tertiary road and 5 km of paved road. The waiting time, which includes loading, unloading and unavoidable delays in the queue were determined using time studies during the operation. The results of estimation are presented in Table 4. The transportation cost from the study was found to be $7.01/Gt.

Table 4. Transportation cost of material from site to mill.

		Distance (km)	Speed (km/hr)	Time (hr)
Traveling both ways	Tertiary Road	4	20	0.20
	Paved Road	10	50	0.20
Waiting				2.15
Total time				2.55
Cost per hour = $ 80 per hour Cost per load = $ 204 per load Green tonnes per load = 29.09 Transportation cost = $ 7.01 per tonne				

Therefore, the total cost of harvesting, processing and hauling forest biomass from the wildfire burnt area to the mill was $23.65/Gt ($16.64/Gt for harvesting and $7.01/Gt for hauling). Assuming an energy content of about 13GJ per tonne in the forest biomass as found above, the total cost translates to approximately $1.82/GJ or $0.007/kWh of fuel. However, it must be noted that this cost excludes the cost of floating the equipment to the site, general administration cost, road construction cost, stumpage and other miscellaneous planning and corporate overhead costs.

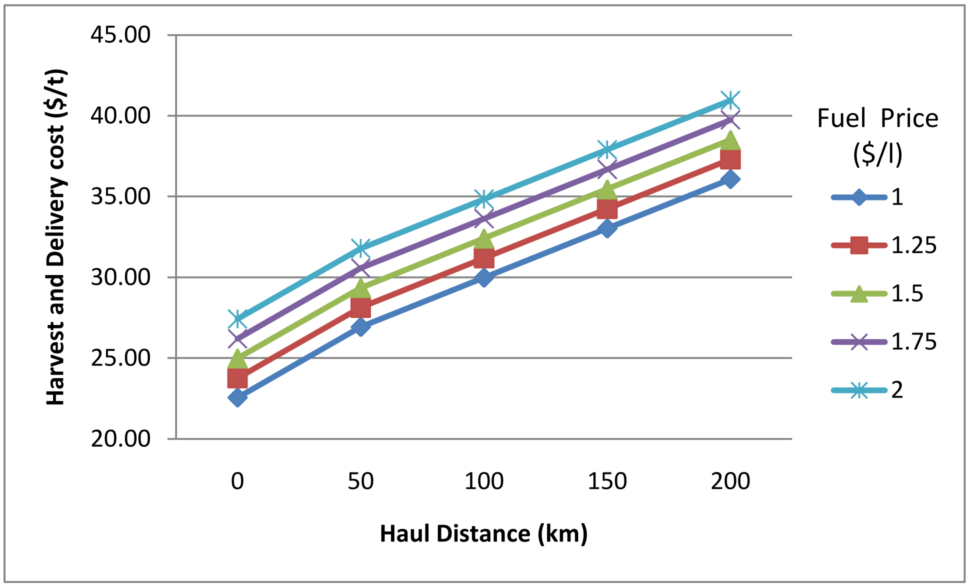

Fig. 2. Trend of harvest and delivery cost as a function of distance and gas price.

As is evident from the theoretical model, the two most important variables that keep changing frequently are cost of fuel and the hauling distance. The cost of fuel has been rising in the international market and is expected to rise further. A cost analysis of harvesting, processing and transportation costs of forest biomass from harvesting site to mill was done for increasing fuel prices and hauling distances (Fig. 2). The analysis assumes there is 5 km of tertiary road with an average speed of 20 km/hr, 5 km of primary road with an average speed of 50 km/hr and the remaining distance is highway with an average speed of 90 km/h. It is found from the graphical display that an increase in 1 km of hauling distance adds $0.07/t and an increase of $0.01 in fuel price adds $0.05/t to the total cost. This cost analysis can be used to determine the break-even point for profitability of a particular operation.

4. Conclusion

The cost for salvaging forest biomass from a wildfire burnt area using a Full-Tree to Roadside, Roadside Crusher system was analyzed. The cost model is applied to assess the total cost of harvesting, processing and transportation of salvaged forest biomass from a 11.2 ha wildfire burnt area in the Hogarth Plantations near Thunder Bay. It is found that the FTR-RCM system is a feasible and cost effective method of processing and transporting salvaged fire-killed wood biomass. However, the total cost depends on yield from the site and hauling distance to the power generating station. Since the distance between the site and mill was small in the present study, the total costs seems to be relatively low. To accurately assess the most efficient system, the cost model needs to be applied to different harvesting systems at different locations.

The available biomass could be accurately estimated in this study as the area covered was small. However, on operations involving larger areas, the estimates will be less precise. The change in total cost with changing fuel prices and haulage distance was also estimated and it was found that the total cost is very sensitive to changes in both variables. The cost of procurement can rise rapidly with a slight increase in any of these two factors. More in-depth studies need to be conducted to identify the inefficiencies of operations for salvage harvesting in burnt areas.

Currently, in northwestern Ontario, most payments for bioenergy material are based on green mass, which does not accurately reflect the energy content of the biomass. There is a need for a shift towards payment based on its energy value. Since the output of the product is measured on its energy value, the biomass also needs to be valued for its energy content to maintain a consistent supply chain. The most efficient use of available forest biomass for bioenergy production requires an accurate inventory for optimization purposes to implement the bioenergy policy of the Ontario Government. Therefore, local volume, mass and energy tables need to be developed.

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Short Rotation Forestry – Growth Productivity of Four Cutting Cycles

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Keywords: short-rotation forestry, cutting cycle, poplar clones, optimal biomass production

ABSTRACT

According to a study by the Austrian Energy Agency the demand of forest products for energy purposes increases year by year. In 2007 the demand will nearly touch the range of 20 mill solid m³ per year. To deliver according to the needs of the Austrian as well as the European forest industry, several researches in timber mobilization were conducted. An emerging alternative might be the timber - respectively biomass production in short-rotation plantations.

In 1987 a series of field trials were established in Austria to determine optimal biomass production on short-rotation poplar plantations. The objective was to gain the increment of five different poplar clones, planted at different spacings and harvested at several cutting cycles. Cutting dates were 1991, 1998, 2001 and 2006. The space layout was 0.8 x 0.8, 1.1 x 1.1, 1.4 x 1.4 to 1.7 x 1.7 m. For each combination a repetition was installed. Altogether 40 sample plots were applied. As the most favorable combination the poplar clone J 104 in a five year rotation at spacing of 1.4 x 1.4 m turned out. Overall sample plots and over all clones the average productivity was 9.86 odt/ha/year.

INTRODUCTION

The demand in Austria of forest products for energy purposes only, will pass the range of 20 mill solid m³ per year. This estimation was conducted by the Austrian Energy Agency for the year 2008. In the year 2006 the biggest solely timber driven CHP-plant in central Europe with its capacity of 66 MW (230.000 m³ solid) has been started to operate in Vienna. A lot of others, partly only marginal smaller have followed. Nemstothy (2007) identifies producers of biofuel of the second generation (biomass to liquid) as another prospective player on the market for timber and biomass. To deliver according to the needs of the Austrian as well as the European forest industry, several researches in timber mobilization were conducted. During the last decades, oil crisis, agricultural surpluses and global climate change has enhanced the interest in short-rotation forestry (SRF) (Vande Walle et al., 2007).
The STATISTIK AUSTRIA (2006) disclosed an area of 1722 ha of short rotation forestry in the report of agricultural affairs. This part of surface shall be increased in the future in a significant manner. Therefore much work in research (all over the world) has already been done, determining the right species, the right cultivar, the right spacing, and the right rotation time for

its respective site and country respectively. Beside the limited transferability of international research results on a national or even sub national level, most of the studies just cover one or two cutting cycles with a total duration of not more than ten years. The Austrian regulatory framework for short rotation forestry determines a life time of thirty years. In order to get constant information over such a period, long term test are necessary.

In Austria in 1987 a series of field trials were established, to determine the optimal biomass production on short-rotation poplar plantations. The aims of these field trials were to investigate the increment of five different poplar clones, at different spacings and at different cutting cycles for Austrian conditions. A particular focus was on results which were provided over the so far 20 year lasting testing period, in specific the change in productivity according to the sequence of the rotations.

MATERIAL AND METHOD

The timber and wood chip production by short rotation forestry is a special branch of the agricultural crop production and can be considered as a further development of the low forest management of former and also present times. Sun loving, fast growing deciduous tree like poplar, willow and robinia are the favorite species in Austria (Liebhard, 2007). According the Austrian law short rotation forestry has to be applied as such at the government agency. The maximum lifetime of a SRF is limited with 30 years. After this period the stools have to be removed (uprooting) otherwise former arable land would (turn into) become forest land.

In 1987 an accurate field trial has been designed in Ritzlhof. Ritzlhof is situated in the basin of Linz with its global position of 48° 18′ 11″ N, 14° 17′ 26″ E and an altitude of 335 meters above sea level. Over the last thirty years mean temperature and mean precipitation per year amounts in 8.8° C and 754 mm respectively (Linz, 2008). The soil can be described as periodically wet, primarily wet phases with a moderate storage capacity. A surface water gley has been identified as soil type. The soil can be characterized as arable land of average kind and quality.

Five different poplar clones were planted at spacings of 0.8 m x 0.8 m, 1.1 m x 1.1 m, 1.4 m x 1.4 m, and 1.7 m x 1.7 m. For each combination a repetition was installed. Altogether 40 lots were applied. Each lot consists of a peripheral and a core zone (Figure 1). The peripheral zone consists of two rows of poplar which were planted around the core zone in order to avoid fringe effects. Due to the different spacings the core zones of the lots varies in size between 71.4 m² and 150.0 m². The total sample area was 1.2 ha (Figure 1).

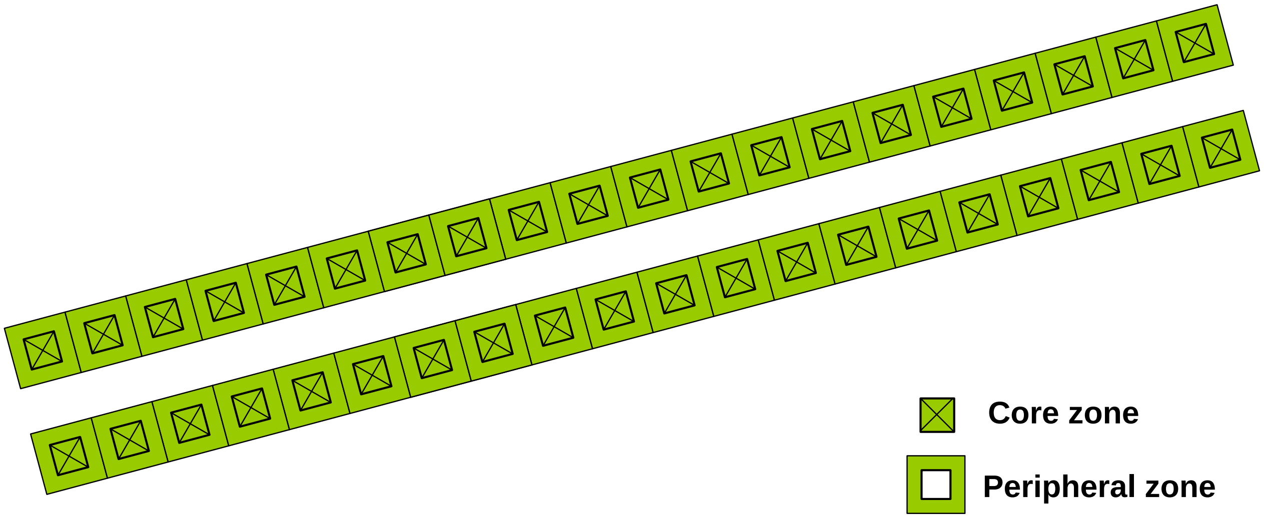

Figure 1: Design of the field trial

The five different clones were Muhle Lasen (ML), an intraspecific hybrid of Trichocarpa (Trichocarpa x Trichocarpa), I 130 an interspezific hybrid of populous nigra x populous deltoids, and three intersectional hybrids, two of them maximowicii x nigra (J 104, J 105) which are close related to the Max clones as well as maximowicii x P. x berolinensis (Oxford).

In 1990/91 the first harvesting operation took place. After seven years (1997/98), four years (2001/02) and five years (2006/2007) respectively, rotation number two, three and four followed. Right before the harvesting, the clones from the peripheral zone were removed in advance. Afterwards the clones of each lot in the core zone were cut by chainsaw and chipped onto a trailer. The weight of the loaded and unloaded trailer was leading to the weight of the cargo. By a heating cabinet two wood chip samples for each lot were dehumified at 105°C until equilibrium. In consideration of oven dry mass, lot size and rotation time the average annual increment of each clone per hectare has been derived.

RESULTS

The first harvesting operation of the poplar clones took place in the year 1990. Then only a few lots were cut. Between 1991 and 1993 the remaining lots were harvested. From Winter 1997/98 on, at each rotation the total field was cut at the same time. Due to this primarily inconsistent use the results of this period are only documented in a reduced style in here.

The average yield of the rotations 1997/98, 2001/02, and 2006/07 over all clones and spacings was 9.86 odt/ha/year. The clones J 104 and Oxford were most productive. Both have achieved an average yield of about 10.7 odt/ha/year. The clones J 105 and ML were nearly in touch with a productivity of 10.0 odt/ha/year. Only the clone I 130 performed with a yield of 8.0 odt/ha/year below average (Figure 2).

Regarding spacings overall clones the results were roughly identical. Figure 3 represents the average values which vary between 9.8 and 9.9 odt/ha/year. By a detail examination of the

combination of clone and spacing, clone J 104 at a spacing of 1.4 m x 1.4 m turns out as most productive (~12,0 odt/ha/year). More than 11.0 odt/ha/year have still achieved the clone J 104 at a spacing of 1.1 m and the clone Oxford at spacings of 0.8 m and 1.7 m each squared.
On the other hand the combination of clone I 130 at a spacing of 1.4 m x 1.4 m emerged as worst combination (6.0 odt/ha/year (Figure 2)).

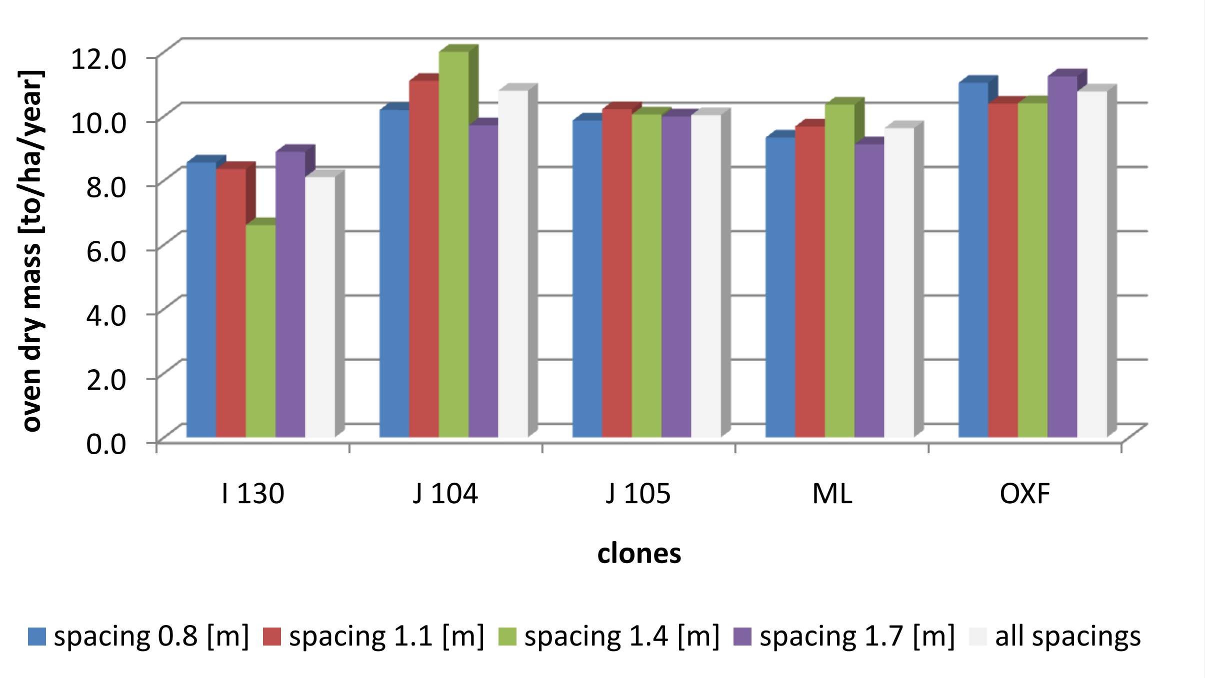

Figure 2: Average yields in oven dry tones (odt) of different clones at different spacings of three rotations (1997/98, 2001/02 & 2006/07)

The Comparison of the different results provided by the single lots and their appropriate repetitions showed a high variability in yield. The results of the clone I 130 between the two different lots at the same spacing of 1.4 m x 1.4 m at the rotation 1997/98 for example vary up to 4 odt/ha/year (Figure 4). In consideration of different rotations the results varied even more. This picture was not only shown by the clone I 130, this variability in yield was also offered by all other clones.

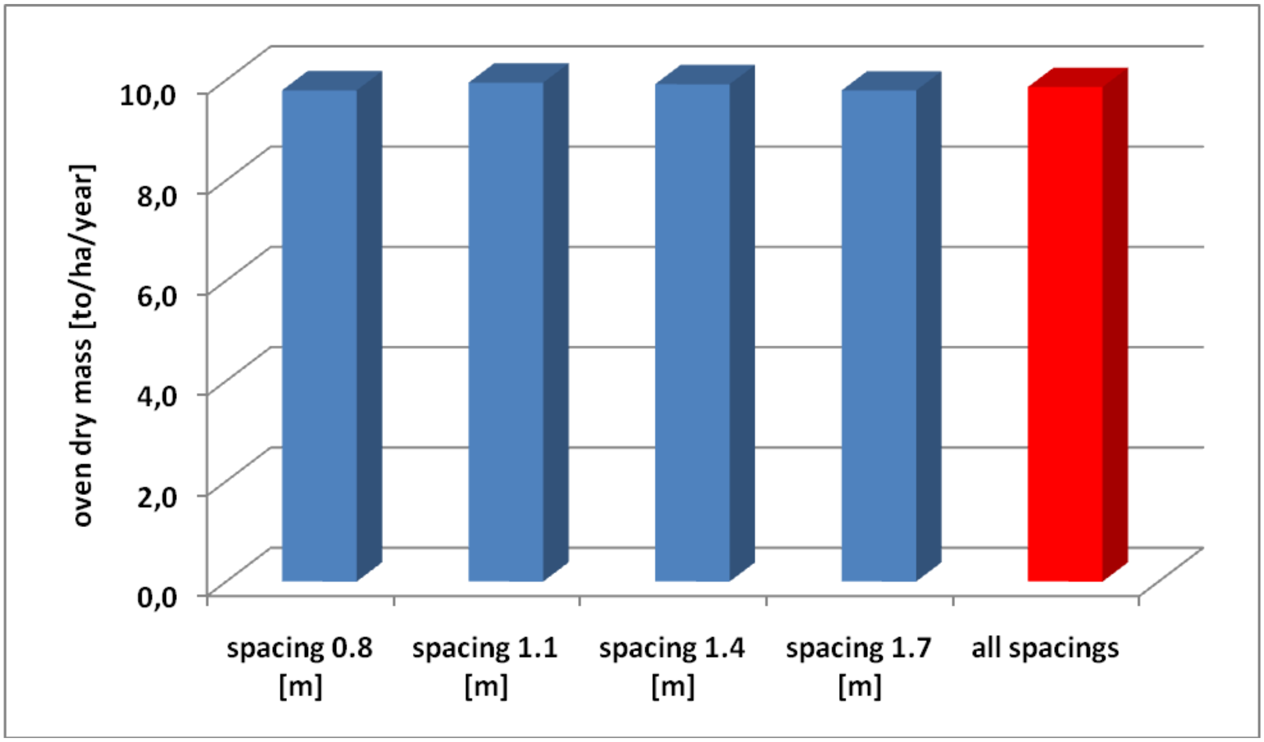

Figure 3: Average yields in oven dry tones (odt) over all clones at different spacings of three rotations (1997/98, 2001/02 & 2006/07)

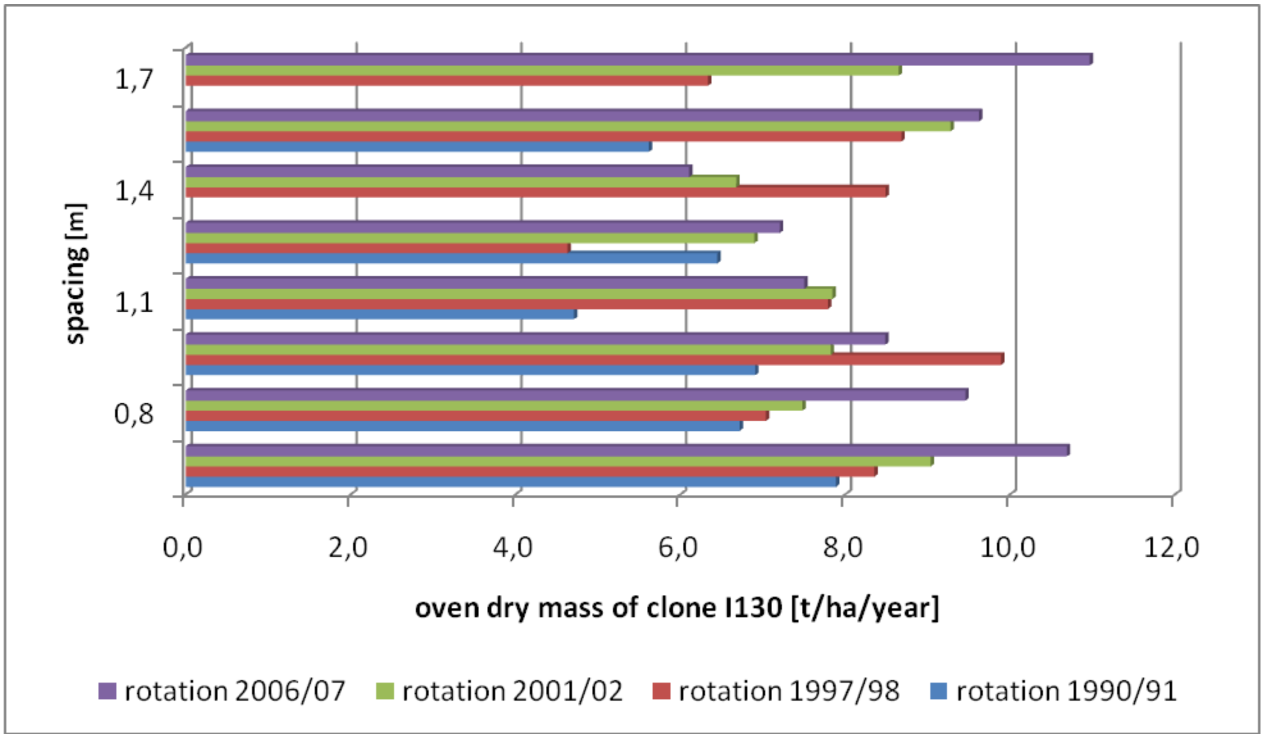

Figure 4: Yields of the clone I 130 at different spacings at different rotations

The first rotation in 1990 and 1991 respectively, provided results between 4.6 und 14.1 odt/ha/year. Over the 30 lots in average almost 8 odt/ha/year was harvested (Figure 5). Only 2 sites exceed the level of 10 odt/ha/year. At the second rotation in the Winter 1997/98 the average yield has increased to 9.6 odt/ha/year. Seventeen of 40 sites have passed the level of 10.0 odt/ha/year. Seven sites have even passed the level of 11.0 odt/ha/year. Another rotation later the average growth remained more or less at the same level as in 1997/98 (9.6 odt/ha/year). Seven sites had a yield of less than 8.0 odt/ha/year, 15 sites exceeded the 10.0 odt level. The so far last rotation took place in winter 2006/2007. The average increment was 10.3 odt/ha/year. Twent five sites had more than 10.0 dt/ha/year. Seven of fourty sites exceeded the 12.0 odt level.

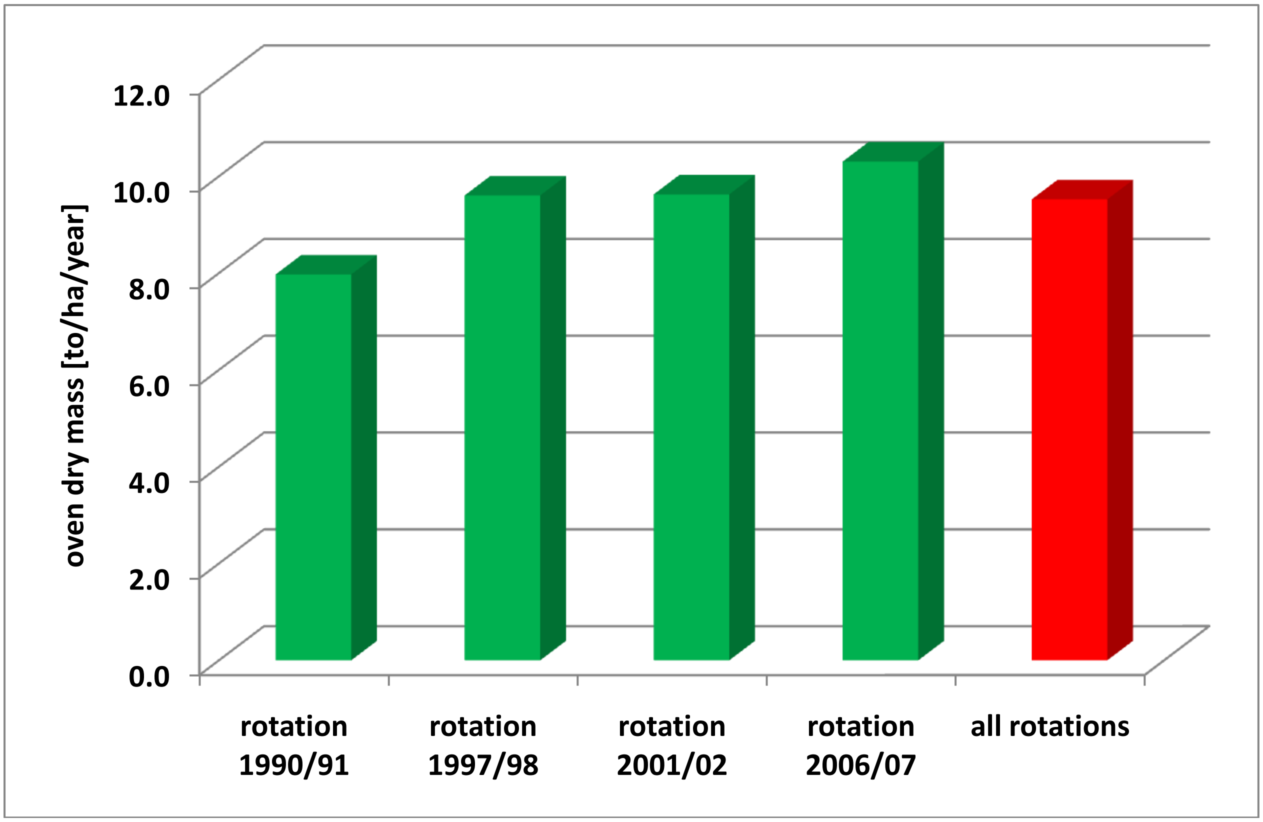

Figure 5: Average yields of different rotations over all clones and all spacings

DISCUSSION

I 130 (Nigra & Deltoides) was the least performing clone with an average productivity of 8.0 odt/ha/year over a period of three rotations. For hybrids of Nigra & Deltoides (Gaver, Gibecq and Primo) Laureysens et al. (2005) reports under suboptimal soil conditions and during a second, three year lasting turnover productivities of 7.1, 6.0 and 3.0 odt/ha/year respectively. As a possible reason Laureysens et al. (2005) mentioned the poor rooting capacity of Populus Deltoides.

For Fritzi Pauley and Trichobel (Trichocarpa & Trichocarpa) which are close related to Muhle Larsen (ML) the yields in her study for each clone were 8.2 odt/ha/year. Hofmann-Schielle et al. (1999) achieved at fertilized and non fertilized sites for ML in a first rotation (5 years) 3.2-6.0 and 3.8-7.1 odt/ha/year respectively, in a second rotation (5 years) 6.8-12.4 and 6.1-13.6

odt/ha/year respectively. In the present study non fertilized sites with Muhle Larsen achieved 9.9 odt/ha/year over a period of three rotations.
Scholz & Ellerbrock (2002) investigated growth production i.e. of Clone J 105 on sandy soil in two year rotation cycles over a period of six years and got similar results to this study (9.86 odt/ha/year over a period of three cutting cycles). The annual growth per ha was about 9.2, 11.0 and 10.0 odt in respect to the sequence of the rotation.
Productivity differences related to spacing were found to be minor (Strong & Hansen, 1993). In this study the results regarding spacing overall clones vary merely between 9.8 and 9.9 odt/ha/year.
Proe et al. (2002) reports 14.4 and 11.2 odt/ha/year for "Balsam Spire" hybrid poplar in a five year rotation period according to spacing of 1.0 m and 1.5 m.
Due to nowadays applied fully mechanized harvesting systems like e.g. Claas Jaguar, spacing and rotation time has to be fitted to the cutting capacity of the machines and might not gain in importance anyway.
Most medium-term planning for power generation assumes that crop yields in the first rotation will be significantly lower than in subsequent cycles. This is a reasonable assumption, based on plant's natural emphasis on root growth during early development (Mitchell et al., 1999). In this study the average yield had his maximum at the fourth rotation (10.3 odt/ha/year).

In the present study but also in other studies the majority of crop yield data are derived from intensively managed, small experimental lots and plots (Mitchell et al. (1999). The validity of exploratoring these experimental yields to field scale might lead to an overestimation and shall be considered.

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A Comparison of Hardwood Log Bucking Practices in West Virginia

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Abstract

An assessment of central Appalachian hardwood log bucking was conducted on six sites across West Virginia in order to analyze bucking practices in the field. Data were collected from crews using chainsaw felling and cable skidding or feller-buncher and grapple skidder system. A total of 300 stems were measured in the field including mostly red oak (*Quercus spp.*), yellow-poplar (*Liriodendron tulipifera*), and black cherry (*Prunus serotina*). Diameter and shape of each stem were recorded at four foot increments using a reference line and equipment to collect data at two degrees perpendicular to each other (0° and 90°) along the stem, together with defect type, size, and location. Number of logs bucked per stem, total log volume and value, stem utilization, product type, and bucking sequences were analyzed among species, stem size, and bucker's experience. Average log volume ranged from 12.6 to 1275 BF. Sawlogs were bucked as the first log 63.3% of the time followed by peeler logs at 31%. Sawlogs and peeler logs were bucked at a high percentage until the fifth and sixth logs from a stem. Species, tree stem dimension, defects, and bucker's experience all significantly affected log bucking and merchandising practices in the region.

Introduction

Hardwood log bucking is one of the most important procedures when recovering value from previously harvested trees. When determining log lengths several considerations must be taken, including: species, diameter, stem quality, mill specifications, and prices. A stem can be cut up into logs in numerous ways and each set of logs will yield a different financial return based upon volume and value of the products created (Wang et al. 2007). However, there is, in many cases one unique bucking pattern that yields the maximum value (Marshall et al. 2006), and this pattern is dependent upon these variables.

Bucking optimization could be optimized at stem, stand, or forest levels Uusitalo (2006). At the stem level, bucking optimization problem is generally formulated using mathematical programming, such as linear programming, dynamic programming, and network analysis (Smith and Harrell 1961, Pnevmaticos and Mann 1972, Nasberg 1985, Sessions 1988). Accordingly, computer programs have been developed to optimize log bucking from a tree stem. A popular program being tested in the region, *HW-BUCK*, was primarily developed for optimal bucking northern hardwoods (Pickens et al. 1992, 1993). This program selects the optimal sequence of bucking for each stem, and optimization is a process whereby all possible combinations of logs and cull sections are evaluated (Haynes and Visser 2004). *HW-BUCK* and other computer programs are useful training tools for operators (Murphy et al. 2004) to gain experience, which would improve value recovery through hardwood log bucking process.

Past studies have shown that the value of a tree was reduced by 20 percent using manual bucking compared to what is normally realized with a sawbuck (Faaland and Briggs 1984). It has been shown that 5% to 26% of the potential value was, at that time, being lost due to sub-optimal bucking choices for bucking softwoods (Geerts and Twaddle 1985, Sessions et al. 1989, Twaddle and Goulding 1989). In hardwoods, improving bucking choices can result in a 39% to 55% increase (depending on the historical price set used) in the value of the logs produced from high quality hardwood stems (Pickens et al. 1992).

A log merchandising study assessed six logging sites of 148 trees in the Appalachian Region of Virginia and West Virginia (Haynes and Visser 2004). Specifically, they compared manual bucking with optimal bucking using HW-BUCK (Pickens et al. 1992). In total 510 logs were bucked and only 11 percent were cut accurately. They found that the optimum bucking was able to achieve a 21 percent increase in yield in comparison with manual bucking. Sawmills generally specify desired dimensions to loggers and base these dimensions on consumer demand. The log bucker must meet mill specifications, while also merchandising the log for the highest possible value. Prices and mill specifications can change on a daily basis depending on market demand. Therefore, it is necessary to evaluate log bucking practices in order to understand what factors drive the decision making process.

Methods and Materials

Six timber harvesting operations were investigated in north central West Virginia for this hardwood log bucking assessment. Equipment combinations and bucker experience varied among the different operations assessed (Table 1). The logging companies assessed in this study are representative of typical logging companies across the state. Felling was conducted with chainsaws on three of the sites and feller-bunchers on the other three. Extraction was done by using grapple and cable skidders, while saw bucks were utilized on each of the operations to conduct the log bucking.

Of the 300 trees measured during this assessment the majority were red oak (*Quercus rubra*) and yellow-poplar (*Liriodendron tulipifera*), but other species were included when necessary or available. Measurements taken prior to felling included species, diameter at breast height, and total height (Table 2). After felling each tree stem was brought into the landing and measurements were taken to assess the defects along the tree stem as well as diameters at four foot increments along the stem. Defects were measured for the entire length of the stem. Defect data included: type, location, and size (Table 2). Defect types are bark distortion, bulge, knot, split, stain, and hole. Defect data were collected in such a way to allow defects to be mapped to know exactly where they occurred along the tree stem.

Table 1. Equipment and buckers experience by site.

	Equipment				Bucker Experience (yrs)
Site	Felling	Skidding	Bucking	Loading	
1	Timbco	John Deere 648G Timberjack 460G Caterpillar 517	CTR Bucksaw Barko 395 ML	Barko 395 ML	14
2	Husqvarna 372 XP	John Deere 540B Case 650G	CTR Bucksaw Serco 200F	Serco 200F	18
3	Husqvarna 385XP	John Deere 648G	Barko 160D	Barko 160D	5
4	Timbco	John Deere 648G Timberjack 460G Caterpillar 517	CTR Bucksaw Barko 395 ML	Barko 395 ML	14
5	Husqvarna 372 XP	John Deere 540B Case 650G	CTR Bucksaw Serco 200F	Serco 200F	18
6	Timbco 445EXL	CAT525B Timberjack 460G	CTR Bucksaw Prentice 384	Prentice 384	23

Each log was measured after the bucking process was completed for the entire stem. Data collected during this phase included: number of logs bucked per stem, large-end diameter (LED), small-end diameter (SED), and length of each log. Once these data were entered into a database log volume was calculated for each log, as well as for each stem using board foot (BF) in Doyle log scale. Log value was then determined in a similar manner for each log and for each stem. Prices were based on the value at the time of the assessment and gathered from mills across the state according to log grade, species, and dimension.

Field bucking data were analyzed statistically. The number of logs processed per stem was also analyzed including product type through the bucking sequence.

Table 2. Statistics of tree stem data.

	N	Mean	Std. Dev.	Min.	Max.
Tree					
DBH (in)	300	17.9	3.7	10.5	35.3
Stem Length (ft)	300	56.4	13.3	24	95.1
THT (ft)	300	96.1	13.1	68	128
Defects					
Number of Defects (#)	300	8.0	4.3	0	27
Avg. Length (in)	289	5.7	3.1	2.6	38
Avg. Width (in)	289	5.4	3.0	2.3	48
Bucked Logs per Stem					
Number of Logs (#)	1124	3.8	1.0	1	6
Avg. LED (in)	1124	16.2	3.1	9.9	33.1
Avg. SED (in)	1124	13.7	2.8	8.4	29
Avg. Log Length (ft)	1124	13.6	2.6	8.1	20.7
Total Log Length (ft)	1124	50.2	14.4	16.2	92.3
Avg. Log Vol. (BF)	1124	91.2	87.8	12.6	1275.2
Total Log Vol. (BF)	1124	341.2	302.6	43.4	3825.5
Avg. Log Price	1124	20.3	20.4	2.9	293.3
Total Log Price	1124	75.5	69.9	8.9	879.9

The general linear model (GLM) was employed to determine interactions among the data and the effects that each variable had on log bucking. The generic GLM model for analyzing log bucking is expressed as:

$$B_{ijklmn} = \mu + SP_i + DBH_j + SL_k + ND_l + BE_m + DBH_j \times SL_k + DBH_j \times ND_l + \varepsilon_{ijklmn}$$

$$\begin{aligned} &i=1,2,3,4 \\ &j=1,2,3,4 \\ &k=1,2,3,4 \\ &l=1,2,3 \\ &m=1,2,3,4 \\ &n=1,2,\ldots.n \end{aligned} \tag{2}$$

Where B_{ijklmn} represents the n^{th} observation of variables affecting log bucking decisions; μ is the mean of each response variable; SP_i is the effect of the i^{th} species; DBH_j is the effect of the j^{th} average diameter at breast height (DBH); SL_k is the effect of the k^{th} average stem length; ND_l is the effect of the l^{th} average number of defects for each stem; BE_m is the effect of the m^{th} number of years for bucker's experience; ε_{ijklmn} is an error component that represents uncontrolled variability; and n is the number of observations within each treatment. Interactions among DBH and stem length, and DBH and number of defects were also considered in the model.

Results

Based on 300 trees measured the DBH ranged from 10.5-35.3 inches with an average of 17.9 inches (Table 2). Average total height of the tree stems was 96 feet, while the average stem length measured at the landing was 56.4 feet. The total number of defects ranged from 0-27 with an average of 8 defects on each stem. The dimensions for these defects varied greatly with average length of 5.7 inches and width of 5.4 inches (Table 2). The most frequently occurred defect was bark distortions followed by knots (Figure 1). A high percentage of knots were found on black cherry, possibly due to its value and the attempt to utilize as much of the stem as possible. Several of the defects occurred at a very low frequency. These defects were bulge, hole, stain, and splits. Figure 1 shows the percentage of defects as they occurred with the stems.

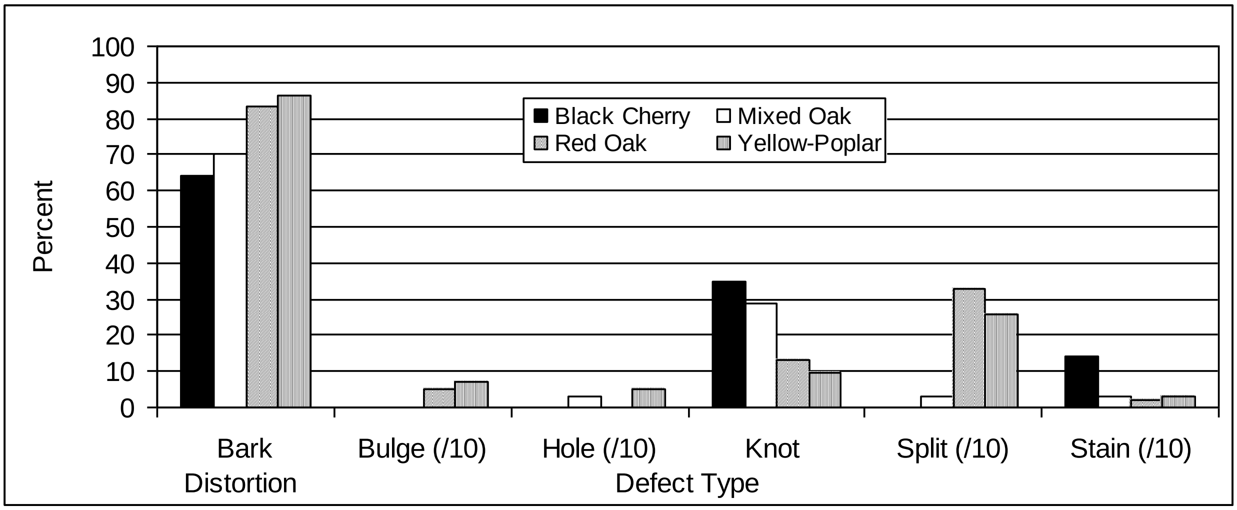

Figure 1. Percentage of defects by type and species.

A total of 1,124 merchantable log products were produced from the stems measured during this study. Three main products realized during this assessment were peeler logs (35%), sawlogs (45%), and pulpwood (12%) (Table 3). Average diameters of the sawlogs ranged from 9.5 to 39.8 inches on the large end and 7.7 to 29.9 inches on the small end of the log. The average diameters measured for peeler logs were 15.8 and 13.7 inches on the large and small end, respectively. Only one company produced logs for fence rails, which accounted for less than 6% of the total products surveyed. The need for rails seemed to outweigh the market for peeler logs for this company since they did not produce any peeler logs. Two of the companies produced only sawlogs and peeler logs from the standing trees.

Table 3. Means of measurements recorded by product class.

Product	N	Measurement	Mean	Std. Dev.	Min.	Max.
Peeler	390	LED	15.8	3.5	8.3	29
		SED	13.7	3	7.2	25.8
		Length	15.5	4	7.2	19.2
Sawlog	505	LED	17.9	4.8	9.5	39.8
		SED	15.2	3.3	7.7	29.9
		Length	11.6	2.7	6.2	16.8
Pulpwood	138	LED	12.7	2.9	6.9	23.2
		SED	9.4	5	4	16.2
		Length	15.5	6.2	5.3	23
Scraggwood	31	LED	13.6	2.7	7.9	18.6
		SED.	9.9	2.1	5.8	15.6
		Length	16.4	5.4	8	26
Rail	60	LED	16.1	3.2	10	25
		SED	14.4	3.1	7.9	22.8
		Length	10.2	1.7	8	14.3
Waste	17	LED	18.1	4.9	11.2	28.5
		SED	16.7	4.2	10.8	25
		Length	7.5	3.2	2.5	14.2

Log bucking is dependent on the species being utilized and the mill to which the logs will be trucked to. Sawlogs were produced from every species, while rails and peeler logs were only produced from yellow-poplar (Figure 2). Each species was used to produce pulpwood, but only the oak species were utilized for scraggwood. As expected, these results are typical for the region. The site assessed having a bucker with 23 years of experience did not produce any peeler logs, and this crew produced rails, scragg wood, and pulpwood. A well planned merchandising scheme was demonstrated by the log bucker to produce the most valuable products.

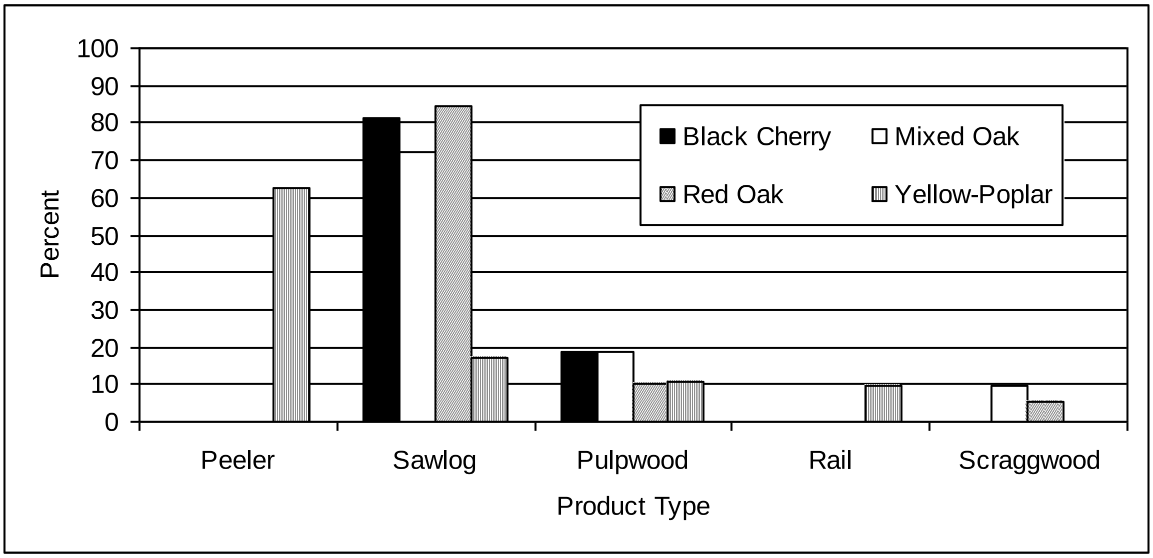

Figure 2. Product diversity based on species.

As many as six logs/products were bucked from some of the stems not including waste material (Table 4). Only 1% of the first cuts produced waste material from the stem and the other 99% were merchantable products. Pulpwood made up 70% of the sixth log to be produced with rails and scragg wood being produced as the sixth log 10% of each. Fence rails and peeler logs were only produced from yellow-poplar stems. Peeler logs were bucked as the first product 31% of the time and then increasing to 40.9% and 40.5% on the second and third log, respectively. Sawlogs showed a different trend with 63.3% of the logs being bucked first then decreasing to 52.3% and 40.1% on the second and third log, respectively. The majority of the pulpwood and scragg wood logs were produced from the third to the fifth log. Scraggwood logs were produced from the oak species and black cherry stems, while pulpwood was produced from each species assessed.

Table 4. Percentage of product type by bucking sequence.

Log Sequence	Peeler	Sawlog	Pulpwood	Rail	Scraggwood	Waste	Total Logs
1	31.0	63.3	0.3	4.0	0.3	1.0	300
2	40.9	52.3	0.0	4.4	1.3	1.0	298
3	40.5	40.1	8.4	5.1	4.0	1.8	274
4	30.6	24.0	29.0	7.7	6.6	2.2	183
5	10.5	6.6	71.1	7.9	2.6	1.3	76
6	0.0	0.0	70.0	10.0	10.0	10.0	10

Conclusions and Discussion

Stem dimension, species, log bucker experience and number of defects on a stem all had significant effects on merchandising of the tree stem. The process of bucking logs from whole tree stems requires the bucker to constantly examine grade, diameter, length, and prices. However, defects and shape also need to be accounted for when determining if a sawlog should be bucked or pulpwood should be the outcome. Also, on-site observation indicated that a product is sometimes determined based on the current or next load of logs to be sent out depending on how much of that product is available.

Bucking results did show that more peeler logs were bucked to be sold as 18 foot logs as opposed to 9 foot logs in this survey. The maximum length found for this specific product type was 19.2 feet, which is nearly a foot longer than actually necessary with trim allowance. This indicates that the extra length on this log could have been merchandized onto the next log with the potential to add value to the second log. Trim allowance must be accounted for in each log, but by exceeding the required allowance the log bucker missed the opportunity to properly merchandize the tree stem.

The majority of products bucked during this assessment were sawlogs, followed by peeler logs and pulpwood logs. This illustrates the market demand for certain products along with harvest proximity relative to product mills in the region. The small end diameter of sawlogs averaged 13.7 inches, which simply indicates that there is the possibility that the stems could have been merchandized for sawlogs further up the stem than it was actually done. However, defect constraints obviously limit the lengths and diameters of sawlogs during the bucking process.

Defects can play a major role in determining where cuts should be made to produce a log of high grade. It is crucial that the log buckers recognize defect size, location, and type in order to make better bucking or merchandising decisions. During field examination a high percentage of the defects were found to be bark distortions and knots. Some of these defects would be difficult to see from a bucking station. Thus, requiring the bucker to have a superior knowledge of defect identification and have the ability to recognize how to potentially place defects on the ends of logs where they will likely be trimmed off would be essential. It is also necessary for the bucker to determine when a section of the tree stem should be cut out, which helps to improve the grade of a log by eliminating defects, sweep, crook, and rot in the end of the log and sacrificing diameter and therefore volume.

It is necessary for the log bucker to remain current with the changing prices that coincide with log grades. This information allows the log bucker to properly merchandize the stem before making any cuts and thus maximizing yield from the entire tree stem. This is a crucial process for the logging company and requires a skilled employee to make quick decisions that can return either gains or losses.

Log bucking and merchandising assessments can help to understand the factors that drive certain bucking decisions. The use of automated log bucking programs as employed in harvesters is not yet feasible for timber harvesting in the region due to terrain and hardwood species. Thus, we investigated the common bucking practices being performed on six logging sites in West Virginia.

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Value Recovery and Product Sorting in the Southeastern United States: A Comparison of Modified and Tree-length Systems

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ABSTRACT

Some systems in the southeastern USA are starting to use harvesters to aid in product sorting and bucking. We compared value recovery and cost of a modified tree-length (MTL) logging system that measures product dimensions using a Waratah harvester to that of a tree-length (TL) system that estimates dimensions. One field test involved paired comparisons of residual timber value (delivered price – harvesting cost) per harvested acre on a series of three planted pine clearcuts. One half of each site was harvested with a TL crew and the other half with a MTL crew. We also developed a cost model to compare the cost of TL and MTL systems. A second field test measured individual stem value recovery of the two systems for 25 felled trees on each paired harvest site.

Although not statistically significant, MTL did recover slightly more residual timber value per acre than TL on three sites despite modeled logging costs that were $0.93 per ton higher. MTL also showed consistent, but not statistically significant, increases over percent cruised value compared to TL. The individual stem analysis using AVIS found MTL and TL to have similar value recoveries that ranged from 68% to 78% for MTL and 73% to 78% for TL.

INTRODUCTION

Some systems in the Southeast are starting to use harvesters to aid in product sorting and bucking at roadside. These otherwise tree-length (TL) operations produce bucked logs similar to a cut-to-length (CTL) operation and will be referred to in this discussion as modified tree-length (MTL) systems. Numerous studies have found that CTL systems recover more value at a lower additional sorting cost than tree-length systems, but most markets in the southeastern US demand tree-length products (Gingras 1996; Gingras and Soucy 1999). Other studies have shown that CTL systems in the Southeast can recover up to 90-94% of the optimum value of a harvested stand (Boston and Murphy 2003; Conradie et al. 2004). MTL systems may cost-effectively recover more value than TL systems in the southeastern US. This study used a paired harvest approach along with individual stem measurements to compare the value recovery of MTL and TL systems in the Southeastern US.

METHODS

Logging Contractors

The TL crew's equipment consisted of two grapple skidders, a John Deere 643G2 and a John Deere 643G3, a John Deere 843H feller-buncher, a Husky 235 knuckleboom loader, two chainsaws, and a delimbing gate. The MTL crew's equipment consisted of a John Deere 2054 shovel with a 622 Waratah harvester head operated as a processor on the landing, a John Deere 648G3 grapple skidder, a Tigercat 230B knuckleboom loader, and a Tigercat 724D feller-buncher with a 5500 felling head.

Study Sites

To conduct the paired comparisons on harvest tracts, we identified three tracts that our industry cooperator had scheduled for clearcut in 2007. Each tract was divided roughly in half to form two blocks of approximately equal acreage. TL or MTL were randomly assigned to each block. For this test we used the same TL crew and MTL crew for all replicates. All study sites were loblolly pine (*Pinus taeda* L.) plantations between 24 and 33 years of age located in central Georgia. Block size ranged from 43 to 67 acres.

Paired Harvests

Each tract was cruised with a 10 basal area factor prism by the industry cooperator. The cruise for each tract was re-worked for each block using the point data from each half. Timber prices were applied to cruised volumes per acre to obtain cruised value per acre. Cruised product values ($/acre) were compared on each crew's section and were found to be equivalent for all study sites with 95 percent confidence intervals.

Prices were determined by applying observed market price differentials to Timber Mart-South (TMS) delivered prices for 2007 Georgia averages (Harris et al. 2008). The residual timber value for each product class was calculated by subtracting harvesting cost from the delivered price. Harvested values were compared to pre-harvest cruise estimates to determine the percentage of pre-harvest cruise value actually harvested by each logger on each block. The percentage of cruised value harvested by each logger was compared with a t-test using SAS (SAS Institute Inc. 2002-2004). The number of loads and tons each system harvested of each product by block was recorded. After the harvests were complete, a paired t-test and Wilcoxon signed rank test in SAS were used to compare tons per acre harvested and average residual timber value per acre harvested by each system (SAS Institute Inc. 2002-2004). All products analyzed were pine, except for one hardwood pulpwood sort (Table 1).

Table 1. Mill specifications for harvested products, prices adjusted TMS 2007 GA Avg.

Product	Mill	Mill Specifications	Delivered $/ton	Stumpage TL ($/ton)	Stumpage MTL ($/ton)
Pole	A	7-8" top, 11" DBH	$76.82	$58.32	$57.39
ST1	B	Min 8" top in lengths of 25', 29', or 33' and greater	$57.00	$40.00	$39.07
ST Precut1	B	Min 8" top in lengths of 12'6" and 16'6" only	$57.00	$40.00	$39.07
ST2	C	Min 8" top, min 12" butt, min 25' length	$54.00	$37.00	$36.07
ST Precut2	C	Min 10" top, min 12" butt; length 12'6",14'6", or 16'6"	$57.00	$40.00	$39.07
CNS A	D	5.0" top, minimum length 29'	$35.00	$18.62	$17.69
CNS B	D	5.0" top, minimum length 21'	$33.00	$16.62	$15.69
CNS Precut1	D	6" top, 16'6" in length	$35.00	$18.62	$17.69
CNS	E	9" butt, 5" top, minimum length 29'	$38.00	$21.62	$20.69
CNS Precut2	E	16.5" length	$38.00	$21.62	$20.69
PSP	F	7-9" butt; 5" top; minimum length 25'	$30.27	$12.87	$11.94
PPW	G	3.0 " top, min length 20' TL, min length 12' DB**, max DOB 26"	$24.02	$6.62	$5.69
HPW	H	6.0-22.0" butt; 3" top; minimum length 21'	$23.62	$7.47	$6.54
Post	I	6-10" butt; 2.5-3" top; min 24' length		N/A	$4.16*

*Product market only available to MTL

**DB=double bunk

Cost Model

We adapted the Auburn Harvesting Analyzer to compare the harvesting cost per ton of MTL and TL systems using the machine rate method (Miyata 1980; Tufts et al. 1985). We assumed that both systems had the same basic equipment configuration including a feller-buncher, grapple skidder, and knuckleboom loader. Two key differences separated the systems: the MTL crew had a harvester to serve as a processor on the landing and the TL crew had two saw-hands to be consistent with the crew in the study.

Individual Stem Comparisons

Twenty-five stems were marked on each contractor's paired harvest block for a total of 150 trees. DBH was recorded on the standing trees. Each selected tree was felled at the time the block was harvested. A 100' tape was attached to the butt of each stem and the following measurements were taken after felling:

1) Large-end diameter (LED) over bark;
2) Diameter over bark at 10 ft. increments up the stem to a 2 in. top;
3) Quality factors such as sweep, knot size and number, and cankers/defects with their corresponding beginning and ending lengths from the large end; and
4) Total tree height, excluding stump.

After the felled trees were measured, they were processed and sorted into product categories. After processing by the logging crew, the product type and destination for all products were recorded as well as their corresponding actual small-end diameters (SED), LED, and lengths.

To determine the value recovery of each system we used AVIS (Assessment of Value by Individual Stems) optimization software (New Zealand Forest Research Institute 1995). Value recovery is the percentage of optimum value that the actual logger solution produces. AVIS has been used for research and industry purposes for many years (Geerts and Twaddle 1984; Boston and Murphy 2003; Conradie et al. 2004).

Our industry cooperator provided mill dimension and quality product specifications (Table 1). Prices were determined by applying observed price differentials to TMS timber prices for 2007 Georgia averages (Harris et al. 2008). These inputs, along with site considerations and stem data, were entered into AVIS to obtain the optimal solution for each stem by site. We also entered each contractor's bucking solution to compare the contractor's actual solution to the optimal solution. Measurements were taken in English units but were converted to metric units prior to entry into AVIS.

RESULTS AND DISCUSSION

Paired Harvests

The MTL system harvested significantly more tons per acre on all three tracts than the TL system (0.05<alpha<0.10) with the paired t-test (Table 2). The p-value of 0.25 reported by the Wilcoxon signed rank test is the best possible p-value for a sample size of three (Hollander and Wolfe 1999).

Table 2 . Volume per acre harvested by product.

	Volume per acre (tons)								
	Site A			Site B			Site C		
Product	TL	MTL	Diff*	TL	MTL	Diff	TL	MTL	Diff
PPole				0.6	2.6	2.0	4.2	12.0	7.8
PST	4.2	8.6	4.4	11.4	13.9	2.5	35.2	38.3	3.1
PST Precut							1.9	0.5	-1.5
PCNS	38.3	27.5	-10.9	24.3	16.7	-7.6	18.2	7.6	-10.6
PCNS Precut		3.5	3.5		2.0	2.0		3.9	3.9
PSP	2.0	0.4	-1.6	1.0		-1.0			
PPW	8.9	22.0	13.1	5.7	17.5	11.9	9.4	24.3	14.9
HPW	0.6	0.9	0.3		0.6	0.6		2.2	2.2
Total	54.1	62.8	8.8	43.0	53.4	10.4	68.9	88.8	19.8

*t p=0.065; SR p=0.250

**Because MTL did not have pole quota on Site A, pole volumes were combined with sawtimber volumes on Site A; likely some of the sawtimber volume produced by MTL would have been pole volume if MTL had pole quota.

Although the MTL system moved more tons per acre than the TL system, there was no significant difference in per acre value produced by the two systems. While not statistically significant, MTL did recover slightly more residual timber value per acre than TL on all sites despite $0.93 per ton higher logging costs. The higher residual timber value per acre for TL was offset by MTL recovering more tons per acre.

Unfortunately, the wood markets did not remain static during the course of the study. Harvest plans and commitments, as well as space and logistics concerns, caused the crews to harvest blocks from the same tract at different times. These uneven product quotas likely affected the results to some extent. MTL crew had no pole quota for three weeks on Site A, so pole volumes were combined with sawtimber volumes for the analysis. TL crew had no pole quota for one and a half weeks on Site C and produced fewer poles than MTL on this tract.

The product pine chip-n-saw (PCNS) was not restricted by the market at the time of the study, yet MTL consistently produced less PCNS value than TL on all tracts (Table 3). Alternatively, MTL produced more pine sawtimber (PST) value on all tracts than TL. One possible explanation is that the MTL crew upgraded wood that would usually be classified as PCNS to the PST or pole classifications because of the measurement capability of the harvester. For example, on Site A MTL produced $268 less of CNS per acre (11 tons less per acre) than TL but produced $173 more per acre of ST (4 tons more per acre). On the other hand, MTL produced $66 more per acre of pine pulpwood (PPW) (13 tons more per acre) than TL on Site A. Some PCNS could have been downgraded to PPW. Another explanation for the additional PPW is that it is PPW topwood from CNS precuts. MTL produced more PCNS precuts than TL on all tracts.

Table 3. Value per acres harvested by MTL and TL systems on all sites.

	Value per acre (US$)								
	Site A			Site B			Site C		
Product	TL	MTL	Diff	TL	MTL	Diff	TL	MTL	Diff
Pole				$33	$149	$116	$246	$688	$442
PST	$162	$336	$173	$439	$544	$105	$1,353	$1,462	$109
PST Precut							$77	$18	-$60
PCNS	$806	$538	-$268	$515	$329	-$186	$390	$146	-$244
PCNS Precut	$0	$62	$62	$0	$36	$36	$0	$70	$70
PSP	$26	$5	-$21	$13	$0	-$13	$0	$0	$0
PPW	$59	$125	$66	$38	$100	$62	$62	$138	$76
HPW	$4	$6	$1	$0	$4	$4	$0	$15	$15
Total	$1,057	$1,071	$14	$1,039	$1,162	$124	$2,129	$2,536	$407

*Because MTL did not have pole quota on Site A, pole volumes were combined with sawtimber volumes on Site A; likely some of the sawtimber volume produced by MTL would have been pole volume if MTL had pole quota.

When the harvested value was compared to the cruised value, there was no significant difference between the MTL and the TL system at alpha = 0.10 (Figure 1). The t-test did not detect a significant difference between the percent of cruised value recovered by MTL and TL at alpha=0.10; however, significant differences are very difficult to detect with small sample sizes. The sample size for each system is three observations. MTL showed consistent increases over percent cruised value compared to TL: 15% on Site A, 9% on Site B, and 15% on Site C. It is possible that with a larger sample size these increases would become statistically significant. Product breakdowns for the cruises were estimated by the cruisers based on tree size and obvious quality features. Errors in estimating the product breakdown volumes could have affected the comparison of harvested value to cruised value. If the cruises were not accurate then an increase in value from harvesting may be attributed to poor estimation in the woods prior to harvest, not value uplift potential of MTL or TL systems. In this study we assumed equivalent bias for each contractor's harvest block; therefore, we could make comparisons between the two systems.

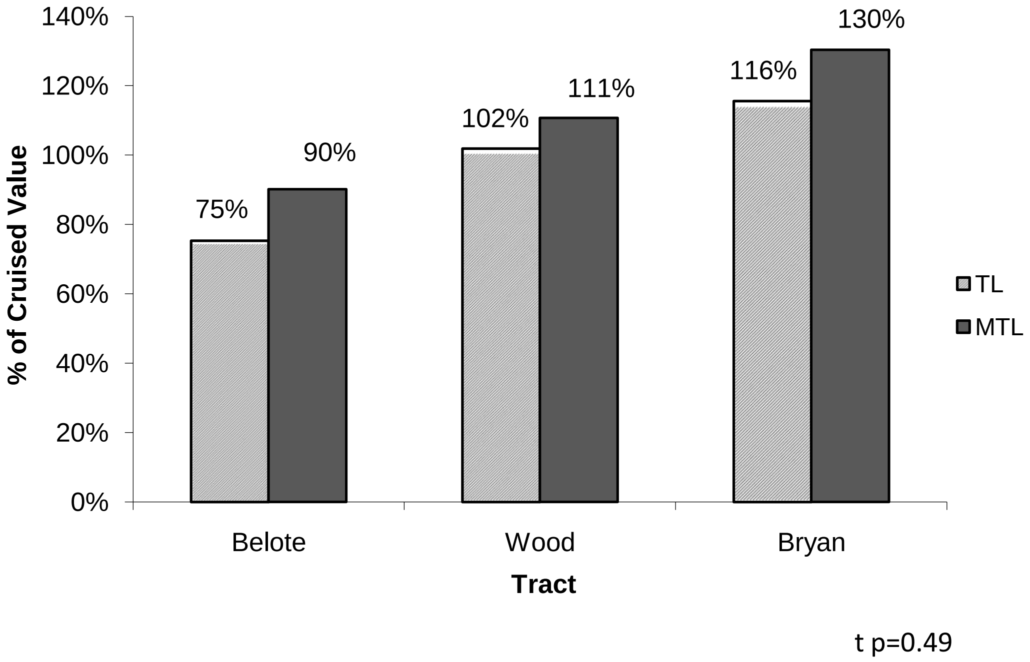

Figure 1. Percent of cruised value that each system recovered on each tract.

Cost Model

Our adaptation of the Auburn Harvesting Analyzer modeled the MTL system harvesting cost at $10.94/ton and the cut and haul cost at $15.74/ton. TL system harvesting cost was $10.01/ton and the cut and haul cost was $14.81/ton. Our model showed a cost difference of $0.93/ton.

Individual Stem Comparisons

TL recovered 78%, 73%, and 77% of optimum value compared to AVIS on Sites A, B, and C, respectively after downgrades for out-of-spec logs. Value losses of 26%, 11%, and 7% resulted from downgrades on Sites A, B, and C. MTL recovered 77%, 78%, and 68% of optimum value on those sites after downgrades for out-of-spec logs. Value losses of 9%, 10%, and 2% resulted from downgrades on Sites A, B, and C.

Value losses for both systems resulted from lower volumes of the highest value product (pole or ST) in the actual solution compared to optimal. Value losses from downgrades ranged from 2-10% in most cases although TL on Site A had the highest value loss of 26% from downgrades of 23 logs. TL had value recoveries of 60% or higher per stem while MTL had value recoveries that ranged from 30% to 100%. The extremely low value recoveries (<50%) were primarily from merchandizing CNS when the optimal solution made ST or poles. These low value recoveries likely reduced the mean value recovery per stem of MTL compared to TL.

The harvester operator of the MTL system did not use a bucking optimization model to aid his decision-making. Although researchers detected no effect of operating speed in the range of 430 to 610 cubic meters per day on value recovery in New Zealand, operators in a Swedish study indicated that they had difficulties seeing defects in logs at the current feeding speed of 4 m/s (Gellerstedt 2002; Murphy et al. 2005). Perhaps the operator in this study sacrificed value for production speed. The lowest value recovery of MTL on Site C of 68% was largely attributed to a failure to merchandize poles. MTL had recently acquired pole quota when they moved to Site C and the operator was somewhat hesitant to merchandize poles. Perhaps this shift in market demand had some effect on the operator’s ability to merchandize poles on that site.

CONCLUSIONS

The small sample size and uneven market conditions between MTL and TL crews were limitations to this study. Although not statistically significant, MTL did recover slightly more residual timber value per acre than TL on all sites despite estimated $0.93 per ton higher logging costs. MTL also showed consistent increases (not statistically significant) over percent cruised value compared to TL: 15% on Site A, 9% on Site B, and 15% on Site C. This gives encouraging evidence to suggest that MTL can recover more value than its system cost compared to TL under similar market conditions.

The individual stem analysis with AVIS showed MTL and TL to have similar value recoveries ranging from 68% to 78% for MTL and 73% to 78% for TL. The MTL harvester operator did not use a bucking optimization program to aid his decision-making. Future work could examine a MTL system that did utilize a bucking program to determine if the bucking program could improve value recovery. It appears there is room for value recovery improvement for these systems as they were below the 90% to 94% value recoveries reported for CTL systems in the southeastern US (Boston and Murphy 2003; Conradie et al. 2004).

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De-Coupling of Cut-to-Length Operations in Ohio

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ABSTRACT

The decoupling of the cut-to-length harvest systems in Ohio has proven itself to be a more efficient, lower cost and more productive means of timber harvesting and delivery compared to using the same equipment in a less efficient manner as before.
What have the benefits been to the company? They have realized a direct savings against wood costs of 15%. The ability to purchase wood stacked at the roadside has allowed the company to store more wood by utilizing the option for in-woods storage. Road maintenance costs have been reduced because the decoupled loading/trucking operation moves a large volume of wood per week from one road compared to previous system that would need 4 contractors maintaining 4 separate road systems. The delivered volumes of wood to the mill are more consistent throughout the year because they are using a high production loading/trucking system. How has the contractor benefited? The contractor has more working days in the year because he isn't affected by downtime of other equipment such as the trucks. Fixed costs are lower because of higher production per year per machine. Contractor has a competitive edge on other loggers because he is able to produce a product to the mill at the lowest cost.

The de-coupling of cut-to length operations in Ohio began in July of 2004. At that time we decided that we would begin this project with an open mind and with the understanding that if we could not realize a savings to our wood costs through de-coupling the operation then it would not be continued. We worked with a contractor who we had a long term working relationship with us and his only request was that "at the end of the day" it had to put more money in his pocket. This contractor had 2 CTL operations. The project began by establishing things through time studies as simple as how long does it take to load a truck with the forwarder compared to how long it took to put wood on the ground or how much wood can be placed in a given amount of space, roadside. By doing these types of studies we established the amount of time that the forwarder had to pick up more wood compared to loading trucks and what size area would be needed to store a given volume of wood along a road. Another part of our project was to look at all of the costs (fixed and variable) of the harvester and forwarder and with this we established the cost to operate each piece of equipment. The next step was to evaluate each sale that the contractor would cut and by using time studies we were able to establish production rates for the processor and forwarder. One variable which significantly impacts the harvester production was tree heights while the forwarders production is effected by forwarding distances. After all these variables are evaluated, then a rate per ton is established and paid to cut and place wood roadside. Within the first 6 months another CTL contractor was added to the mix and for the first 2 years these 3 CTL systems were involved in this project. During the first 2 years the original contractor who partnered with us took care of loading and trucking all of the wood produced by 3 operations. In March of 2006, we added another contractor who would do the loading of the wood. His investment was a Prentice 180E loader mounted on a "Big John" self-propelled carrier. The loading price was established and based on an annual delivery of 75,000 tons / year.

All of the trucking was done by 4 independent owner-operators. Trucking rates are established using 2 calculations. The first component being allocated to the fixed costs and the 2nd component being the fuel cost/load. The fuel cost is built using roundtrip miles to the mill divided by an average of 5 miles/gallon and multiplied by the current cost per gallon for diesel. A price per load is established by adding both calculations together. Each contract truck gets about 4 loads per day, 5 days / week and 50 weeks / year.

In December of 2006 we added a wireless scale link to one of the forwarder cranes in order to get accurate weights for wood as it is placed roadside. It is accurate to within 2-3% and we pay for that wood when it is placed roadside. A second wireless scale was purchased by the contractor in December of 2007. It has improvements which allow the scale to take a dynamic weight of each grapple bite of wood while it is being downloaded to the ground. The accuracy of this wireless scale has proven to be within 3% of the mill scales when the wood is delivered. The wireless scale was purchased from a Swedish company called Intermercato AB at an average cost of $ 12,000.00 US.

In April of 2007 we contracted with a CTL operator from Michigan to come and cut for 6 months and be in this system. In June of 2007 we contracted with his son to do the same. After 6 months his son relocated to Ohio and he is in the system to stay. His dad will be here for an undetermined amount of time, also.

At the end of 2007 the de-coupled system had delivered approx. 74,000(dry) tons (3,200 loads), maintained approx. 10,000 tons of stacked-wood inventory in the woods and returned a direct cost of wood savings of 15%. The benefits to our company over and above the wood cost savings have been to conserve mill inventory space through the in-woods storage option. We have lower costs associated with road maintenance because of trucking from one location at a time. In other words, the loading/trucking operation will move an equivalent volume of wood in one week that it would take 4 separate CTL operations to deliver in that same amount of time. Therefore, if we were hauling wood the conventional way we would be paying road maintenance costs on 4 logging roads. Contractors are more viable because they now have higher production per year, more working days available, and lower fixed costs due to higher production. The system is now fully de-coupled even to the extent that one contractor owns a forwarder but does forwarding for 2 harvesters. The other contractor only owns a harvester but pays for the forwarding to be done.

The next step we are taking will involve bringing light weight, self-loading trucks into the system. These trucks will have aluminum wheels and standards, super single tires and a detachable, light weight, high speed loader. We believe that when the trucking component is in place and operational that this will be the most efficient, productive and cost effective system available, to harvest and deliver timber in Ohio.

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Reisenberg’s principles revisited: a portable rail system for use in forest operations in sensitive areas

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Abstract

We developed the conceptual plan for a low-impact forest transportation system for use in sensitive areas and on small parcels. The system shares three design principles with a portable railroad prototype developed by F.S. Reisenberg during the early twentieth century (Reisenberg 1920). The system is characterized by 1) a lightweight, portable rail network, 2) horizontal rather than vertical distribution of transported mass, and 3) moving materials smoothly over, rather than smoothing over, irregular terrain surfaces. If developed in such a way that it were practical to deploy, the system could help to alleviate operational effects on wetlands, such as rutting and sedimentation. It could also reduce soil compaction on main trails, erosion, and damage to advanced regeneration. We added a fourth design principle to improve the system’s potential for use in forestry: integrating the continuous flow and queueing characteristics of recirculating manufacturing conveyors. In order to explore the wood flow characteristics of the system while designing a prototype, we are developing a simulator to model its application in forest operations on small parcels. Using the simulator, we compare material flow on the rail system with that of a single piece of skidding equipment hauling larger, pulsed loads. Based on sensitivity analyses of simulator parameters with Latin Hypercube Sampling (LHS), the productivity of the portable rail system is more uniform over time than that of the skidder. Field testing of a prototype rail system will identify limitations due to drive systems, turn distance, and slope, while monitoring site effects on soil bulk density and regeneration processes.

Introduction

The year 1920 marked the beginning of a decade during which the use of agricultural farm tractors increased by 275% in the United States (Ankli 1980). In that year, a patent was approved for a portable railroad system intended to move weight-distributed materials lightly over irregular terrain. At the time, the invention may have represented a pinnacle in technological advancement in narrow gauge rail design, in some respects. However, it appears to have received little attention as rapid increases in production and use of mechanized equipment were just beginning to transform agriculture and forestry. Nearly ninety years later, a variety of adverse silvicultural and ecological effects are perceived to be associated with forest roads and skid trails which rely on heavy equipment to transport wood in large, pulsed loads. These include soil compaction, erosion, sediment and nutrient loading into watersheds, disturbance of advanced regeneration, and adverse aesthetic effects (see, e.g., Forman et al 1998, for an exhaustive review of general ecological effects of roads). In light of the large amount of research devoted to these concerns, it may be useful to revisit three principles underlying Reisenberg’s portable rail system when developing extraction systems for sensitive sites. The core concepts were 1) lightweight portability, 2) horizontal rather than vertical distribution of transported mass, and 3) moving smoothly over heterogeneous terrain on elevated track.

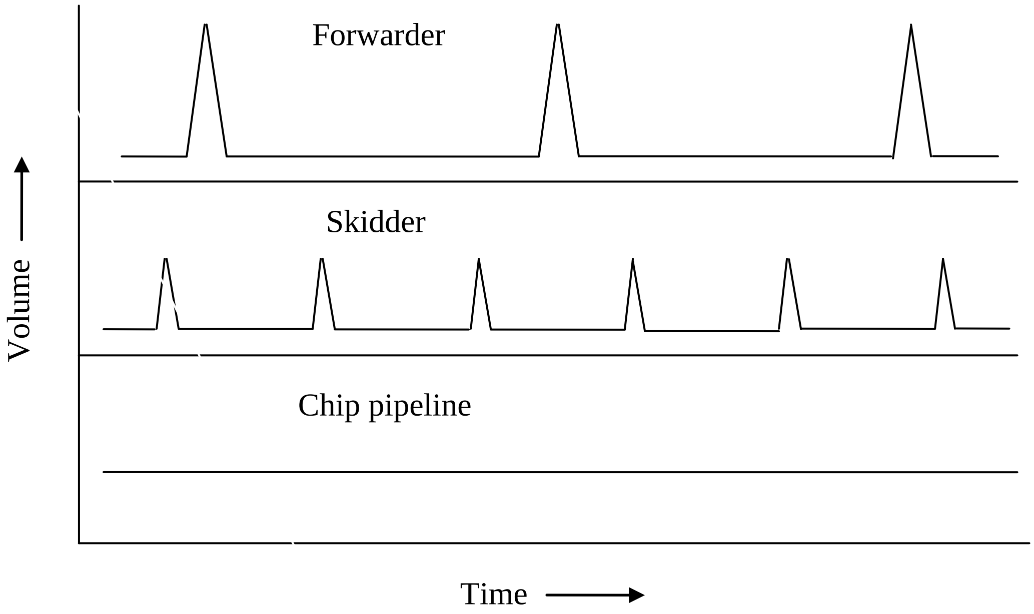

Figure 1: Variation in wood flow over time in three forest transportation systems.

An important factor affecting the productivity of wood transport systems is the extent to which variability in flow rate is affected by variation in the forest stand, harvest design, and other uncontrollable influences such as weather. An ideal transportation system could function equally well under a high degree of variation in these factors, delivering consistent production rates independently. In practice, most types of equipment fall on a gradient of variation in product flow over time. Figure 1 shows the flow pattern for a large forwarder hauling infrequent loads of logs, a skidder hauling smaller twitches at a higher speed, and an experimental long distance chip slurry pipeline system constructed and evaluated in Quebec during the late 1950’s and early 1960’s (Thiesmeyer 1964). This latter example comes closest to the style of uniform material flow which typifies recirculating conveyors used in indoor manufacturing and processing facilities. Analytical models for recirculating conveyors have received much attention in operational research. Models for multi-station conveyors have been proposed by Muth (1975) and others. Simulation and analytical approaches accounting for the load buffering and storage capacity due to station queueing, as well as the temporary storage capacity provided by recirculation, have been presented by Schmidt et al. (2000).

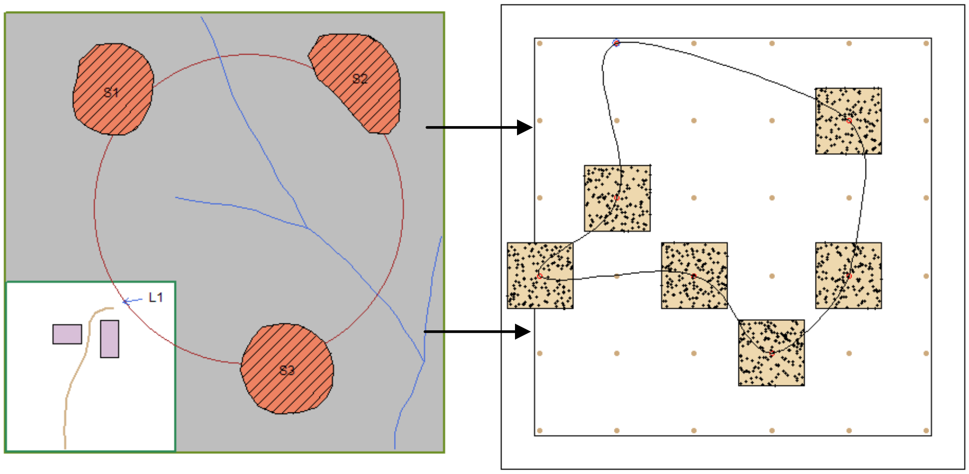

Figure 2: *Left*: Example uneven-aged management scenario on a 20 acre Nonindustrial Private Forest (NIPF) parcel for which the portable rail system may be suited. S1, S2, and S3 are small group selection cut areas of approximately 0.5 ac, and L1 is the unloading area (landing) adjacent to a private homestead. *Right*: generalized example cut and rail pattern produced by the simulator with lot area = 50 ac, number of cuts = 6, cut size = 1.0 ac, and Xspline shape parameter = -0.5.

In this study, we are considering a theoretical rail design for small woodlots that integrates desirable principles associated with portable rail with an additional characteristic from the conveyor literature: the highly stable material flow rates achieved by multi-station, closed-loop conveyors. While developing a prototype of the machine, we are seeking to evaluate operational aspects of the design and identify shortcomings using simulation. We are coding the simulator based upon a conceptual 2 rail narrow gauge track design with continuous, small log carts attached either by cable sections or synthetic rope, and powered by a winch at the landing. The rail sections are elevated approximately two feet above the soil surface on legs which extend or contract to provide a leveled pathway over obstacles and along side-slopes. Carts might carry large logs individually, or a few small diameter pieces, or small chip containers. Truss sections are used to bridge wetlands.

Methods

The simulator is being programmed to represent the effects of a lightweight recirculating, portable, narrow-gauge rail conveyor being used in uneven-aged management on small parcels (< 150 ac) using the open-source statistical programming environment, R (R Development Core Team 2008). Input variables which may be varied in the simulator include the forest area, number of group selection cuts, size of group selection cuts, cart speed, log capacity of carts, spacing of carts, and the intensity of the spatial pattern of trees within cuts, which are drawn from a Poisson point process. The recirculating path layout is constructed using an Xspline (Blanc et al. 1995) which connects uniform, randomly drawn cut locations. Before fitting the spline, randomly selected cut centers are first sorted by 1) the quadrant in which they occur, and 2) the angle from the centroid of the stand to each tree. This encourages the creation of a continuous path which tends toward a circular pattern, transitioning smoothly from cut to cut.

Varying the Xspline shape parameter allows the user some control over the sharpness of turns which form. Within each cut, the movement of a small piece of equipment, such as an All Surface Vehicle (ASV) equipped with a harvesting shear, travels from the log loading point to each tree and back, so that logs are queued at each loading station (one within each cut) and loaded when an empty cart is present. The simulator cycles in one-second intervals.

We used an early version of the program to conduct exploratory runs and two small sensitivity analyses in order to compare wood flow dynamics using the rail conveyor with that of an individual skidding vehicle that is able to travel faster and carry larger loads. All trees were assigned identical volumes of 200 bf / tree and skidder capacity was fixed at 3 logs (600 bf/turn) for the simulation. Rail cart spacing was set to 103.67 ft, and the Xspline parameter was held at -0.2. Five parameters of interest were allowed to vary as uniformly distributed random variables (Table 1) within ranges that are plausible for small-scale forest management on the NIPF land base. Two sensitivity analyses were performed by cycling the simulator through 500 runs with parameter estimates drawn in a Latin Hypercube Sampling (LHS) design (Stein 1987). Separate analyses were conducted for the rail system and skidder. Linear models were fit to the resulting matrices of input parameter values and predictions, and the relative effect size of predictors were estimated using bootstrapped linear model estimates with R^2 values averaged across parameters to account for variation in term order (Lindeman et al 1980).

Table 1: Distribution and ranges of parameters varied in LHS sensitivity analyses.

Parameter	**Forest area (ac)**	**Number of cuts**	**Cut area (ac)**	**Cart speed (mph)**	**Skid speed (mph)**
Min	20	3	0.5	0.5	3
Max	150	7	1.5	1.5	7
Distribution	Uniform	Uniform	Uniform	Uniform	Uniform

Results

Figure 2 (right) shows a typical cut and rail pathway generated by the simulator. The output from two example simulations shown in Figure 3 demonstrate the ability of the model to capture the effect of turn distance on the productivity of a skidder (negative sloping line) and the more consistent productivity of the continuous rail system. Effect sizes from bootstrapped linear models fit to simulator runs using LHS shown in Table 2 provide evidence that the productivity of the portable rail system is largely unaffected by either the *cut area*, the *number of cuts*, the *total forest area*, or *turn distance*.

Table 2: Proportion of production estimates (bf/t) explained by selected simulator parameters for two LHS sensitivity analyses (500 draws). Values of medium (>0.15) and high (>0.35) importance are shown in bold text.

Simulation	Parameter	Effect size (%)	Lower 0.95	Upper 0.95
Portable rail	Cart speed	**0.976**	**0.950**	**0.990**
Portable rail	Number of cuts	0.004	0.001	0.015
Portable rail	Cut area	0.001	0.000	0.008
Portable rail	Forest area	0.010	0.002	0.025
Portable rail	Turn distance	0.007	0.002	0.018
Skidder	Skid speed	**0.282**	**0.245**	**0.324**
Skidder	Number of cuts	0.040	0.025	0.060
Skidder	Cut area	0.006	0.001	0.017
Skidder	Forest area	**0.174**	**0.148**	**0.199**
Skidder	Turn distance	**0.394**	**0.366**	**0.422**

In the simple model, with each sampled parameter included as a linear effect, *cart speed* explained over 97 % of the variation in productivity of the rail system. The relative contribution of this parameter was significantly different from all others, while the contributions of other variables were not different from one another. By contrast, *turn distance*, *forest area* and *skid speed* all affected productivity for the skidder simulations, while only 90 % of the variation in productivity was explained by the model. This suggests that, conditional upon our many simplifying model assumptions, the material flow rate of the skidder system is less robust to heterogeneous site and harvest plan characteristics (Table 2). In individual simulations with other inputs held fixed, the productivity of the skidder varied indirectly with distance, as reported in recent field trials conducted by Wang et al. (2004) and Behjou et al. (2008).

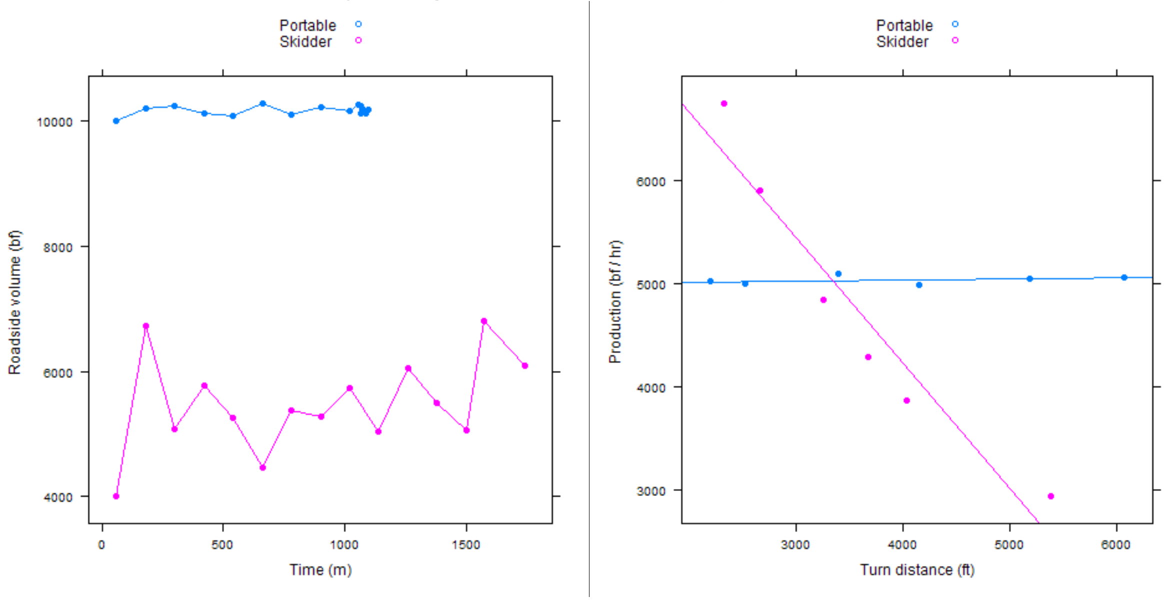

Figure 3: *Left*: Example variation in volume arriving at roadside (last 60 min) in separate simulator runs with increasing simulation time (2 hr intervals); 1 mph rail and 5 mph skidder speeds. *Right*: effect of increasing turn distance on productivity of simulated portable rail system and skidder. Separate model runs were made for each simulation time; rail and skidder speeds are 0.5 mph and 5 mph, respectively.

Discussion

Based on the low variability of production estimates obtained in this preliminary simulation exercise, and the potential for reductions in multiple site impacts, further development of a portable rail system for testing in management activities at the Wildland Urban Interface, near wetlands, and on working forest conservation lands may be justified. On these parcels, small-scale equipment may be more appropriate than mechanized harvesting for several reasons (Wilhoit and Rummer 1999). While current predicted skidder production is generally in a similar range to productive machine hour values reported by Wang et al. (2004), Behjou et al. (2008), and others, it will be critical to calibrate the simulator with parameter estimates and distributions based on published operational studies and to formally validate the model behavior before applying it in an operational setting. Subsequent work will integrate skidder motility functions, and soil compaction effects for both transportation systems. Set-up and take-down time requirements for portable rail will be critical determinants of the efficiency and practical utility of the design. Although they were held fixed in this study, varying the scheduling, rate, sequence of harvests, and delivery to loading sites within each cut area could provide for a wide range of flexibility in equipment layout and processing scenarios on small parcels. In future field testing of the prototype, soil bulk density, biophysical seed germination processes, and suitability of post-operational microenvironments for seedling growth should be evaluated along with production rates. Practical portable rail limitations associated with drive mechanisms, maximum slope, and maximum turn distances need to be determined.

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Improving Helicopter Pilot Training with On-Board GPS

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Abstract

Helicopter yarding is incredibly versatile due to its ability to avoid many of the obstacles that encumber ground based and skyline systems. Helicopter yarding is employed for a variety of reasons including site sensitivity, urgency to remove or deliver the product, lack of access, and slope of the terrain. Because of the high cost of helicopter yarding, maximizing productivity is critical. There are many site and stand factors that affect productivity. Pilot experience is also known to be an important productivity factor. On-the-job training of new pilots can be very expensive through loss of productivity (opportunity cost). Basic time and motion studies can show differences in productivity. Using an on-board GPS system to capture elemental time study data that is geo-referenced makes it possible to isolate, in detail, during what phase of the turn cycle a trainee is not efficient. Using data collected at two different sites, basic productivity curves were developed for each element of the yarding cycle. For these case studies, the trainee pilot was losing most of his time positioning the helicopter for hooking the logs, although reduced acceleration and maximum top velocity was also noted. With detailed feedback from an onboard GPS system, the trainee pilot and or trainer can focus the improvement efforts reducing overall costs.

Introduction

Helicopter yarding is incredibly versatile due to its ability to avoid many of the obstacles that encumber ground based and skyline systems (Conway 1976; Burke 1973). Today this yarding system is employed for a variety of reasons including site sensitivity, urgency to remove or deliver the product, lack of access, and slope of the terrain. The use of helicopters in forestry continues to grow. Where there were only a handful of firms offering the helicopter logging services in the early 1970’s (Conway 1976), today the Helicopter Association International estimates almost 175 forestry or logging companies use helicopter logging as a principal means of yarding timber (Bruce 2003).

The variety of helicopters used is also fairly extensive. Table 1 indicates the manufacturers and models used in British Columbia, Canada. Helicopters are typically rated by payload capacity which ranges from 1134 kg for the Eurocopter Lama to 12727 kg for the Boeing CH234.

Table 1. Specifications for helicopters commonly used for logging in British Columbia, Canada (Krag and Evans 2003).

Manufacturer	Model	Rated payload capacity (kg)	Engines	Engine power (kW)	Main rotor diameter (m)	Tail rotor diameter (m)
Bell	204B	1814	1	820	14.6	2.6
Bell	205A	2268	1	1044	14.6	2.6
Bell	212	2268	2	671 (each)	14.7	2.6
Bell	214B	3636	1	2185	15.2	2.6
Boeing	V-107 II	4773	2	932 (each)	15.5	n/a
Boeing	CH-234LR	12727	2	3039 (each)	18.3	n/a
Eurocopter	SA-315B Lama	1134	1	640	11	1.9
Kaman	K-1200	2722	1	1342	14.7 (×2)	n/a
Kamov	KA-32A	5000	2	1645 (each)	15.9 (×2)	n/a
Sikorsky	S-58T	2268	2	700 (each)	17.1	2.9
Sikorsky	S-61N	3629	2	1044 (each)	18.9	3.2
Sikorsky	S-61N Shortski	4084	2	1044 (each)	18.9	3.2
Sikorsky	S-64E	9072	2	3356 (each)	22	5
Sikorsky	S-64F	11340	2	3579 (each)	22	5

Despite its wide use, helicopter yarding is a relatively high cost extraction method. While Hartsough et al. (1997) found ground based skidding to account for approximately 20-25% of the stump to truck operation costs, helicopter yarding ranged between 65 and 78% of the stump to truck costs (Krag and Evans 2003; Dunham 2003). Currently Helicopter ownership costs are at least $500 per hour for the smallest machine, up to approximately $4500 for the larger machines.

Helicopters have various designs and abilities. The type of helicopter used will influence speed, angle of ascent, and maximum payload (Conway 1976). The operation will be dependent on equipment and personnel, for example the firm chooses which helicopter to use, who to employ, and level of support the operation will receive. Of course this is complicated by reality and can be constrained by available technology, labor markets, and limited capital.

Optimizing the payload is a key factor in achieving efficient yarding (Burke 1973; Hartsough et al. 1986). The location and layout of the log landing is also a crucial factor. The primary concern is the yarding distance, which generally is the distance from the hook point to the log landing (Burke 1973). Weather not only limits when operations may occur, but it also influences helicopter capability during operations. The density of the air impacts both the ability of the helicopter to achieve lift and the horsepower of the engine (Wagtendonk 1996).

Other operation dependent factors that may influence productivity are the pilots themselves. When a helicopter yarding organization employs a pilot new to logging work, they are likely to experience higher costs (Warren 1996; Stampfer et al. 2002). Stampfer et al. (2002) shows that an experienced pilot delivered 59% more volume to the landing than a trainee-pilot did.

With the high cost and wide range of factors affecting helicopter yarding, sound formulas for estimating and evaluating yarding system production should be available. New technology allows us to more accurately measure the helicopter yarding process and better predict the production rates at future sites. Recent forest operation research used ground based equipment with on-board Geographic Positioning Systems (GPS) to conduct more precise production and site impact analysis (McDonald et al. 2002, McDonald et al. 2000).

Heinimann and Caminada (1996) recommend employing GPS to gather more precise data on helicopter operations. Using onboard GPS, these activities can be mapped (Figure 1).

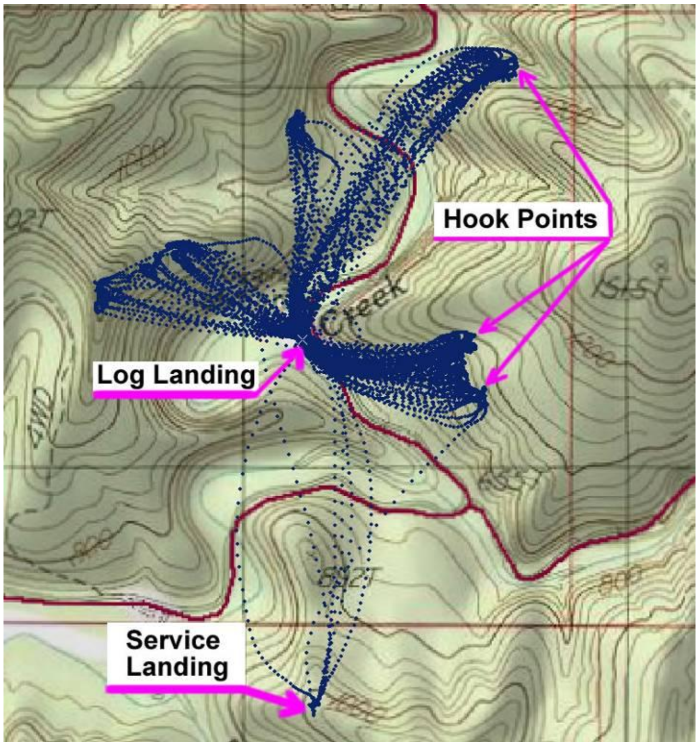

Figure 1. Mapped helicopter yarding data from an on-board GPS unit.

On-board GPS can aid the helicopter yarding industry. This study aims to demonstrate this by measuring the impact of pilot experience on productivity. Knowing where a trainee-pilot is likely to need the most improvement may assist the industry in selecting optimized training routines.

Methodology

The data used for this paper is part of a larger comprehensive study into measuring helicopter productivity using GPS and GIS analyses. It includes over 35 days of helicopter data gathered at 9 different sites on 3 different helicopters. At two specific locations the operation included an inexperienced pilot, which for the purpose of this study is defined as a pilot with less than 100 hours flying in logging operations (Warren 1995). Both sites were thinning of a mixed conifer stand, in the Pacific Northwest, yarded in the summer.

At each site an attempt was made to capture at least 30 turns, whereby the inexperienced and experienced pilot flew consecutive yarding cycles ensuring consistency in weather, stand and terrain factors. GPS data was collecting using a Trimble Geo XT with EVEREST technology mounted on board the helicopter. Location information was gathered at one-second intervals. The data was downloaded from the GPS unit at the days end.

Some basic programs were developed to aid the evaluation of the data, including auto location of the four phases that make up a typical turn cycle. Landings were located using position with a 35 meter radius. Hook points were identified using velocity and altitude with a 20 meter radius. Outhaul and inhaul were velocity and position dependent. The programs used the GPS data, landing coordinates, and radii input by the researcher.

Describing the Helicopter Yarding Process

The process of helicopter yarding can be broken into yarding cycles, turns, and elements. The basic definition for a cycle is leaving the service landing, flying a number of turns and returning to the service landing. The basic definition for a turn is leaving the log landing and traveling to the location of the payload (outhaul), picking up the payload (hooking), returning to the log landing with that payload (inhaul), and releasing the payload at the log landing (unhooking). Each segment of the turn just described is an element.

Beginning at the service landing the helicopter will fly to the harvest area and begin yarding logs. During the hooking element there will often be a person, the hooker, on the ground with pre-choked logs ready to be connected to the hook at the end of the helicopters long line (Figure 2). The pilot locates the hooker and maneuvers the hook near the hooker. Then the hooker slides the chokers into the hook. The pilot then lifts the logs off of the ground and clear of the forest canopy.

Figure 2: A hooker putting the chokers onto the hook.

The inhaul element begins and the pilot flies toward the log landing. At the landing the pilot sets the logs on the ground in the drop zone and releases the chokers from the hook (Figure 3). With the load released, the pilot clears the log landing and enters the outhaul element, flying back to the woods for another load of logs. If chokers are needed, they may be attached to the hook prior to departing the log landing (Figure 3). The entire process, hook, inhaul, unhook, and outhaul is commonly referred to as a turn. If no problems occur, this continues for 60 to 90 minutes, until the helicopter must be refueled. The pilot must then return to the service landing for fuel. When the helicopter is in the hooking, inhaul, unhooking, or outhaul elements, this is called the yarding cycle. When the helicopter is flying to or from the service landing or being fueled or repaired, this is called the service cycle.

Figure 3. Left: Helicopter at the drop zone (unhooking), and right, helicopter with chokers going to woods (outhaul).

Table 1. Description of the numerical variables and time components.

Type	Name	Description	Unit
Dependant-Variables	Outhaul	Time for the helicopter to fly from landing to hook point	sec
	Hook	Time at 'hook point', which is defined by a radius of 20 meters around the actual hook point	sec
	Inhaul	Time for the helicopter to fly from hook point to landing	sec
	Unhook	Time at 'landing', which is defined by a radius of 30 meters around the actual landing	sec
	TurnVol	Sum of the log volumes extracted in one turn	kg
Covariables	TreeVol	Average log volume	kg
	ExtDist	3d extraction distance	meter
	ElvChange	Change in Elevation	meter
	Slope	Slope between landing and hook point	%
	TreeTurn	Number of logs per turn	number
Factors	PilotEx	Pilot experience, as defined by 100 flying hours in logging	0 / 1
	ChokDrop	Turn that includes dropping off a bundle of chokers	0 / 1
	ChokPick	Turn that includes picking up a bundle of chokers	0 / 1
Time	Vel	Max velocity (Flyout and FlyIn)	m/sec
	Accel	Max Acceleration (Flyout and FlyIn)	m/sec2
	Decell	Max Deceleration (Flyout and FlyIn)	m/sec2

Statistical analysis was carried out using SAS JMP 7.0, including basic mean comparisons as well as linear regressions to build the models. Comparison of means was tested at the 0.05 level, whereby stepwise model development used a threshold of 0.10 for parameter inclusion. Specific Helicopter and site information is considered confidential by the helicopter companies, and hence not reported here.

Results

Case study 1

Average extraction distance was 1028m (range 476 to 1457), with an average payload of 3528 kgs and 2.9 logs. The total average cycle time was 194 sec (3 min 24 sec); whereby 48, 66, 56 and 24 seconds were used on average for outhaul, hooking, inhaul and landing respectively. This resulted in an average productivity of 71 tons/PMH. Average Elevation change was only 30 m.

An initial review of productivity data indicates a significant difference between the in-experienced and experienced pilots (40.7 versus 82.2 tons/PMH). However many factors can influence productivity so it would be more correct to build a productivity model with pilot experience as a block factor.

A basic productivity equation is;

Eq (1): Prod (tons/hr) = 106.2 – 33.5 x PilotEx – 17.5 x ChokDrop – 19.6 x ChokPick - 0.02 x ExtDist – 0.05 x ElvChang

($r^2 = 0.79$)

Equation 1 indicates that under similar conditions, the inexperienced pilot produces 33.5 tons/PMH less.

Analyzing the available data in more detail, we can look at the four phases of the turn to identify specific differences.

For the Outhaul phase, time from Landing to Hook point should just be a function of extraction distance and change in elevation, as well as the block factors ChokDrop and PilotEx.

Eq (2): OutHaul (sec) = 0.055 x ExtDist – 0.092 x ElvChange + 28.5 x ChokDrop

($r^2 = 0.65$)

So for outhaul the pilot experience factor was not significant. We can also look at both maximum acceleration as well as average velocity during the Outhaul phase to confirm this difference. The inexperienced pilot had a slightly higher average velocity (145 m/sec) than the experienced pilots (126 m/sec), as well as a slightly average maximum higher acceleration (3.1 versus 2.7).

For the Hook phase, we would expect the number the total payload weight and number of logs, as well as pilot experience to influence the total hook time.

Eq (3): Hook (sec) = 8.4 + 0.011 x TurnVol + 84.7 x PilotEx

($r^2 = 0.74$)

This indicates that the inexperienced pilot takes more than twice as long to hook up the load.

For the inhaul phase, we might expect the payload, the elevation change and the extraction distance, in addition to pilot experience to be important factors.

Eq (4): InHaul (sec) = 31.5 x 0.021 x ExtDist + 8.3 x PilotEx

($r^2 = 0.42$)

Neither elevation change nor the payload was significant, and the experienced pilot was in fact flying a little faster during the inhaul phase. Once again we can look at the details of velocity and acceleration.

The experienced pilots on average flew a little faster (105 versus 100 m/sec), accelerated away a little quicker (1.9 versus 1.6 /sec2) and were able to decelerate the helicopter a little quicker when approaching the landing (1.7 versus 1.4 m/sec2).

For the unhook phase of the flight, the size of the payload, the number of logs, in addition to the pilot experience and whether or not they pick up a bundle of chokers might influence the length of time over the landing area.

Eq (5): Unhook (sec) = 16.9 + 14.9 x PilotEx + 26.5 x ChokPick
($r^2 = 0.65$)

Although neither the size of the load nor the number of trees influenced the time over the landing unhooking a load, the experienced pilot took on average 7 seconds less, and on average it took 13 seconds to pick up the chokers.

Overall, it is clear from this short data set (2.5 hours of data) that we can clearly identify that the inexperienced pilot should focus on the hook phase of the operation – where there is clearly the largest difference.

Case Study 2:

Average extraction distance was 1770m, with an average payload of 3300 kgs and 4.4 logs. Average element times were 50 sec out, 69 hooking, 52 sec back and 25 at landing for a total average cycle time of 196 sec (3 min 26 sec). This resulted in an average productivity of 68 tons/PMH. Average Elevation change was only 25 m and the average distance was 1045m (range 36 to 2819m). Average velocity was 80 km/hr on the outhaul, and 68 km/hr for the inhaul.

However, there were clear differences between the experienced and inexperienced pilot. Overall, the productivity was 77 and 38 tons/PMH for the experienced and inexperienced pilots respectively.

Eq (6): Prod (tons/PMH) = 99.1 – 36.3 x PilotEx – 12.9 x ChokDrop – 13.4 x ChokPick
- 0.013 x ExtDist – 0.9 x NumLogs
($r^2 = 0.73$)

The equation for the Outhaul phase is;

Eq (7): OutHaul (sec) = 0.039 x ExtDist – 0.011 x ElvChange + 19.8 x PilotEx
+ 23.5 x ChokDrop
($r^2 = 0.70$)

Unlike case study one; the inexperienced pilot is some 20 seconds slower on average flying out. For the hook phase:

Eq (8): Hook (sec) = 15.5 + 0.008 x TurnVol + 64.6 x PilotEx + 2.32 x NumLogs

$(r^2 = 0.60)$

Similar to case study 1, there is a large difference in the length of time it takes the inexperienced pilot to hook. For the flight back

Eq (9): $\text{InHaul (sec)} = 18.6 \text{ x } 0.030 \text{ x ExtDist} + 0.07 \text{ x ElvChange} + 16.4 \text{ x PilotEx}$ $(r^2 = 0.42)$

Again, the experienced pilot is somewhat faster by on average 16 seconds. Finally, for the unhook phase:

Eq (10): $\text{Unhook (sec)} = 17.0 + 19.7 \text{ x PilotEx} + 22.1 \text{ x ChokPick}$ $(r^2 = 0.64)$

For this phase in particular, all of the parameter coefficients are almost identical to case study one.

The results analyses have focused primarily on the experience pilot factor. A closer review of individual parameters, such as the impact of distance, either picking up or dropping off chokers, or simply the length of each phase in the overall cycle on productivity provides valuable production management information.

Conclusions

Integration of new technologies can provide significant opportunities to improve productivity of existing timber harvesting operations, and thereby reduce costs. This study has demonstrated the opportunity for using onboard GPS for the benefit of identifying training needs for inexperienced helicopter pilots flying in logging operations. Although some automation of the data interpretation was achieved during this study, opportunities exist for improved data synthesis.

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DIAG-FOR : a benchmarking tool for forest contractors

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Abstract

Typically, forest contractors have limited tools at their disposal to analyze their operations, benchmark their performance or develop a continuous improvement plan for their business. The FERIC division of FPInnovations, in cooperation with a large forest company in eastern Canada, developed a diagnostic and process improvement tool. DIAG-FOR (DIAGnostic for FORest contractors) is an internet-based tool that contractors can access to benchmark their performance level for eight management indicators against the average results contained in the database. The eight performance indicators are human resources, productivity, mechanical availability of equipment, utilization rate, product quality, health and safety, environmental compliance and business management. Articulated around a series of progressively more difficult questions as the user advances in performance level, the yes/no answers indicate a performance level attained for each indicator. The user can then obtain a report card describing his level of performance, as well as a series of recommended actions for improvement and progression along the performance scale (level 1 to 5). The presentation (or poster) will provide an overview of DIAG-FOR and it's mode of operation.

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Stream crossings and water quality in the Virginia Piedmont

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Keywords: Forestry roads, Erosion potential, Sediment, Timber harvesting, Water quality

Abstract

Erosion potential was estimated for road approaches at four phases of a timber harvesting schedule for 23 stream crossings in the Virginia Piedmont. The objectives of this study were to: 1. examine four different types of stream crossing structures (steel bridges, pole bridges, standard culverts, and re-enforced fords) in order to determine if the type of stream crossing affects erosion potential and 2. evaluate the potential erosion associated with the stream crossing approaches using the Water Erosion Prediction Project for forest roads (WEPP) and the forestry version of the Universal Soil Loss Equation (USLE). An unbalanced replication resulted in six replications of each crossing, except pole bridges (7) and fords (4).

Results indicate that any of the stream crossings may be appropriate if located, installed, and maintained properly. However, we found that approaches associated with culverts had the potential for the highest soil loss rates as estimated by both WEPP (46.2 t/ac/yr) and USLE (85.8 t/ac/yr). Both of these models showed a general decrease in the potential for erosion from the during harvest phase to the post-road closure phase.

Introduction

Stream crossings can produce a number of water quality pollutants, but sediment is usually the primary concern. Research indicates that roads create more pollution, in the form of sediment, than harvesting activities. Furthermore, stream crossings are the most frequent sources of sediment introduction (Rothwell 1983). Road construction and associated stream crossings are common activities for conventional harvest operations. Sediment produced at stream crossings originates from two primary sources: the stream crossing structure itself, and the road approaches to the crossing (Taylor et al. 1999). Locating the least steep approaches for stream crossings and choosing good locations are common Best Management Practices (BMPs) recommended for minimizing sediment pollution. The potential for water quality impacts other than sediment also exist at stream crossings. Nutrients attached to sediment particles, which are transported directly to stream systems may also present additional non-point source problems in forested watersheds (Grace 2005).

Study Area

Study Site Description

The Piedmont region of Virginia is in the central part of the state and all counties involved in this study are displayed in Figure 1. The Piedmont developed due to erosion and has a gentle slope from the mountains to the Coastal Plain (Daniels et al. 1973). The interior of the province typically has a gently rolling landscape with a relief of 15.24 meters bounded by steeper, deeper valleys of the modern streams (Daniels et al. 1973).

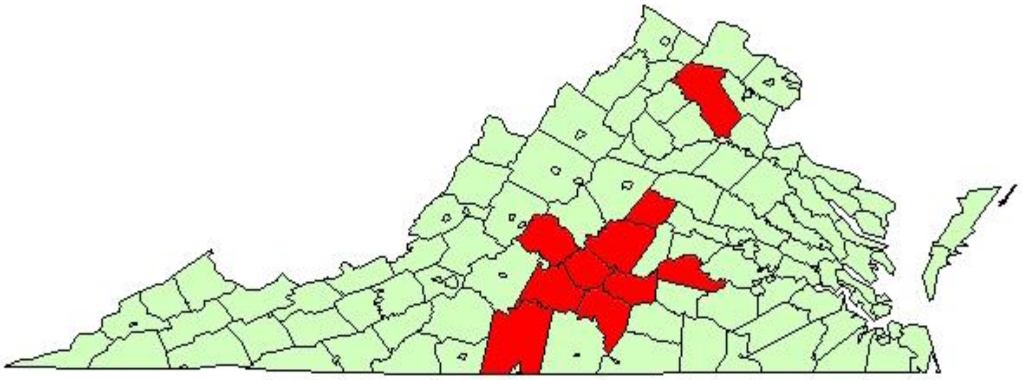

Figure 1. Map of Virginia with marked study counties.

Most study sites were located on private properties that were under contract or land owned by MeadWestvaco or Huber Engineered Woods. Stands harvested ranged from mixed hardwood with white oak (*Quercus alba*) and yellow poplar (*Liriodendron tulipifera*) to loblolly pine plantations (*Pinus taeda*). A range of road classes were used to acquire all four types of stream crossings, ranging from skid trails (Class IV roads) to permanent haul roads (Class II-III roads).

Methodology

Field visits were conducted during four different phases of the harvesting operation: pre-reopening/pre-installation, post-installation/pre-harvest, during harvest, and post-road closure. Stream crossings were associated with permanent haul roads, temporary haul roads, or skid trails.

Data were collected to predict erosion from both the entrance and exit approach to the stream crossing. Weather information, slope length, slope width, slope percent, slope shape, road management, and soil texture were collected to estimate the approach erosion values with the Water Erosion Prediction Project (WEPP) (Forsyth et al. 2005). The Universal Soil Loss Equation (USLE) model was also used to predict erosion from the approaches. Estimated soil erosion is represented by the following equation for USLE:

$$\text{Estimated soil erosion} = A\ (\text{tons/acre/year}) = RKLSCP$$

Where:

R=Rainfall and Runoff index
K=soil erodibility
LS=slope length and steepness
CP=Cover-Management Practice Factor for Untilled and Tilled Forest land

The CP factor has several sub factors that influence the estimate such as bare soil, residual binding, soil reconsolidation, canopy, steps, onsite storage, invading vegetation, high organic matter content (for untilled only) (Dissmeyer and Foster 1984).

Erosion prediction models were used to estimate the amount of sediment being contributed from road approaches each year on a per acre basis. WEPP Version 2006.5 is a computer based model published by the USDA Agricultural Research Service. This model is used to estimate sheet and rill erosion (Forsyth et al. 2005). Inputting weather station, slope, road management, and soil texture information in this program allow it to predict erosion (tons/acre/year). The program was run to predict erosion for a 10-year period and obtains an average soil loss value. The USLE manual was the other main source of information to calculate the predicted soil loss. This model is effective for predicting sheet and rill erosion on forest land (Dissmeyer and Foster 1984).

Data analysis was performed using the Number Cruncher Statistical System (NCSS 2005). Analysis of variation (ANOVA) tests were done at the $\alpha = 0.10$ level. The Tukey-Kramer multiple comparison test was used to show significant differences of the four types of stream crossings at the $\alpha = 0.10$ level.

Results

Evaluation of the erosion rates associated with the approaches to the various stream crossings using the WEPP model indicated no significant differences between the four stream crossing types for the pre-installation phase (p-value = 0.201), post-installation/pre-harvest phase (p-value = 0.89), or post-road closure phase (p-value = 0.15). However, the during harvest phase resulted in significant differences between the four stream crossings (Table 1) (p-value = 0.07). During harvest, culvert crossing approaches resulted in significantly more estimated erosion (46.2 tons/acre/year) than the ford, pole bridge, or steel skidder bridge (18.6, 21.6, and 29.7 tons/acre/year, respectively) (Table 1). Higher estimates at the pre-installation phase may be due to pre-existing road construction conditions for culvert, ford, and steel bridge stream crossings.

Table 1. Mean values of the four stream crossing types during each sampling period as predicted by the WEPP model. Lower case letters indicate statistical significance at the $\alpha = 0.10$ level. ns = none significant.

	Sampling Periods			
Stream Crossing Type	Pre-reopening/ Pre-installation	Post-installation/ Pre-harvest	During harvest	Post-Road Closure
	----------------------	**tons/acre/year (tonnes/hectare/year)**	---------------------	-----------------------
Culverts	10.7 (24.0) ns	26.2 (58.7) ns	46.2 (103.5) a	24.4 (54.7) ns
Fords	22.2 (49.7) ns	15.8 (35.4) ns	18.6 (41.7) b	19.9 (44.6) ns
Pole bridges	6.2 (13.9) ns	23.0 (51.5) ns	21.6 (48.4) b	11.8 (26.4) ns
Steel bridges	11.9 (26.7) ns	22.1 (49.5) ns	29.7 (66.5) ab	25.5 (57.1) ns

Estimation of the erosion rates associated with the approaches to the studied stream crossings using the USLE model indicated no significant differences between the four stream crossing types for the pre-installation phase (p-value = 0.16). However, the pre-harvest/post-installation phase (p-value = 0.08) and the during harvest phase (p-value = 0.0006) resulted in significant differences between the four stream crossings (Table 2) Also, the post-road closure phase resulted in significant differences in approaches among the four crossings (Table 2) (p-value = 0.055). During harvest, approaches associated with culvert crossings resulted in significantly more estimated erosion (85.8 tons/acre/year) than the ford, pole bridge, or steel skidder bridge (23.4, 4.5, 18.7 tons/acre/year, respectively) (Table 2). Culverts, fords, and steel bridges showed a decrease in estimated erosion (50.5, 20.6, and 15.6 tons/acre/year, respectively) at the post-road closure phase. Pole bridge approaches increased from the during harvest phase estimated erosion rate of 4.5 tons/acre/year to 10.3 tons/acre/year following road closure. Although significant differences of approaches were realized for the pre-harvest/post-installation phase, the Tukey-Kramer multiple comparison test was unable to detect groups due to a limited sample size.

Table 2. Mean values of the four stream crossing types during each sampling period as predicted by the USLE model. Lower case letters indicate statistical significance at the $\alpha = 0.10$ level. ns = none significant.

		Sampling Periods		
Stream Crossing Type	Pre-reopening/ Pre-installation	Post-installation/ Pre-harvest	During harvest	Post-Road Closure
	---------------------	**tons/acre/year (tonnes/hectare/year)**	--------------------	----------------------
Culverts	3.8 (8.5) ns	34.4 (77.1) ns	85.8 (192.2) a	50.5 (113.1) a
Fords	2.7 (6.0) ns	9.8 (22.0) ns	23.4 (52.4) b	20.6 (46.1) ab
Pole bridges	0.1 (0.22) ns	1.7 (3.8) ns	4.5 (10.1) b	10.3 (23.1) b
Steel bridges	2.2 (4.9) ns	34.2 (76.6) ns	18.7 (41.9) b	15.6 (34.9) ab

Discussion

WEPP Estimates of Approach Erosion

Failure to detect differences in erosion estimates between treatments prior to installation of the crossings indicates that the subsequent treatments were being installed on relatively similar sites, which can be expected due to low disturbance before construction or harvesting activities. Each of the four types of stream crossings had at least one crossing that was installed with pre-existing road conditions. Ford crossings had more pre-existing crossings and approaches than any other crossing type. These pre-existing conditions probably contribute to the higher levels of estimated erosion rates at the pre-reopening/pre-installation phase (Table 1). Field observation and evaluation showed that the WEPP model projected a large amount of annual soil loss on approaches due to cover management practices and slope grade and length, during harvest. Absence of rock or gravel, except within the SMZ where the stream crossings were installed, caused higher erosion potential for some crossings (Figure 2). After harvest activities included implementing BMPs and reestablishing vegetation. Most stream crossing approaches decreased in WEPP erosion potential from the during harvest phase to the post-road closure phase with the exception of the ford stream crossing, which slightly increased (Table 1).

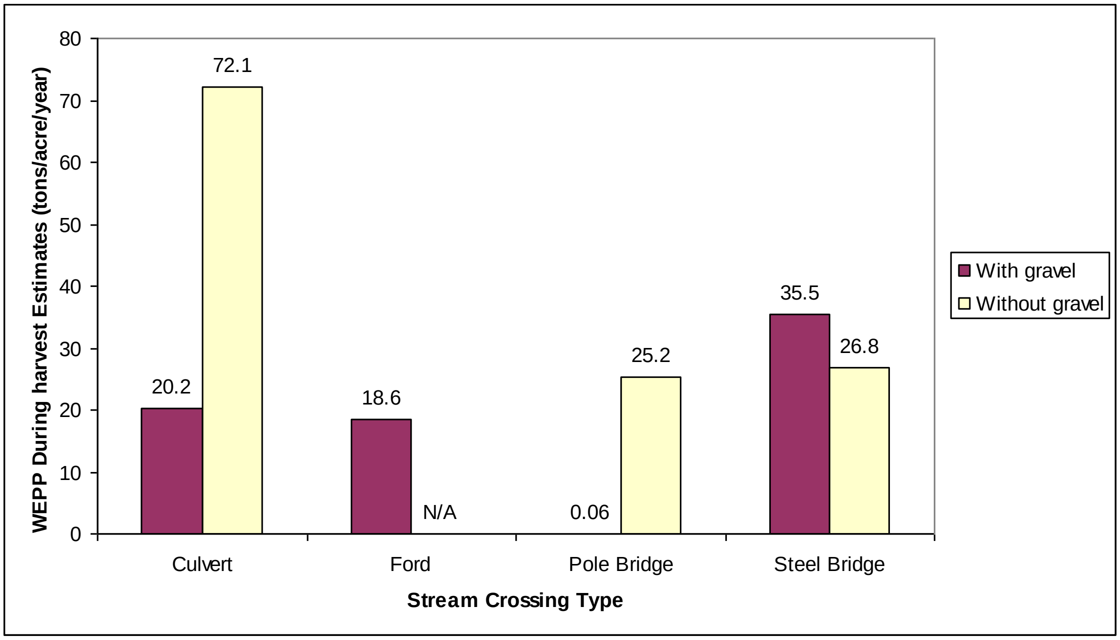

Figure 2. WEPP during harvest estimated erosion rates showing the differences in erosion rates for gravel/rock application to road approaches for each of the four types of stream crossings.

USLE Estimates of Approach Erosion

All stream crossings showed low erosion potential, less than 4 tons/acre/year (9 tonnes/ha/year) (Table 2) at the pre-installation/pre-reopening phase (Figure 3). Post-installation/pre-harvest mean erosion estimate values showed a p-value of 0.079 which revealed significance among crossing types. However, data recorded for this phase of harvest were limited due to factors such as immediate use of stream crossings and pre-existing conditions of previously used crossings. USLE mean erosion estimates displayed a significant difference among stream crossing approaches during harvest (Figure 4). Approaches to stream crossing erosion means decreased from the during harvest phase to the after harvest phase with the exception of road approaches associated with pole bridge crossings (Table 2). Possible explanations of this increase for pole bridge approaches from 4.5 tons/acre/year (10.1 tonnes/ha/year) during harvest to 10.3 tons/acre/year (23.1 tonnes/ha/year) after harvest are increases in bare ground and removal of natural vegetation. Often logging contractors will remove "rub" trees which are commonly used to change the direction of a skidder's load of timber to minimize stream channel contact. This removal of trees adjacent to the approach decreases the amount of cover.

Figure 3. Before-installation phase with a flagged grade line for an approach to a new culvert crossing.

Figure 4. During harvest phase at crossing previously shown in Figure 3.

Conclusions

The evaluation of erosion potential from road approaches leading to 23 stream crossings throughout the harvest process allows the following conclusions to be drawn:

- Approaches associated with culvert stream crossings provide the highest potential for soil erosion of the four types of stream crossings studied as estimated by both WEPP: Road model and USLE: forestry version.
- Implementing BMP practices to reduce bare soil, increase the residual natural vegetation, and minimize slope length can help in maintaining low potentials for estimated erosion on an annual basis.

Acknowledgements

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Sedimentation Rates of Temporary Skid Trail Head Water Stream Crossings

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ABSTRACT One of the primary concerns associated with timber harvesting is the production of sediments from stream crossings. While research has shown that using improved skid trail crossings can mitigate sediment production in perennial streams compared to the use of unimproved crossings little research has been undertaken on temporary skidder crossings of headwater streams, a situation common to a significant percentage of ground skidding operations. This experiment consisted of a controlled replicated testing of the effectiveness of four types of temporary skidder stream crossings (unimproved ford, corrugated culvert, wood panel skidder bridge, and PVC pipe bundle) relative to suspended sediment production. Automated samplers were used to monitor sediment production during the construction, use, removal, and post-removal phases associated with the use of these temporary crossings. Results showed that improved crossings mitigated total sediment production compared to unimproved fords. Further, wood panel bridges yielded lower amounts of sediment than culverts but PVC pipe bundles show no difference between bridges or culverts. Sediment production varied by crossing type and use phase. While no differences were found among crossings types during construction, there was a difference between improved crossings and fords during use. Further, bridges and PVC pipe bundle crossings produced significantly less sediments than culverts during both their removal and during post-removal sampling and fords produced the largest amount of sediments during these phases.

INTRODUCTION

A majority of the wood for Kentucky's forest industry is harvested using ground skidding methods using wheeled skidders. This type of harvest creates roads and stream crossings that expose bare soil that can become sources of nonpoint source pollution. A majority of sediment from timber harvesting comes from road construction (Kochenderfer 1970, Patric 1976). On these roads, stream crossings are the most frequent sources of sediment introduction because stream crossings serve as direct conduits of sediment into the hydrological system (Taylor et al. 1999).

Research has documented the effectiveness of improved stream crossings on higher order perennial streams (Taylor et al. 1999). It is not known if these conclusions can be extended to headwater streams. Headwater streams are very different when compared to higher order perennial streams. Headwater streams have smaller flow levels, respond quickly to storm events, and are more sensitive to anthropogenic disturbances compared to higher order perennial streams (Richardson and Danehy 2007). Headwater streams are 93% of all skid trail crossings on Kentucky logging jobs (Stringer 2005). There exists a knowledge gap between where current research is focused and what on the ground operators are running into.

The objectives of the study were to determine the effectiveness of temporary improved crossing structures against unimproved crossing structures on the unique environment of headwater streams. Do the same conclusions of the effectiveness of improved crossing structures compared to unimproved structures on higher order perennial streams apply to headwater streams? Effectiveness among the different types of improved crossing structures was also determined. Among all crossing types the amount of contribution from each phase of the crossings' life was determined as well.

METHODS

Improved crossing types chosen for experimentation were a wood panel skidder bridge, PVC pipe bundle, and corrugated culvert. These three improved crossing types were compared to unimproved crossings. An unimproved ford offers no protection and the log skidder goes directly through the stream.

Twelve headwater streams were identified in the Cole's Fork watershed of the University of Kentucky's Robinson Forest for crossing installation. These twelve streams had similar soils, similar drainage areas, easy equipment access from the main road, and similar crossing approaches. The approaches were either uphill or flat to minimize sediment input from the roads. The headwater streams were randomly assigned a crossing type. The study had a one-way classification structure with four different treatment types replicated three times per crossing type.

To determine effectiveness of all crossing structures the response variable measured was the amount of sediment generated in grams from each structure. It was assumed that sediment is generated during four phases of a crossings' life. Sediment is generated during the installation of the crossing structure, actual passes over the structure, removal of the structure, and post-removal. Sediment during these phases was partitioned and comparisons among crossing types were made with analysis of variance procedures. However because of a lack of rain that caused all headwater streams to dry up before the removal phase, it was impossible to partition sediment during this phase. As a result removal and post-removal phases were combined.

To determine total amount of sediment generated the sediment concentration levels (g/L) were multiplied by the flow occurring at the time sampled (L). Before each sediment generating event a sample was collected for comparison upstream from the crossing structure. The difference between the sediment levels of the downstream and upstream of the crossing location was the sediment generated by the structure. During installation samples were collected downstream from the crossing at five minute intervals until installation was complete. Once installation was completed sampling continued every ten minutes for one hour.

The structures were then driven over 22 times by a 540 John Deere cable log skidder with two logs. This was considered the pass over phase and sediment was measured each pass. Immediately after the structure was driven over a sample was taken. Samples were also taken at five, ten, fifteen, and thirty minutes after a pass. Sediment generated during all 22 passes was combined to create a total amount of sediment generated during this phase.

Sediment was also collected during high flow events caused by heavy rains. Isco automatic water samplers were installed upstream and downstream of every stream with liquid level actuators to turn on when flow levels had risen. Once activated a sampler would take a sample every ten minutes until the flow subsided. Once a rain event is completed the composite sample was analyzed to determine the concentration levels downstream and upstream.

Sampling during the removal of the structures was going to be similar to the installation. Because of the lack of flow the last two phases, removal and post-removal, were combined. It was impossible to determine without flow whether the sediment was from the act of removing the crossing structure or was washed out during a rain event post removal.

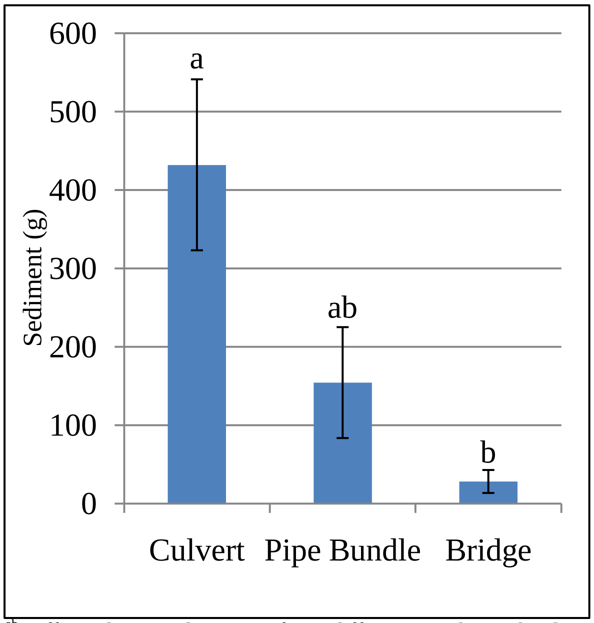
After removal, rain events were continually monitored for three months with the automatic samplers and levels of sediment collected. As stated before these sediment levels were added to the removal phase.

The samples were vacuum filtered to determine concentration levels (mg/l). The Manning's equation was used to determine the velocity. This empirical formula is used to determine velocity for open flow channels and is multiplied by the stream's cross sectional area at the time of sampling to determine flow. The flow was multiplied by the concentration to determine total sediment generated for that sample's time frame.

RESULTS AND DISCUSSION

Results indicated that improved crossings mitigated total sediment production significantly at the 5% level compared to the unimproved crossing type with levels of 7,888.32 g with a standard error of 1,614.23 g and 204.72 g with a standard error of 64.77 of total sediment produced, respectively ($p<0.0001$). Section one of Kentucky's legislatively mandated BMPs states that operators should "use or install bridges or culverts to cross streams (perennial or intermittent) or ephemeral channels, where feasible" (Stringer and Perkins 2001) is supported by the results. Using any type of improved crossing causes on average a 97% decrease in sediment production of headwater streams.

Significant differences among improved crossing types did occur in terms of total sediment production (Fig. 1). Wood panel bridges yielded statistically significant lower amounts of sediment than culverts but PVC pipe bundles show no significant differences between bridges or culverts. These results mirror those of previously studied higher order perennial streams because bridges are an above crossing structure that requires no backfill to keep the structure stable compared to culverts (Taylor et al. 1999). Although not statistically different from the other tested improved crossing types the results do indicate that pipe bundles could be a recommended improved crossing type to mitigate sediment from headwater streams. Even though not being verified experimentally it is reasonable to assume that pipe bundles could be recommended for higher order perennial channels as well.



[ab] Different letters indicate significant differences at the 5% level

Figure 1. Mean total sediment produced by improved crossing structures.

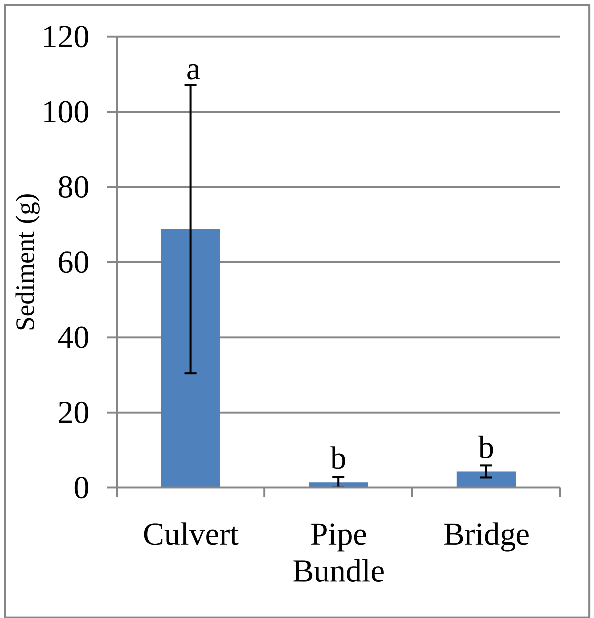
Sediment levels during the installation showed no significant differences among all crossing types (p=0.56). Sediment productions levels during installation were similar because the flow levels were typical for headwater streams. It was hypothesized that the backfill required for a culvert would cause significantly higher sediment levels than the other crossing types during construction but this was not the case. The low flow of headwater streams did not have the energy to move sediment that was being placed in the stream as backfill for culvert installation. Any sediment that was picked up had enough time to move out of suspension and not become a pollutant. The above channel design of a bridge introduces low amounts of sediment only from being dragged across the channel for installation and construction of approach ramps up to the edge of the wood panel structure. The pipe bundle only has backfill across the top of the structure and large amounts of sediment do not come into contact with the stream itself.

While no differences were found among crossings types during construction, there was a difference between improved crossings and fords during the pass over phase. Fords generated a total of 6,555.85 g with a standard error of 2,521.24 for all 22 passes. This was significantly higher than the average of 50.10 g with a standard error of 22.76 for the improved crossing types ($p<0.0001$). During the pass over phase significantly higher levels of sedimentation from the fords were caused by the skidder passing directly through the stream. Even with low base flows, having the skid trail go directly into the stream drastically impairs the water quality. There were no significant differences among improved crossing types during the actual passes over by a loaded cable skidder. This indicates that once the structures are in place they successfully mitigate sediment introduction into streams.

During rain events while the structures were still in place fords did not produce significantly higher levels of sediment than the improved crossing types (p=0.58). Sediment during rain events was 24.81 g with a standard error of 15.62 for improved crossing types and 897.85 g with a standard error of 816.85 for unimproved fords.

Fords and culverts are not significantly different than each other during rain events but are significantly higher than bridges and pipe bundles while the structures were still in place. But among improved crossing types culverts are significantly higher than bridges and pipe bundles during rain events (Fig. 2). There are no differences between pipe bundles and bridges. Culverts and unimproved fords had high levels of sediment production during rain events while the crossings were still installed because of the direct contact with sediment that the higher flow dislodges. In the case of unimproved fords previously dislodged sediment that was not moved by the low energy of the flow of headwater streams was moved into the stream when high flows eventually did occur. For culverts the source of sediment was the backfill around the pipe. Higher flows during rain events dislodged the backfill around the culvert moving sediment into the hydrologic system.

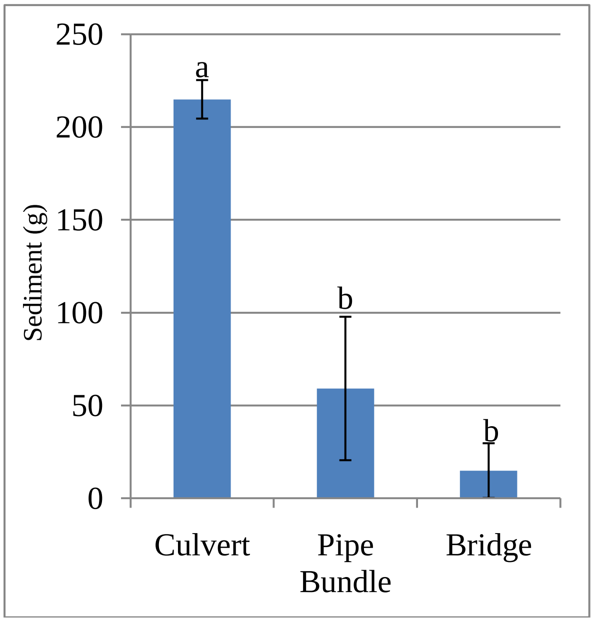
Pipe bundles and bridges did not have the backfill in the stream that culverts have while the structures are installed. There was backfill for the pipe bundles but it was above the stream and did not come into contact with the stream even during the higher flow rain events. A geotextile mat between the structure and backfill prevented dirt from entering the stream as well but still allowed for water to pass through the mat.
During removal and post-removal activities unimproved structures produced significantly higher amounts of sediment than improved crossing structures at the 5% level (p=0.04). Improved structures generated 395.77 g with a standard error of 189.19 compared to the lower value of 96.30 g with a standard error of 32.72 for all improved crossing types. Even though there was no disturbance occurring after removal and skidder ruts and streambanks were stabilized, unimproved fords continued to add high amounts of sediment to streams.



[ab] Different letters indicate significant differences at the 5% level

Figure 2. Mean sediment produced for improved crossing types during rain events while structures were still installed

Among improved crossing types bridges and PVC pipe bundle structures produced significantly less sediments than culverts during both their removal and during post-removal sampling and fords produced the largest amount of sediments during these phases at the 5% level (Fig. 3). Culverts contributed significantly lower amounts of sediment than fords but higher than pipe bundles and bridges because of the sediment remaining in streams after the culvert is removed. Bulldozers attempted to get into streams and to clean out as much backfill as possible. With the size limitations of headwater streams equipment operators could not fully remove backfill and it eventually flowed out of the crossing area during a high flow event as suspended sediment.



[ab] Different letters indicate significant differences at the 5% level

Figure 3. Mean total sediment generated during removal and post-removal activities among improved crossing types

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Estimation of Forestry Losses at Of-the-Road Operation

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SUMMARY

Forest roads carry out various functions. The number of roads in a forest is usually estimated by using the forest road network density measured in kilometers per square kilometer. If the network density is high enough, the Forest Management Unit (FMU) easily transports wood and the cargoes necessary for forest care. However, construction of a high density road network is expensive. On the contrary, if it is not enough roads in a forest, the forest management sustains various losses. Transportation becomes more expensive, the forest care operations are not carried out in due time, the damage is put with wildfires, etc. To define the forest road network optimum density we have suggested a forestry losses estimation technique.

INTRODUCTION

The motor transport is an integral technological part of the Russian forestry. The transport expenditures share in the total forestry expenditures amounts to 35% on average comparing with that of 10% in most branches of industry. The motor transport costs influence negatively the forestry economic results so their decrease is an important reserve for the national forestry efficiency improvement. The transport costs level in forestry costs is determined by several factors. One of them is a road network's disposition, density and technical conditions in forest areas.

The financial losses sustained by forest management units as a result of the road impassability form the certain share of the transport expenditures. Their establishment and estimation in the structure of the transport expenditures is a difficult task. The actual road impassability losses establishment method consists of quantitative local and forest management unit roads impassability losses estimation on the basis of the statistical data analysis and schemes of the forest management unit and their forest organization projects.

MATERIALS AND METHODS

The certain part of the forestry's transport expenditures is formed by its financial losses sustained from lack of good roads. One must estimate such losses to determine the forestry's work efficiency and, yet, to calculate the efficiency of the arrangement of the new forest roads.

To estimate the road network efficiency for the forestries (and not only for them) the economic efficiency's value is used calculated by following formula

$$H = P_c + \Delta T - E \cdot D - T,$$

where P_c - road lack transport losses of the forestry enterprises in the first evaluated year;

ΔT - effect resulted form the forest freight transport losses decrease in relation to the developed road network;

D – perspective forestry road network's construction, repair and maintenance for the calculated period (road component);

T – forestry freight transport costs using the perspective truck road network for the calculated period (transport component);

E - standard different time reduction ratio.

Apparently, it is impossible to estimate the economic efficiency H without having calculated the road lack transport losses of the forestry enterprises P_c first.

The losses entailed by the bad road conditions or road impassability can be divided into transport losses, forestry losses, social and other losses (see Fig. 1).

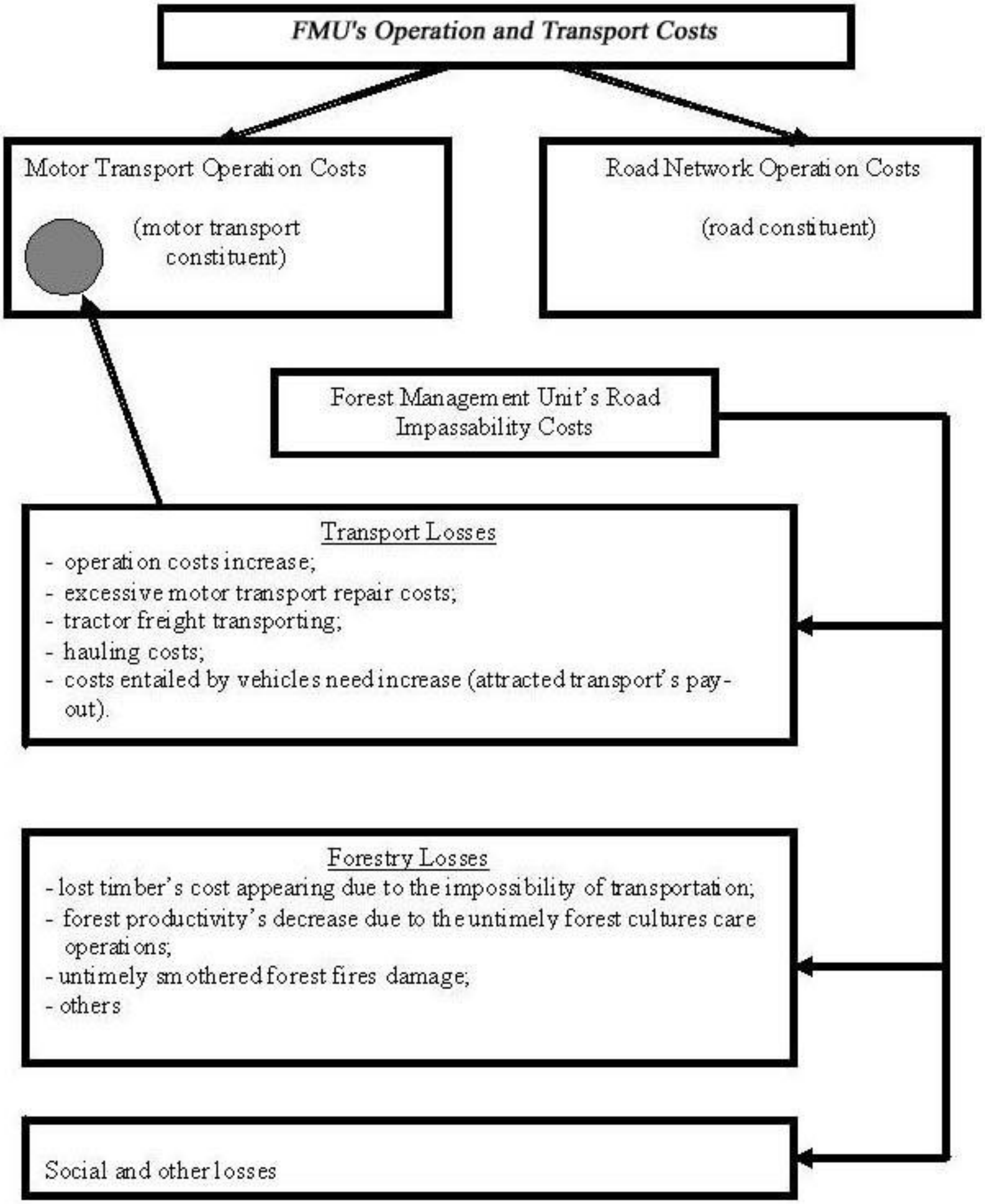

Figure 1. FMU's transport expenditures and financial losses structure due to road impassibility

We offer to estimate the forest management unit road impassability losses for the starting year as follows:

$$\Pi_c = \Delta P + \Delta C + \Delta T + \Delta \text{Б} + \Delta \Pi_p .$$

The operation road impassability freight costs growth can be explained by the increased fuel and lubricants consumption. The additional fuel and lubricants consumption costs amounts to the following:

$$\Delta P = 10^{-2} A \times z \times l \times N \times a_1 \times C_r (H_l + 0{,}5 \times H_z \times Q),$$

where **z** – roadless share of the ***l*** road network's operation length;

H_l, H_z – standard fuel consumption per 100 km (linear) and per 1 t of the freight (additional) consequently;

C_r - price of 1 kg fuel;

a_1 – fuel consumption increase rate due to roadless conditions

The extraordinary motor car repair costs entailed by the road impassibility traffic can be estimated by the following formula:

$$\Delta C = 10^{-3} A \times z \times l \times a_2 (H_m \times N + H_{aux}),$$

where **H_m, H_{aux}** – money repair costs and motor car auxiliary costs per 1000 km, roub. consequently;

a_2 – motor car repair costs increase rate at roadless conditions.

Additional costs due to tractor hauling instead of truck transporting:

$$\Delta T = a_3 \times \Delta P (1 - d),$$

where **d** – road network length share fit for truck transporting;

a_3 – transport work cost increase rate when using tractors.

Truck's tractor hauling in roadless conditions can be evaluated using the tractor operation costs estimation:

$$\Delta \text{Б} = \Delta T + \Delta P = \Delta P \, [1 + a_3 (1 - d)]$$

The bad roads in the forest management units (i.e. road impassability) (**z** **l**) entail the productivity decrease in these areas. If the other entitys' motor transport has been involved for the compensation thereof, the expenditures on it shall be equal to the following:

$$\Delta \Pi_p = z \times a_4 \times T_y + S_a$$

where **a_4** – motor transport productivity decrease rate in road conditions;.

S_a – total attracted transport rent costs

Thus, to estimate the FMU's transport losses caused by road impassability one needs the data featuring the forest road network, forest management unit's work first cost and **a_1 a_2 a_3 and a_4** rates. Their values can be calculated using the expert estimations, standard and statistical data. E. g., according to our data, **a_1** rate amounts to 2.5. The agricultural production transporting's research (which can be characterized by the same road conditions) brings to the conclusion that **a_2** rate amounts to 1.45-1.65. **a_3** rate can be estimated by comparing the truck and tractor operation calculations at the identical freights transporting. The preliminary calculations demonstrate **a_3 =** 1.3-1.5. Finally, the motor transport productivity decrease in roadless conditions is entailed by the average technical velocity fall. As for **a_4** it's rate for different types of the trucks amounts to 4.5-5.3.

The new trucks and tractors allow to expand the start information to establish **a_1 a_2 a_3 and a_4** rates, and the additional research work allow to precise this information. Indeed, this will be useful to determine the forest management unit's transport losses due to road impassability.

The road conditions influence most the fuel and lubricant consumption; we know that due to the roads lack the truck's maintenance term diminishes by 40% on average, and the supplementary capital repair expenditures increase by 30% [1].

According to the different estimates the first cost of the transporting on the truck roads with different pavement's types shall be 4-5 times less than on the earth roads. The research studies of the actual and planned fuel consumption in the forestries of the Central Russia have discovered the fuel's overconsumption in the size of 90$м^3$ per 1,000 km, at the expense of the overmileage, slip, fuel's overconsumption on the earth roads in the forestries with low transient pavement road network's density. The fuel and lubricant consumption shall be lower in the forestries with high road density and large freight turnover. However, the road conditions also influence the forestry's first cost in other way than through the transport costs. The transport costs diminution in the national economics by the means of the road construction can be realized by transportation's first cost lessening, freight and passengers' overmileage reduction. Calculating the road construction's efficiency in the forests one should take those savings into account resulted not only at the expense of the transportation and maintenance costs, but also accrued due to the forestry's road lack losses liquidation. The complete calculation of the economic efficiency facilitated by the capital investment in the road construction shall essentially reduce the roads recoupment term.

The road network's technical condition and development level in the forestries influence both transport costs and forestry's efficiency parameters (its production's first cost, labour productivity, gross production's (forest productivity) value, profitability) etc. Nowadays up to 70-80 % of the forest freight transporting is accomplished on the earth roads or no-pavement rods, i.e. in road lack conditions, actually. The technological operations in the forestry are separated in their time and place, but their particularities needs the strictly definite terms. The violation of the forestry activity's technology due to the term shift (caused by road lack) in the sylvula care operations, sowing, gum harvesting, forest nonwood production's harvesting, agrotechnical measures, as well as different felling types, indeed, entails the economic losses for the forestries. Their estimate for the forestry is utterly important for the transport network's development methods in the woodlands.

The forestry's direct and indirect losses encompass the lost production due to the impossibility of its haulage, losses resulted from the roadside vegetation's dustiness, price of the manures and herbicides misdelivered to the forest, forest's productivity decrease due to the untimely sylvula care operations, forestry's manufacturing technology violation and others).

CONCLUSIONS

A great deal of factors influencing the road network's disposition do not allow to account all of them for the development of the forest management unit's transport losses estimation methods because it's very difficult to state them in one index. Taking all of the expenditures into account in this situation, our task will be hampered without changing the calculation's result essentially. During the study of the forest management unit's losses caused by the roadless conditions for the subsequent establishing of the forest road network's development strategy improvement's efficiency it is possible, in our opinion, to exclude the group of the forest management unit's direct and indirect losses from the calculations. Some of them connected with the environment pollution will be insignificant due to small traffic's intensity, the estimation of another part (technological and forest care terms violations) is an object of the separate study, as it was stated before.

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Mulch Alternatives for Skid Road Reclamation

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Abstract:

A distinguishing characteristic of a Central Appalachian forest harvest site are the constructed skid roads used to access the felled timber that traverse the steep mountain sides. In West Virginia, the Logging Sediment Control Act, which mandates adherence to the state's Best Management Practices (BMPs), requires the reclamation of skid roads. The required reclamation procedures include stabilizing and retiring the skid road by outsloping, removing berms, installing water bars, seeding, and mulching the road surface, before skidding on other sites can occur. While mulching is only required on skid roads with grades over twenty percent, the steep, broken topography of the region results in many of the roads requiring this treatment. Traditionally, a logger would hand disperse straw over these roads, or in areas close to the haul roads they may use a spray hydromulch to meet these requirements. A relatively new product consisting of water soluble polyacrylamide polymers (PAM-12) may also provide cost efficient protection of the soil surfaces. A study is being completed to reclaim 12 skid roads with different combinations of manual, spray hydromulch, and PAM-12 treatments. Sediment from each of the trial and control skid roads is being collected and measured in order to quantify the effectiveness of each treatment. Costing procedures for the traditional and the newer mulching alternatives are also presented in order to assist operators make effective decisions for their specific site conditions.

Introduction:

Forest roads and landings are often a primary source of potential erosion and sedimentation from logging operations and are a continuing concern in the steep mountains of West Virginia (Egan et al. 1996; Egan et al. 1998). Many states have developed a set of forest practice standards or best management practices (BMPs) that require the control of sediments from exposed areas (Grushecky et al. 2007). These practices often include leaving log slash, seeding fill areas, creating broad-based drainage dips, daylighting and matting (Grushecky et al. 2007; Kochenderfer 1970). However, the costs and efforts to reclaim forest roads and follow the BMPs can be considerable (Egan 1999).

A distinguishing characteristic of a Central Appalachian forest harvest site are the constructed skid roads used to access the felled timber that traverse the steep mountain sides. In West Virginia, the Logging Sediment Control Act (LSCA), which mandates adherence to the state's Best Management Practices (BMPs), requires the reclamation of skid roads. The required reclamation procedures include stabilizing and retiring the skid road by outsloping, removing berms, installing water bars, seeding, and mulching the road surface, before skidding on other sites can occur. Through the application of these BMPs, water quality impacts from timber harvesting activities are minimized (Wang et al. 2007). As landings, roads and skid roads are the largest potential source for sedimentation; it is natural that the forestry community should focus resources to improve efforts in these areas (Grushecky et al. 2007). When vegetation does not quickly establish erosion can occur, leading to sedimentation of nearby streams. Sediments that make their way to a stream can have negative effects on both vertebrate and non-vertebrate aquatic wildlife population and the entire stream ecosystem (Grushecky et al. 2007).

PAM-12, a relatively new technology developed by ENCAP, LLC, uses recycled office paper byproducts to create a pelletized mulch that can be used to stabilize soil, improve seed establishment and reduce hydrophobicity of the soil (Sabel 2007). The key component in this mulch is the polymer polyacrylamide (PAM), which has been used in agriculture for decades to increase infiltration, and reduce sediment loss; however it has always been a difficult to apply (Sabel 2007; Sojka et al. 1998). PAM-12 addresses these application issues through the encapsulation process used to create the mulch granules. Polyacrylamide is designed to cause small soil particles to aggregate into larger soil particles, making these larger soil particles more difficult for water to move. PAM-12 has been tested in postfire rehabilitation, against traditional straw methods, and shown to reduce total soil movement by over 60 percent compared to straw (Sabel 2007). New vegetation cover establishment was shown to be much higher using PAM-12 opposed to traditional straw, according to Davidson et al. (2008). The increased vegetation response to the PAM-12 treatments was most likely the result of the increased retention of seed on the slope based on the increased soil stability and water availability provided by the PAM-12 application (Davidson et al. 2008).

Additionally, minimizing costs associated with reclamation activities is a continuing concern for logging contractors. PAM-12 has the potential to be more economically efficient than traditional methods. A Virginia Department of Transportation trial compared PAM-12 application to their traditional straw and seed method and found that PAM-12 could be more cost effective because it only requires one pass to complete the coverage, whereas traditional straw methods require 3 passes. They also suggested that PAM-12 products may become more desirable as transportation costs for straw increase and as straw availability decreases.

Methods

Study sites were identified in the Upper Elk Watershed of the Elk River Watershed in West Virginia (Figure 1). Within this watershed private individuals own most of the land, however 26 percent is public land in the Monongahela National Forest. The Upper Elk watershed is 95% forested and supports some of the highest quality hardwoods in the United States.

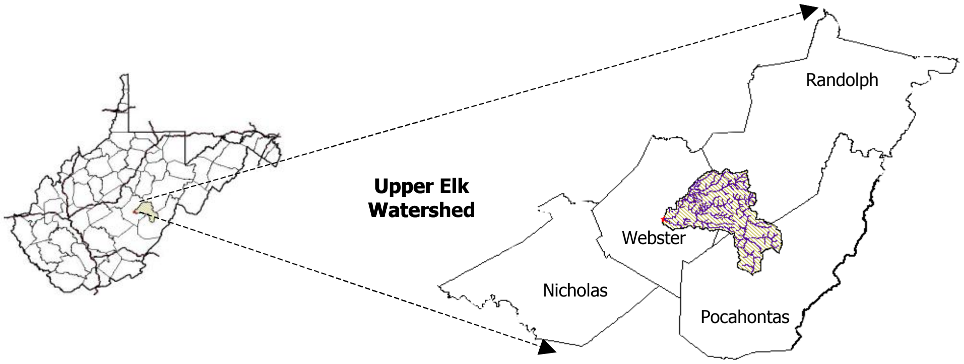

Figure 1. Location of the Upper Elk Watershed in West Virginia.

Collaboration among partner organizations, local logging contractors and landowners provided excellent opportunities to test new reclamation methods. Twelve skid road sections were identified on two different timber harvest units on privately owned forestlands. The average section is approximately 18.3 feet wide and 80 feet long, with a slope break or a waterbar located on the upper end. The lower end of the road sections have soil erosion plots established based on the methodologies developed by Robichaud and Brown (2002). On average, the road sections are approximately 1466 ft^2 (0.03 acres). The skid roads segments had been constructed with slopes between 15 to 20%, which according to the WV BMPs require reclamation after harvesting. Specific requirements include the installation of waterbars, smoothing of the road surface, outsloping of the road, and removal of any outside berms that restrict drainage. While mulch is only required on slopes over 20%, all identified road sections in this study all were treated with a mulch or mulch equivalent. Each of the four different mulch and seed treatments are applied on three road sections. The treatment types are as follows:

1. Basic BMP compliance standard of straw mulch and seeding
2. Hydromulch and seeding
3. Dry application of PAM-12 and seeding
4. Wet application of PAM-12 and seeding

The basic straw mulch and seeding and the dry application of PAM-12 are both hand applied, while the hydromulch and wet application of PAM-12 are applied using a hydromulch and seeding system. The hydromulch system used in this study has been specially designed for use on logging skid roads, where traditional systems are unable to reach.

U.S. Weather Bureau type rain gauges are used to monitor rainfall amounts at each of the two harvest unit sites. Sediment trapped in the soil erosion plots are collected at regular intervals and adjusted for water inputs in order to quantify the load from each treatment method and the resulting change of each method over the traditional BMP reclamation process.

Discussion

At the time of this report, the reclamation process has started, however the application of the mulch has not yet occurred. Mulch costs for each of the systems will be calculated on the actual cost to purchase all material and the labor and equipment required for application. Based on previously published research, we expect to find that the PAM-12 is an effective alternative to straw mulch and seed that has been the standard for many years under the WV BMPs (Davidson et al. 2008; Virginia Department of Transportation 2006).

Supply costs of each material vary drastically on a per unit basis (Table 1), however the application rate has a large impact on the overall cost of the mulch material required per acre. For example, the recommended rates for straw mulch, the least expensive material was 4000 lbs/acre for a on a 3:1 slope, while hydromulching material rates for paper, wood fiber or mixed mulch were closer to 3000 lbs/acre on similar slopes. PAM-12 application rates were lower at 1500 lbs per acre. Other costs involved with each mulch method include application equipment and labor costs. The wood fiber and paper mulch products are usually applied with a hydromulching system that can cost anywhere from a few thousand dollars to hundreds of thousands of dollars. Unfortunately, most hydromulchers are not capable of traversing the steep mountainsides where skid road mulching is required (Grushecky et al. 2006), so custom equipment must be developed. PAM-12 can also be applied wet through a hydromulcher in order to immediately activate the granules when soil conditions are dry. The costs associated with the hydromulch equipment can often be partially offset by the large capacity, high efficiency, and speed that these machines work.

Table 1. Application rates and costs of mulch materials for skid road reclamation

Mulch Material			Cost/Unit	Cost/Acre
PAM-12	30	bags/acre	$ 30.00	$ 900.00
	50	lbs/bag		
	1500	lbs/acre		
Wood Fiber Mulch	60	bags/acre	$ 15.45	$ 927.00
	50	lbs/bag		
	3000	lbs/acre		
Paper Mulch	60	bags/acre	$ 10.15	$ 609.00
	50	lbs/bag		
	3000	lbs/acre		
Straw Mulch	80	bales/acre	$ 5.60	$ 448.00
	50	lbs/bale		
	4000	lbs/ac		

In contrast, the manual labor required to spread straw mulch over remote skid roads can be high, compounded with lower productivity than that of a hydromulcher. Straw bales are often delivered to the landing area where they then must be manually moved to the application site. Bales can be cumbersome and bulky in comparison to packaged materials such as the paper and wood fiber mulch and PAM-12, in which most of the air space is removed and packages are created for easy handling. With skid roads often over 3000 feet long, the time and effort required to move many large straw bales can be significant. Manual application of PAM-12 is also appropriate when the soils contain enough moisture to activate the granules at the time of application. This dry application method is potentially the least expensive option, as a broadcast spreader is the only equipment required. The spreader can distribute a combined mixture of seed, PAM-12, fertilizer, and most other soil additives, in a single pass by one person. However, this method is only appropriate when the soils are moist enough to activate the granules. Otherwise, the PAM-12 will not activate until the next precipitation event and could potentially fail to provide necessary soil protection during that specific event.

Each of the mulching method must also include appropriate applications of seed, fertilizer, lime, or other compounds where necessary. Each of the mulch methods work to protect the soil from moving water. Seeding the skid roads provides an extra layer of protection that will stabilize the soils as the mulch eventually degrades or is displaced from the site. The hydromulch applications soak the seeds in a water and mulch slurry that will help the seeds germinate and establish themselves quickly. Dry applications typically require the seeds to germinate naturally once applied to the site, often resulting in fewer seeds growing and an overall slower establishment of vegetative cover. While the reclamation process can be carried out with many different mulch and mulch application options, logging contractors are more apt to adopt options that provide the most protection at the least overall cost.

Conclusion

Mulch applications on skid roads play an important part in protecting forest soils from erosion. The WV LSCA requires that logging operators follow BMP guidelines to reclaim skid roads, including the application of mulch on the steeper roads. While logging contractors have typically used straw mulch that can be difficult and time consuming to apply, new mulch opportunities are available that may be both effective and less expensive to apply.

Note: This project is funded through a 319 CWA award by the WV Department of Environmental Protection. PAM-12 is a registered trademark of ENCAP, LLC. Trade or brand names used in this publication are for educational purposes only. The use of such product names does not imply endorsement by the WVU Extension Service to the exclusion of other products that may be equally suitable.

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A Systematic Approach to Increasing the Payload Capacity of Log Trucks within Existing Regulatory Frameworks

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Abstract

The transportation of raw fiber from the harvesting site to the conversion mill is a major cost in the overall supply chain. When the trucking routes are on public roadways, weight and dimension regulations can be load-limiting factors. Significant operational savings can be realized if new truck configurations with increased gross weights can be approved for legal operation on the public system. Beyond the productivity gains, other societal benefits associated with deploying larger capacity combinations include reductions (expressed in units of payload) in fuel consumed, in Green House Gases (GHGs) generated, and in exhaust emissions. To achieve these benefits, a systematic process is applied, using generally accepted engineering methods, to address the factors that currently limit the move to heavier trucks.

This paper describes the approach and methods that have been successfully used by FPInnovations - Feric Division in concert with government and industry, to bring about regulatory approvals for new configurations with increased allowable weights without compromising safety or the infrastructure. The key elements typically addressed are: truck dynamic stability and handling characteristics, pavement and bridge impacts, road fit, and ease of enforcement for compliance. This paper discusses each of these elements and includes examples where the process has resulted in the deployment of new, more productive combinations.

Introduction

The transportation of raw fiber from the harvesting site to the conversion mill is a major cost in the overall supply chain. When the trucking routes are on public roadways where weight and dimension regulations are load-limiting factors, significant operational savings can be realized if new truck configurations with increased gross weights can be legally operated on the public system. Beyond the productivity gains, other societal benefits associated with deploying these larger capacity combinations include reductions (expressed in units of payload) in fuel consumed, in Green House Gases (GHGs) generated, and in exhaust emissions. More productive vehicles will also reduce the number of trucks on the roads and in turn, help to alleviate the shortage of qualified drivers.

From the regulatory perspective, it must be recognized that the weight and dimensional limits for heavy trucks are generally in place to help ensure that an acceptable level of road safety is maintained and that the public infrastructure is not compromised. Within this overriding perspective, a systematic process that uses the appropriate engineering methods can be applied to address the regulatory hurdles that typically limit the increase of truck size and weights.

Methodology

In general, four key areas (Figure 1) need to be addressed by regulating agencies when considering the approval of any new truck or truck/trailer combination: the impacts on pavements and bridges, dynamic stability and handling characteristics, geometric road fit, and the ease of which any new configuration "fits" within existing regulations and enforcement protocols.

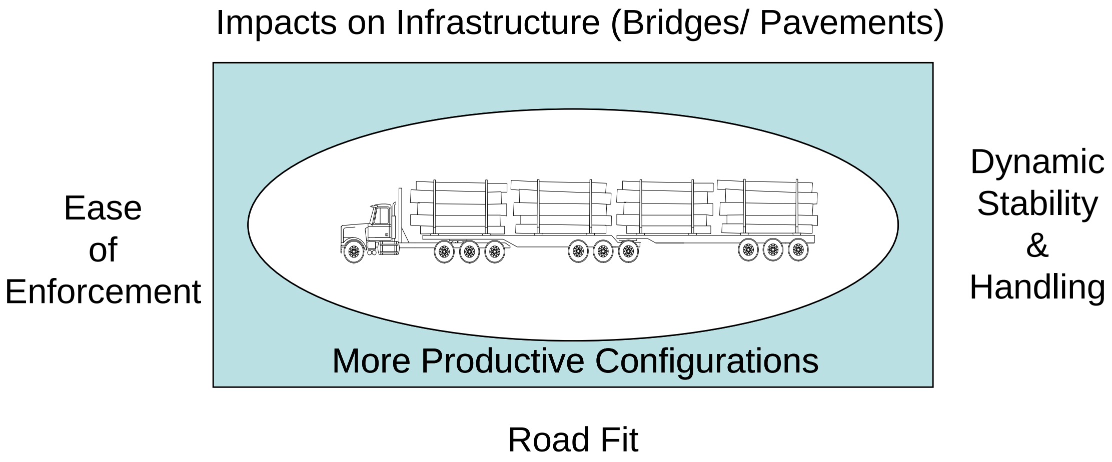

Figure1: Key elements limiting truck weights and dimensions

The initial step in this process is to accurately characterize the load (or range of loads) in terms of log lengths and the densities of the log bundles (includes air voids within the load). From this point, the most-likely increased-capacity configuration(s) can be selected and the new payload estimates can be established. As a simple example, if the existing situation is such that a six-axle tractor/semi-trailer reaches maximum axle weight capacity but room remains for more payload volume, then a potential option might be the addition of another axle to the trailer. However, the existing regulations would not allow a four-axle semi-trailer, a seven-axle combination, or gross weights to exceed the six-axle maximum limit. From this point, the process to address the limiting factors begins. The process is usually iterative in nature because as one key element (or limiting factor) is addressed, another is usually affected.

Assessment of Impacts on Infrastructure: The impacts on pavements and bridges are two key areas of concern and will more or less dictate the layout of the configuration in terms of axle numbers, location/spacing of axles, and axle group weights.

In terms of assessing pavement impacts, the engineering method generally accepted by regulating agencies is the Equivalent Single Axle Loading (ESAL) approach (HRB.1962). This method is a means of estimating the rate at which heavy trucks cause pavements to wear; an ESAL value is assigned to a configuration through an analysis that determines the equivalent number of passes that an 8.18 tonne (18,000lb) single axle would impart to the pavement. For instance, if an existing configuration operating at full legal weights imparts a given number of ESALs, with the addition of another axle the payload can be increased to a point where the overall ESAL value remains the same as the original; a good example of this is replacing a tandem axle group with a tridem group. Another valuable metric is the number of ESALs per tonne payload.

Bridge impacts are also a prime consideration. These analyses are usually undertaken by the engineering staff within the regulating agency as they often have intimate knowledge of the individual structures. This process usually dictates where additional axles are placed within a given configuration and the maximum loads that are allowed on the various axle groups. This is frequently the most challenging step in the overall process. At times when a particular bridge is the limiting factor, a bridge upgrading assessment and financial analysis is undertaken to determine if there is a business case to justify the upgrade; these activities are usually financed by the proponent or in some cases, are cost-shared with the appropriate government agency.

Dynamic Stability and Handling: As previously discussed, the bridge and pavement impact analyses will more or less dictate the layout of the configuration in terms of axle numbers, location of axles, and axle group weights. Using these references, the proposed configuration can then be designed and, in turn, assessed for safety performance using internationally accepted computer modeling tools and methods (Prem et al. 2002); this involves running a series of vehicle dynamic simulations to establish the dynamic stability and handling performance that is characteristic of the proposed configuration. The various resulting measures of performance (Appendix I) are then compared to the accepted standards (Pearson 2002 and El-Gindy 1992). Where the proposed configuration is found deficient, modifications to improve performance will be tested in an attempt to arrive at an optimal design.

Dynamic stability, in general, refers to the ability of the vehicle to resist rolling over during a high speed steady-state turn or an evasive maneuver; the specific performance measures for dynamic stability are *rollover threshold, rearward amplification, and load transfer ratio*. Handling refers to the ease with which the driver is able to control the vehicle; the measures for this are *understeer coefficient, friction demand, and lateral friction utilization*.

Road Fit: This element is generally concerned with ensuring that the truck/load combination remains within its designated lane on the roadway and does not encroach into adjacent lanes while traveling straight ahead or during low or high speed turns. Basic truck and load dimensions such as width and length are the more obvious factors, however other, less obvious ones are important as well, e.g., front and rear overhangs as are vehicle parameters such as wheel base, trailer kingpin offset, and trailer turn centre to name a few. A similar approach to that described in the *Dynamic Stability and Handling* section is employed using established standards (Appendix I); specific performance measures for road fit include low speed offtracking, high speed steady state offtracking, and transient offtracking.

Ease of Enforcement: In some cases, the resultant proposed configuration may incorporate special components or arrangements that are not obvious or are difficult to determine functionality when roadside enforcement officers inspect for compliance. An example is a liftable axle which must be deployed when on the public highway but can be lifted when empty or during off-highway travel. When deployed, it must also be loaded within legal limits. In a case such as this, it is difficult for enforcement officers to ensure the configuration remains in compliance. One possible solution is an on-board monitoring device that, through a series of sensors, records or transmits a record of relevant information easily accessed by the authorities.

An initial pass through this overall process usually results in conflicting requirements and the steps must be reworked to produce an adjusted version of the configuration. For example, in the process of designing the ideal bridge-friendly combination, the wheel bases of a tractor and trailer may be extended to a point where, in terms of road fit, the off-tracking performance fails; this then leads to a compromise that will somewhat satisfy both parameters, but is less than ideal for either.

Conclusions

Larger, more productive vehicles present a possible solution to many of the industrial and societal challenges currently facing the forest industry. Where regulating agencies are open to the concept of larger combinations, provided they are responsibly evaluated, the process described in this paper can lead to the deployment of configurations capable of transporting significantly greater payloads while not compromising safety or the infrastructure. FPInnovations has realized a number of successes as a result of this process; these include tridem drive trucks and tractors, extended length single and double trailer combinations, and flexible trailer systems where axle groups can be added or detached as seasonal changes are reflected in the regulations.

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Appendix I

Description of Heavy Vehicle Performance Measures

Dynamic Stability

Static Rollover Threshold (SRT): This is the level of steady lateral acceleration beyond which the configuration rolls over. The measure is expressed as the lateral acceleration (in gs) at which all wheels on one side, except the steer axle, lift off the ground. Configuration performance is considered satisfactory if the static rollover threshold is greater than or equal to 0.35 g.

Load Transfer Ratio (LTR): The load transfer ratio is defined as the ratio of the absolute value of the difference between the sum of right wheel loads and the sum of the left wheel loads, to the sum of all the wheel loads. The front steering axle is excluded from the calculations because of its relatively high roll compliance. Configuration performance is considered satisfactory if the LTR is less than or equal to 0.60 (TAC performance standard). This performance measure is evaluated during a rapid lane change maneuver conducted at 100 km/h, yielding a lateral acceleration amplitude of 0.15 g and a period of 2.5 seconds at the tractor's steering axle.

Rearward Amplification (RWA): Rearward amplification is defined as the ratio of the peak lateral acceleration at the mass centre of the rearmost trailer to that developed at the mass centre of the tractor. Configuration performance is considered satisfactory if the RWA is less than or equal to 2.2, which is the current TAC performance standard. This performance measure is evaluated in the same maneuver as LTR.

Handling

Understeer Coefficient at 0.25 gs (USC): This measure is used to evaluate handling performance at steady-state conditions by calculating the USC at 0.25 gs. This measure is expressed in degrees per g which represents the slope of the handling diagram. Positive and negative values indicate understeer and oversteer levels respectively. This performance measure is determined during a ramp steer maneuver (ramp steer rate of 2 deg/sec at steering wheel) at a forward velocity of 100 km/h. The pass/fail criterion is addressed by comparing the understeer coefficient with the critical understeer coefficient, which can be expressed as -Lg/U2, where U is the vehicle speed (U = 27.77 m/s (100 km/h)), L is the tractor or truck wheelbase (in meters), and g is acceleration due to gravity (9.81 m/s^2). If the value of the USC is greater than the critical value, the vehicle will meet the criterion (TAC performance standard).

Friction Demand (FD): The friction demand performance measure describes the non-tractive tire friction levels required at the drive axles of a tractor. Excessive friction demand is a contributing factor to jackknife and also results in excessive tire wear. Friction demand is the absolute value of the ratio of the resultant shear force acting at the drive tires divided by the cosine of the tractor/trailer articulation angle to the vertical load on the drive tires. Configuration performance is considered satisfactory if FD is less than or equal to 0.1 (TAC performance standard). This performance measure is evaluated in a 90-degree turn at a vehicle speed of 8.25 km/h. During the maneuver, the centre of the front steer axle tracks an arc with a 12.8-m radius (approximately a 14-m outside-wheel-path radius).

Lateral Friction Utilization (LFU): Lateral friction utilization is a measure proposed by National Research Council of Canada (NRC) to characterize the highest level of the lateral friction utilization at the steering axle. LFU is defined as the ratio of the sum of lateral forces to the vertical load, and the peak tire/road coefficient of adhesion. The tires of a steering axle that achieves a lateral friction utilization level of 1 are said to be saturated. Configuration performance is considered satisfactory if LFU is less than or equal to 0.80 (NRC recommended performance standard). Initially this performance measure was evaluated on a high friction surface. Feric modified this measure by evaluating LFU on low friction surfaces, which are more critical for steering performance, by using low friction tire characteristics (□□= 0.2). This performance measure is evaluated using the same maneuver as FD.

Road Fit

Low Speed Offtracking (LSOT): Low speed offtracking is measured as the maximum lateral displacement of the centre-line of the last axle of the configuration from the path taken by the centre of the steer axle. Configuration performance is considered satisfactory if LSOT is less than or equal to 6 m (TAC performance standard). This performance measure is evaluated using the same manoeuvre as FD and LFU.

High Speed Steady State Offtracking (HSOT): High speed offtracking is measured as the maximum lateral displacement of the centre-line of the last axle of the configuration from the path taken by the centre of the steer axle. Configuration performance is considered satisfactory if HSOT is less than or equal to 0.46 m (TAC performance standard). This value represents a minimal clearance of 0.15 m between the trailer tires and the outside of a 3.66-m wide conventional traffic lane. This performance measure is evaluated when the vehicle is operated in a 393-m curve radius, at a speed of 100 km/h, thereby attaining a steady lateral acceleration level of 0.2 g.

Transient Offtracking (TOT): Transient offtracking is measured as the maximum lateral displacement of the centre-line of the last axle of the configuration from the path taken by the centre of the steer axle. Configuration performance is considered satisfactory if TOT is less than or equal to 0.8 m (TAC performance standard). This performance measure is evaluated in the same manoeuvre as LTR and RWA.

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Opportunities for Reducing Hauling Costs With Longer Logs

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Costs of log transport have markedly increased due to rapidly rising fuel costs and higher emission standards. One opportunity to reduce log transport costs is to increase load size. For trucks with pole trailers, hauling longer logs potentially permits increasing load size in the western states. We examine potential increases in load size with longer logs and discuss associated issues including road standards, log value recovery, and mill handling costs and constraints.

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Optimization of pooled log transport

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More efficient transport of timber has become an issue of increasing importance as fuel costs have risen. Most changes in log transport systems have sought to increase trucking efficiency through enhanced routing, which can increase the percentage of loaded miles and, perhaps, reduce the number of trucks required to deliver a given quantity of wood. For this study, a trucking company using dispatch to organize log deliveries provided data for an entire day of operation. Information was available on truck arrival/departure times from mills and logging decks, plus driving distances between all source and destination points. Trucks started and finished their working day at a single location. A person dispatched trucks in a manner felt to reduce unloaded mileage, although not in an optimal sense. For this study, a model of truck dispatch was also created and a simulated annealing approach was used to generate near optimal routing solutions. Among several constraints, the objective function could be altered to assign a variable penalty for trucks sitting in a queue waiting to be loaded. This reduced 'bunching' of truck arrivals and made the solutions more realistic. For the day in question, 68 trucks delivered 171 loads from 22 loggers to 13 mills. This required a total driven distance of 20,630 miles, 49 percent of which (10,028 miles) was loaded. The optimized results indicated that, had the algorithm been used to dispatch trucks, the total miles for the same delivery schedule could have been reduced to 17,127, 55 percent of which were loaded.

Harvesting Biomass to Improve Low-Value Beech Dominated Hardwood Stands in Maine

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ABSTRACT

Feller-buncher productivity and residual stand damage were evaluated for a mechanical whole-tree harvest removing pulpwood and non-traditional biomass (energywood) from natural hardwood stands dominated by small diameter, diseased, beech (*Fagus grandifolia* Ehrn.) in central Maine. Two trail spacings (18.3 m and 12.2 m) were tested to determine if modified harvesting practices could improve the productivity of a tracked, swing to tree, feller-buncher. Residual stand damage was evaluated following the harvest to assess the relative impact of harvesting and skidding operations at both spacings. Time studies were conducted on the feller-buncher to assess the influence of small-diameter stems and narrower trail spacings on the harvesting operation. Feller-buncher productivity did not differ significantly ($p = 0.48$) between the two trail spacings. Mean productivity (green tonnes per hour) was 74.2 using an 18.3 m spacing and 57.4 using a spacing of 12.2 m. Time study elements did not differ significantly between the two trail spacings (p-values > 0.05). The proportion of residual trees receiving one or more injuries ($\bar{x}$ = 34% at 18.3 m, $\bar{x}$ = 43% at 12.2 m) also did not differ significantly (p = 0.12) between the two trail spacing treatments. Based on the results of this study there seem to be no advantages to selecting one of the two trail spacing over the other.

INTRODUCTION

Recently, interest in using woody forest biomass as a renewable alternative fuel source in the United States has resurfaced. Currently low-value, small, defective trees, as well as previously unmerchantable species are becoming economically viable forest products as a result of whole-tree harvest technology and improved markets for whole-tree chips. Growing markets for non-traditional forest biomass (energywood) have the potential to assist landowners in improving the composition and quality of their stands by improving the economics of costly rehabilitation work. In Maine, a stand condition where a significant opportunity exists in this regard can be found on mid-site sugar maple (*Acer saccharum* Marsh.), yellow birch (*Betula alleghaniensis* Britt.) stands that were shelterwood harvested over the past 20 or more years and have become dominated by diseased beech (*Fagus grandifolia* Ehrn.). There is currently no financially feasible silvicultural approach to rehabilitating these sites by shifting the regeneration to maple and yellow birch; however, an integrated system of biomass harvesting and vegetation management may provide an economic means for landowners to rehabilitate these stands.

This article reports on the energywood harvesting phase of rehabilitating young beech-dominated hardwood stands in Maine. The purpose of this research was to investigate the influence of 18.3 m and 12.2 m trail spacings on a whole-tree energywood harvest operation. 18.3 m was selected as a spacing commonly used in whole-tree thinning operations in Maine. A narrower spacing of 12.2 m was selected to evaluate if feller-buncher productivity could be improved by limiting its movement to the harvest corridor, relying mainly on the boom reach to harvest the residual strips in between. An assessment of residual stand damage was used to determine the relative impact of the two harvest layouts.

METHODS

Three study blocks, each 1.2 ha (73.2 m x 165.0 m) in size, were established in natural hardwood stands dominated by small diameter, diseased beech trees in Township 32, in Hancock County, Maine. Blocks were located within 1,500 m of one another. Each of the three study blocks were divided in half (0.6 ha – 36.6 m x 165.0 m) and assigned one of two treatments; (*i*) mechanized whole-tree harvest using a trail spacing of 18.3 m (measured from trail centerlines), and (*ii*) mechanized whole-tree harvest using a trail spacing of 18.3 m. Trail spacings were established by using one trail in the center of harvest blocks assigned a spacing of 18.3 m, and three trails in harvest blocks assigned a spacing of 12.2 m. The harvest prescription for each block was to remove the existing beech-striped maple (*Acer pensylvanicum* L.) understory, including all stems >2.54 cm DBH, while leaving overstory sugar maple and yellow birch unless they were standing in the trail.

A preharvest cruise was used to assess stand composition (Figure 6) and biomass quantity. Twenty four, 0.002 ha fixed radius sample plot centers were established in each harvest block. All stems, including both live and standing dead, >2.54 cm at DBH within the plot were sampled. Species and DBH were recorded for each sampled tree. Total green tree weight estimates were calculated using species specific DBH-weight relationship equations developed by Young *et al*. (1980).

Harvest operations were conducted by a contractor hired by Huber Resources Corporation using a John Deere 853G tracked feller-buncher with an FS22 continuous type disk saw felling head. Harvest activities were recorded using two handheld digital video cameras so feller-buncher movements could be analyzed later. One camera was held inside the machine cab behind the operator to record machine movements associated with the felling head. The second camera was operated at a safe distance away from the machine to record machine movements associated with the carriage, cab, and boom. A post-harvest time study was conducted on each harvest block using the harvest videos and UMTPlus® time and motion study software (Laubrass Inc. 2006). The harvesting work cycle was divided into the following elements:

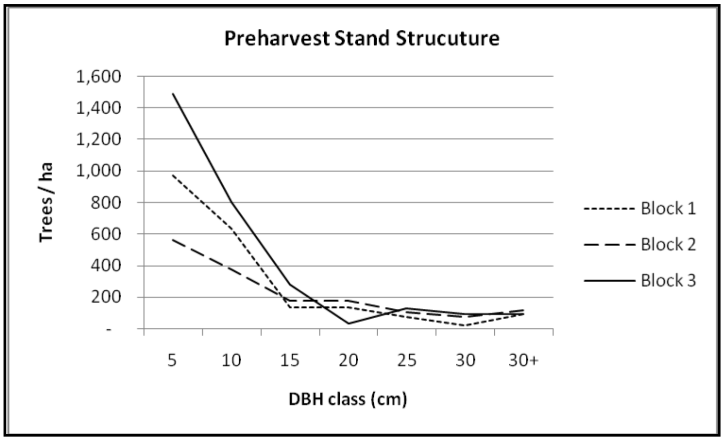

Figure 1. Preharvest stand structure of the three study blocks.

Productive movement: Begins when the feller-buncher starts to move (track movement), and ends when the harvester stops moving.

Selecting tree: Begins when the feller-buncher begins swinging and/or moving the boom towards the tree and ends just before the tree is cut.

Felling: Begins when the head begins cutting through the tree and ends when the stem has been accumulated (i.e. the accumulator grab arms on the head have secured the tree).

Bunching: Begins after the feller-buncher has cut the last tree and starts moving towards the twitch location and ends when the bunch is dropped from the felling head.

Time study analysis began when the feller-buncher started cutting within the harvest block and ended when it exited the harvest block. The same researcher conducted the time studies for all blocks. All analysis is based on productive machine hours.

Energywood was the primary product from this harvest; however, the contractor also sorted out pulp quality logs. Each truckload of pulp was weighed at the mill to determine the total tonnage removed from each block. Energywood produced on each block was estimated by subtracting pulpwood weights and estimates of residual biomass based on post-harvest cruise data from preharvest biomass estimates.

Following harvesting and skidding operations, residual trees were examined for damage. A complete tally of all standing residual trees 2.54 cm or greater at DBH was conducted within each harvest block.

Analysis of variance was used to determine whether the harvesting treatments were statistically different. All statistical analyses were performed using a significance level of $\alpha = 0.05$. The Shapiro-Wilk's W-statistic was used to test the null hypothesis that samples came from normally distributed populations. A Brown-Forsythe test was used to verify the assumption of equal variance of the two samples.

RESULTS

Production studies

Table 1. Summary of total productive harvest time (in decimal hours), and productivity in tonnes/hr and stems/hr by harvest block and treatment.

Harvest Treatment	Total harvest time, (h.hh)	Productivity, tonnes/hr	Productivity, Stems/hr
18.3 m trail spacing			
1a	2.08	58.1	355
2a	1.85	106.9	292
3b	2.31	57.7	358
Avg.	2.08	74.2	335
12.2m trail spacing			
1b	2.39	36.4	381
2b	1.91	83.5	325
3a	2.59	52.3	361
Avg.	2.29	57.4	356

Overall, total harvesting times varied from 1.9 hours (blocks 2a and 2b) to 2.6 hours (block 3a), but there were no significant ($F = 0.80$, $p = 0.4204$) differences in total harvesting time between treatments. On average, blocks harvested using the wider trail spacing harvested 16.8 more tonnes of total biomass (pulpwood and energywood) per productive hour than blocks harvested using the narrower trail spacing; however, the difference was not significant ($F = 0.53$, $p = 0.5059$). The highest feller-buncher productivity (106.9 tonnes/productive hr) was achieved on block 2a using the wider trail spacing, and the lowest productivity (52.3 tonnes/productive hr) occurred on block 1b using the narrower trail spacing. The number of trees felled per productive hour varied by harvest block from 292 – 381, but also was not significantly different between treatments (*F* = 0.59, *p* = 0.4862).

Similar proportions of time were allocated to each of the four work tasks tracked in the time study (Figure 7). There were no significant differences in total bunching times (*F* = 0.94, *p* = 0.3876), moving times (*F* = 0.28, *p* = 0.4082), or selecting times (*F* = 0.54, *p* = 0.5042) between treatments. Total felling time composed an insignificant proportion (less than 2%) of the total harvest times and was not analyzed.

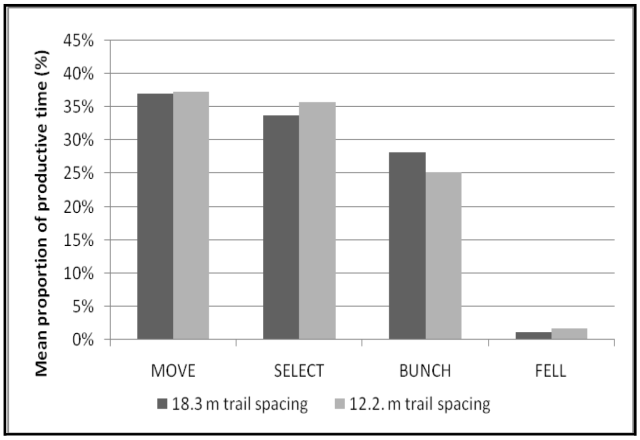

Figure 2. The average proportion of total productive time allocated to the feller-buncher work tasks move, select, bunch and fell by treatment treatment.

Stand damage studies

At least 30% of the trees in each block were damaged to some degree. Out of a total of 595 residual trees assessed for damage across the three harvest blocks treated using the 18.3 m trail spacing, 200 (34%) were found to be injured. Mean diameter of trees wounded was 4.1 cm (± 4.4 cm). The blocks treated with the 12.2 m trail spacing had a higher proportion of residual trees injured (163 out of 376, 43%); however, the difference was not significant (*F* = 3.84, *p* = 0.1217). Half of the residual stems on blocks 2b and 3a were injured. Mean diameter of trees wounded at this spacing was 6.6 cm (± 5.5 cm). 37% and 35% of all injured trees had observed root and/or crown damage for the wider and narrower trail spacing, respectively.

Only a small proportion of the stems wounded in either treatment received multiple wounds and the average number of injuries found on trees wounded multiple times was relatively low. At the wider trail spacing the mean number of wounds per injured tree was 1.2 with over 80% of injured trees receiving only one wound. On blocks treated with the narrower trail spacing, the mean number of wounds per injured tree was 1.3, with an average of 74% of injured trees receiving only one wound. Less than 12% of wounded trees on any of the six harvest block received three or more wounds.

DISCUSSION AND CONCLUSIONS

Reducing skid trail spacing to a 12.2 m interval for the most part limited feller-buncher activity to the trail corridor while the 18.3 m spacing required the feller-buncher to track short distances off of the trail in order to harvest the block. Theoretically, the narrower spacing allowed trees to be harvested from the residual strips between trails much faster, but required that the operator spend more time harvesting corridors to the back of the block. Twice as much time should have been dedicated to harvesting trail corridors at the narrower trail spacing in this study. On the other hand, while the wider trail spacing theoretically should have reduced the amount of time dedicated to harvesting trail corridors, more time should have been required to move from bunching sites on the trail out to the block boundaries and back. Based on the results of this study these trade-offs proved to be relatively equal, resulting in insignificant differences in productivity between the two treatments.

The insignificant differences in feller-buncher productivity between the two trail spacings cannot be explained by the time studies that were conducted as individual elements of the harvest work cycle also did not differ significantly between the two treatments. Further investigation of the actual layout of harvest trails within each block and a more detailed time and motion study may help in forming an explanation.

Although no significant differences were found between mean productivity using the 18.3 m and 12.2 m trail spacings, it is important to note that productivity was considerably greater in the blocks harvested at the wider trail spacing than the narrower trail spacing. In each of the three harvest block pairs (a & b) the block harvested using the wider trail spacings had productivity levels 10 to 60 percent greater in all cases than the block treated with the narrower trail spacing. The ANOVA test may not have been sensitive enough to conclude that the difference in productivity was statistically significant due to small sample size and the amount of variation in productivity levels between harvest blocks in each treatment.

Proportions of residual stand damage were comparable with those reported in other mechanized whole-tree partial harvests in northern hardwood stands (Kelley 1983, Nichols *et al*. 1993). Although not significantly different by treatment, the highest overall proportion of injured trees occurred in block 2b treated with the narrower trail spacing, while the lowest overall proportion occurred in block 2a treated with the wider trail spacing.

While Ostrofsky *et al*. (1986) found that residual stand damage levels were significantly different between trail spacings of 20 m and 40 m, it may be that the substantially narrower trail spacings used in this study were too similar to result in different damage proportions. It is also possible that at these narrow trail spacings the relationship between distance from trail and probability of being wounded becomes less distinct. Similarities in proportions and character (i.e. height above ground, area, severity) of residual damage among treatments in this study should be somewhat expected since blocks were harvested and yarded using the same machines, operators, and harvesting method. Based on the results of this study we cannot conclude that there are any advantages to selecting one of the two trail spacing over the other.

ACKNOWLEGEMENTS

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Production for a Biomass Harvesting System in Pine

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ABSTRACT

A substantial amount of woody biomass feedstock is available on a sustainable basis from forests in the eastern United States. Current harvesting methods are limited in their ability to sustain the growing demand for biomass feedstock and cannot cost-effectively harvest small diameter material. Auburn University and cooperators have developed and are currently testing a harvesting system designed primarily for the purpose of producing biomass feedstock. The components of the system include equipment for felling (John Deere 75C with a Fecon shear head), extraction (Awassos MD-50 skidder), and processing (Morbark Typhoon self-loading chipper). This system will be used under a variety of silvicultural prescriptions in both pine and hardwood ecosystems. A trial harvest was performed to familiarize the operators with the equipment and to provide information about the machinery. Anticipated benefits of the harvesting system include cost-effectively utilizing small diameter material, maintaining low residual stand damage in dense or sensitive stands, and the ability to work on small tracts and urban areas.

INTRODUCTION

Approximately 368 million dry tons of biomass is available annually and on a sustainable basis from forest resources in the U.S. (Perlack et al. 2005). This represents a huge potential resource for energy production (Rummer et al. 2002), as well as, the production of a variety of industrial and consumer bioproducts that directly displace petroleum-based feedstocks (Energetics 2003).

Based on current forest practices, the majority of woody biomass feedstock in the United States will come from the Southeast (Perlack et al. 2005). The current, dominant logging technique in the Southeast is fully-mechanized, whole-tree harvesting, and the most cost-effective method for biomass feedstock removal are in-woods chipping systems which are adapted to work on fully mechanized operations. In-woods chipping operations such as these produce "dirty" chips in conjunction with pulp wood and chip-n-saw sized material. Therefore, the amount of chips produced is dependent upon the amount of available material that is not merchantable otherwise. Additionally, in-woods chipping operations are limited to areas within close proximity to biomass feedstock consuming facilities, because the relatively low market value for feedstock ($18-$20/ton) limits the economic feasibility of moderate to long hauling distances.

As the biomass market continues to grow, harvesting systems that are capable of producing biomass feedstock as a primary output on a consistent and cost effective level will be needed. Systems such as these would target material with no other commercial value; this material would primarily be between 3 and 9 inches DBH. Trees of this size can be found in upland hardwood areas throughout the eastern U.S., and in early pine plantations in the southeastern U.S. Additionally, a biomass market would minimally compete with the pulpwood market since the biomass market would operate in diameters below pulpwood size, and in areas where there is no pulpwood market.

There are currently no known harvesting systems which can target only small diameter material on a cost-efficient basis. Therefore, the objective of our research is to develop, test, and if successful, promote a cost-effective harvesting and transportation method for producing biomass feedstock for the market. This article will provide an overview of the system and results from the initial harvesting trial.

SYSTEM COMPONENTS

Felling: A John Deere 75C excavator (Figure 1) mounted with a bunching shear head will be the system's felling component. When felling heads were first developed they were adaptable to a variety of carriers. Specialization for high production in pine has lead to the nearly exclusive use of purpose-built, wheeled, feller bunchers. Tracked feller-bunchers have evolved into large specialty machines for difficult terrain and large trees. The system envisioned requires a carrier that can minimize soil disturbance, maximize operating time and lower capital cost. The ability of this machine to reach for trees rather than driving from tree to tree should enhance productivity with the small stems. It will also minimize residual stand damage and ground disturbance. This machine will also be light enough to be hauled with a typical heavy-duty pickup truck.

Figure 1. Small excavator with bunching shear head (John Deere 75C).

Extraction: The primary extraction machine will be an Awassos MD-50 skidder (Figure 2). Much research has been done evaluating different types of small scale extraction systems, primarily with agricultural tractors and skid steer machines. These machines tend to be ill-equipped for high production (agricultural tractors), have high operating costs (skid steer) or result in high levels of residual damage (agricultural tractors and skid steers). On the other hand, conventional harvesting systems have moved almost exclusively to purpose-built skidders. The

Awassos MD-50 will provide the system with the benefits of a purpose-built forestry machine on a level that promotes low residual stand damage and low fixed and operating costs.

Figure 2. An Awossos® MD-50 skidder.

Processing: Once the material is brought to the landing, it will be processed into chips with a self-loading chipper. The processing machine is the Morbark® Typhoon self-loading chipper. This chipper is rated at 325 hp and is small enough to keep fixed costs low, yet powerful enough to maintain a profitable production rate. This chipper reduces fixed and operating costs by incorporating both the loading and processing functions into one.

Figure 3. Self-loading Morbark Typhoon chipper - 325hp.

DATA COLLECTION METHODS

Productivity: Elemental time studies will be performed on each piece of machinery. Small video cameras will be the primary method of this data collection. The cameras will be adapted to each piece of machinery in a location that will record the machine functions of each element/process and the number of stems per load or cycle. A measuring system will be adapted to the machinery to estimate DBH (on the excavator) or butt diameter (on the skidder). Additionally, where time and money permit, DBH measurements will be taken manually to gather more accurate data.

The basic elements of the excavator that will be studied are; felling time, bunch time, dropping the bunch, movement during harvest, and various types of delays (mechanical, operational, and other). The elements of the skidder that will be studied are; gathering a load, haul loaded, haul unloaded, unloading, deck preparation, and various types of delays (mechanical, operational, other). The elements of the loader that will be studied are; movement with load to the chipper, adjusting trees in the chipper, movement from chipper to gather another load, deck/area cleaning, adjusting the load on the ground, and various types of delays. Video tape will be reviewed in the office to determine times for each element.

In addition to the basic time and production data we will also look at other factors that affect the system or are important when analyzing it. These include such things as: (a) The average trees per bunch and their DBH will be combined with cycle times to measure the capabilities of the system, (b) The arrangement of bunches will be studied to determine the best configuration for the skidder. For example, are scattering the bunches generally in the same location opposed to stacking them side-by-side more beneficial to the skidder, or is choking one large bunch (a pile of 3 or 4 shear bunches) faster than choking 3 or 4 individual bunches, and (c) The average trees per excavator location will be collected for comparisons between silvicultural treatments (i.e. on average, how many trees can the excavator reach before having to move the machine). Other factors that will be recorded are slope, terrain roughness, understory composition, weather conditions, soil type, and soil conditions.

To record movement in the woods of the felling and skidding machines, GPS units will be installed. Data from the units will be used to determine skidding distances, and look for any unique movement characteristics that the machines (thus, their operators) follow. Skidding distances will be used to determine optimal skidding distances for the system.

Cost: In addition to the classic productivity calculations, machine costs will also be calculated to determine a $/ton basis for each silvicultural regime. Machine costing will be calculated using methods described by Tufts (1982 and 1985). Data for costing will be collected from the equipment manufacturer, relevant literature reviews, and from field collection (fuel and lube, repair and maintenance). This data can then be used to determine the overall viability of the system and as a cost comparison to other biomass harvesting systems. Additionally, transportation costs will be estimated from literature reviews, transportation trucking models, and concurrent research being conducted at Auburn University. This cost will be combined with the system's cost to determine a viable hauling distance and total cost to mill.

Stand Damage: Line transects will be used to evaluate soil disturbance. Soil disturbance will be classified on a descriptive scale similar to ones used by McMahon (1995) and Turcotte et al. (1991). Residual tree damage will also be assessed during the pre and post harvest cruises during the study. Damage will be assessed by factors of wound size and depth and/or percentage of crown damaged.

TRIAL HARVEST

The initial harvesting trial was located in the piedmont region of eastern Alabama. The site was a 14 year old naturally regenerated pine stand with 2,112 TPA. Slopes ranged from 0 to 10 percent, but were generally less than 5 percent. Underbrush was minimal on account of the heavy tree density. The silvicultural prescription was a heavy thinning with a target residual stand of 400 TPA. The trial harvest was intended to provide valuable operating time for the employees in preparation for future research. While production data was inconsistent, other data gathered from the operation is valuable for future machine costing.

Stand composition for both pre and post harvest can be seen in Figure 4. Treatments were implemented by operator selection. The actual post harvest revealed a TPA of 373 trees; a deviation of only 27 TPA from the prescribed treatment. Approximately 50 tons per acre were removed from the site. The maximum rate of harvest during the trial was approximately 50-60 tons per day. The low production rate was due to extremely long skid distances and the thickness and irregularity of the natural stand.

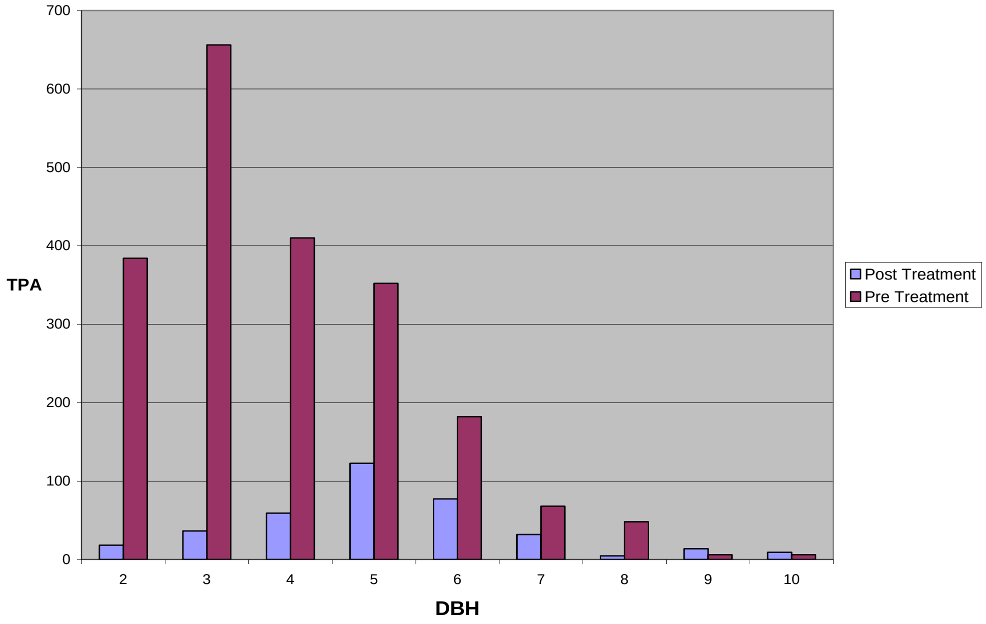

Figure 4. Stand composition for pre and post harvest.

Felling was performed by cutting rows and returning later after the row had been cleared of the bunches to thin within the rows. Cycle times were slowed by the density of the stand and lack of maneuverability of the boom on the machine. Fuel consumption for the felling machine is approximately 1.8 gallons/hour.

The average skidding distance was 320 feet, with some distances in excess of 1,500 feet, and the average cycle time was 7.2 minutes. Bunch sizes of the skidder were typically equal to those produced by the felling machine. The skidder was limited by the inoperability of a hydraulic pump, which contributed to high cycle times. Additionally, the grapple of the machine has the capability of supporting a larger grapple that will allow for larger payloads. Fuel consumption for the skidding machine is approximately 1.3 gallons/hour.

The chipper has the capacity to produce approximately 25 tons of feedstock per hour. Therefore, the chipper is operated under a combination of a hot and cold decking system to conserve fuel. The skidder decks the material until no excess room is left at which time the chipper will start operating and will continue until all the material has been processed. This is done concurrently while the skidder is still operating. This system allows the supervisor of the system to have down time while the deck is being filled to perform other duties. Fuel consumption for the chipper is approximately 7.5 gallons/hour.

EXPECTED OUTCOMES

Many beneficial and applicable results are anticipated upon the completion of the project. We anticipate that a cost effective harvesting system will be established that can economically work in large thinning and TSI operations, as well as small urban interface tracts. In addition to the revenue generated from the harvests, additional value will be gained in the residual trees due to the reduction in competion for scarce resources. The system can be used as a tool to improve forest health by removing and utilizing the small, less desirable and unmarketable trees and turning them into a marketable product. The lighter and smaller equipment should limit ground disturbance, which will minimize sedimentation into nearby streams.

We believe this system will be available for immediate implementation once production and profitability is demonstrated. Such systems can be targeted to tree-care companies, can complement existing logging contractors, or be a niche market for new contractors. The intended system has the potential to provide employment opportunities in rural areas consistent with the skill of the local workforce. Future development of additional plants in rural areas will increase the scope of opportunity by providing close and stable markets for biomass.

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Processing Woody Biomass with a Modified Horizontal Grinder

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Abstract. This study documents the production rate and cost of producing woody biomass chips for use in a power plant. The power plant has specific raw material handling requirements. Output from a 3-knife chipper, a tub grinder, and a horizontal grinder was considered. None of the samples from these machines met the specifications needed. A horizontal grinder was modified to replace the teeth on the drum with chipping blades in order to process whole trees into biomass chips that met the power plant’s size specification. The study was installed on the Shoal Creek Ranger District, National Forests in Alabama, near Heflin, AL. This biomass removal project was the first step in a wildlife habitat improvement treatment to convert a 37-acre stand of off-site planted loblolly pine (Pinus taeda L.) to longleaf pine (Pinus palustris M.). The trees were 15 years old with an average dbh of 4.0 inches and average total height of 30.5 feet. The time and motion study gathered data on whole-tree processing for short fiber chips (up to ½-inch long), short fiber chips from trees that had been partially delimbed to remove needles, and long fiber chips (up to ¾-inch long). The average production rate ranged from 24.9 – 38.2 green tons/productive machine hour (gt/pmh). A machine rate of $161.20/pmh was calculated, resulting in a cost of $4.22/gt for producing the long fiber biomass chips.

1.0 Introduction

A critical barrier to utilizing unmerchantable wood as a renewable energy source is the cost of processing and transporting the material to the end user. Stringent biomass specifications can make the processing more problematic.

The USDA Forest Service, Forest Products Lab funds several grants each year for the purpose of studying woody biomass utilization. One selected project proposed removing small diameter stems and unmerchantable woody material from National Forest lands and delivering it to a power plant in Alabama for co-milling with coal. There are many aspects to this study, and the partners include: The USDA Forest Service, National Forests in Alabama; CAWACO RC&D; Forest Based Economic Development Services; Southern Company, Precision Husky Corporation; Auburn University, Forest Products Development Center; and University of Alabama, Center of Economic Development. The Shoal Creek Ranger District of the Talladega National Forest and Plant Gadsden served as the demonstration areas for the project.

The objective of this study was to determine the costs associated with processing whole tree loblolly pine trees into biomass chips. Specifically, this study included (1) finding a machine that could process whole trees into biomass chips that meet the physical characteristics required, and (2) determining the production rate and cost of the machine.

1.1 Study Area

The study was installed in August, 2007 near Heflin, AL. Personnel of the Shoal Creek Ranger District identified a 37-acre stand of planted loblolly pine (*Pinus taeda L.*) for the study. From the land manager's perspective, the purpose of the biomass removal was the first step in a wildlife habitat improvement treatment to convert the stand from off-site planted loblolly pine to longleaf pine (*Pinus palustris M.*). The operational terrain was mostly flat with gentle slopes ranging from 0 - 15%.

District personnel performed a low intensity cruise (seven, 1/5-acre plots) to estimate the biomass available for removal. Trees ranged in size from 1 to 8-inches in dbh. The average dbh in the 15-year-old stand was 4.0 inches and the average height was 30.5 feet. The majority of the stems to be removed were pine (97%), with soft hardwoods (2%) and hard hardwoods (1%) making up the rest of the stand. The operational terrain within the stand was mostly flat with gentle slopes ranging from 0 - 15%. Trees over 8.5-inches in dbh were not included in the cruise and were not removed during the study. Volume to be removed was estimated to be 90 tons/acre, or 3,335 total tons. Of this volume, only 1,000 tons were needed at Plant Gadsden for the trials.

1.2 Equipment Selection

Felled trees needed to be processed to meet specific handling requirements of Plant Gadsden. Initially, a maximum 1/2-inch chip length was requested by the power plant engineers. Equipment selection began by examining the output from a variety of biomass communition machines.

The first chips examined were from a Precision Husky 1858 whole-tree 3-knife disc chipper. The raw product used was whole-tree small-diameter pine trees from a pre-commercial thinning operation. Fuel chips from this machine resulted in an unacceptable end product. The first problem was that the chip fibers were oriented mostly lengthwise. Since the disc is oriented at an angle to the end of the tree stems, it created chips with long fibers. When these longer chips reach the riffles in the plant's pipes, they will not pass through or break, causing plugging in the plant. The second problem occurred when handling small diameter material. The small branches and small stems tilted upward before being chipped resulting in longer chips. In addition, the thickness and width of the chips could not be adequately controlled with this machine.

Some of the chips from the first analysis were re-processed using a ProGrind 2000 tub grinder to try to further reduce the size of the comminuted material. Although this process resulted in an output that met the size and fiber orientation requirements, a new problem surfaced. The edges of the fuel chips were not sharp or clean. The grinder created fuzzy fibers on the edges of the chips that caused the wood particles to stick together. This new property would cause unacceptable handling problems within the plant.

Horizontal grinders were also considered. The fiber orientation and chip length could be more readily controlled with the horizontal drum as opposed to a chipper disc mounted at an angle.

However, the comminution action is by grinder teeth rather than knives, resulting in fibrous edges.

Chip width, length, thickness, fiber orientation, and clean edges were just some of the characteristics that were further defined due to the physical handling requirements in the plant. After review of output from several types of chippers and grinders, plus consideration of reprocessing in-woods whole tree chips, a proto-type machine was selected. Precision-Husky offered to modify one of their horizontal grinders (a ProGrind H-3045) to produce the biomass characteristics required for the power plant trials. Precision-Husky of Leeds, AL modified the basic machine to replace the coarse grinding teeth with cutting knives to meet the biomass specifications with one-pass processing.

1.3 Operation

A logging contractor, and his sub-contractor, provided all of the equipment (other than the Precision-Husky H-3045) used to create the chips for the power plant. A Hydro-Ax 670 drive-to-tree feller-buncher was used to fell and bunch trees. Bunches were skidded to the landing by a John Deere 648 G-III grapple skidder. At the landing, the skidder deposited bunches directly under the grapple of a Prentice 210D loader. Once the skidder left the immediate area around the loader, the loader operator picked up groups of stems and fed them into the Precision-Husky. The Precision-Husky was controlled by wireless remote from the loader. Chips were conveyed from the grinder's out-feed into open-top walking floor chip vans. All equipment operators had 20 years of experience or more.

2.0 Methodology

A time and motion study was performed on the loader. Landing operations were observed by researchers prior to starting the time and motion study to identify cycle elements. A cycle was defined as the time it took to process enough material to fill a chip van. A stopwatch was used to time individual elements on 17 loads. Trucks were weight scaled at the power plant. The total study time was 57 hours.

Only one productive cycle element was identified for the chipper, processing stems. The cycle element ended when the chipper was out of wood. A cycle for the chipper began when the loader began feeding stems and ended when the last chips came off of the out-feed conveyor.

The loader was either in productive time feeding stems, or in non-productive operational delays (wait for skidder, wait for truck to move van forward for loading, mechanical adjustments) or administrative delays. The number of stems per loader grapple were counted and recorded to determine the number of stems per load.

Moisture samples were collected by taking a composite sample from various areas of each of the sampled loads. Fourteen samples were collected in labeled 2-gallon plastic zippered bags to limit moisture loss during transport. Samples were collected using the same procedure that was used by power plant personnel. Moisture content was determined using ASTM Standard D4442-92(1997).

During the course of the field operations, an initial trial was run using the in-woods chips at Plant Gadsden. The initial test using the small (3/8 – 1/2 inches in length), specified chip yielded positive results with no feeding or handling problems. Based on the initial results, power plant engineers requested four different chip types for additional tests. The original size was the small, whole tree chips (short fiber). One of the alternate chips requested was short fiber, clean chip with fewer needles. Without having a gate delimber or other delimbing equipment available to make cleaner chips, the skidder backed drags (bunches) into an area of standing trees to break off limbs and small tops, in order to remove as many needles as possible. The other two alternate chips required an adjustment to the cutting blades on the grinder. The blades were adjusted outward from the rotor to make a chip with a longer fiber (1/2 – 3/4 inches in length). "Delimbed" and whole trees were used to create the long fiber clean and dirty chips. Data were collected on the delimbed and whole-tree short fiber chips, and on the whole-tree long fiber chips.

The hourly costs for the equipment were calculated using the machine rate approach (Miyata, 1980) with assumptions described in Brinker et al. (2002). Because this operation was implemented on federal land, federal wage rates were used (US Department of Labor, 2006).

3.0 Results and Discussion

Time and motion data for the Precision-Husky ProGrind H-3045 were collected on 17 loads consisting of: 7 clean small fiber loads, 7 dirty small fiber loads, and 3 dirty long fiber loads. The average productivity for a load was 29.22 green tons/productive machine hour (gt/pmh). The average moisture content was 53.78% (wet basis). Production rates for the three fiber types observed are listed in Table 1.

Table 1. Production Data for Precision-Husky H-3045

	Whole-tree					Delimbed				
Variable	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
Short fiber										
Gross time (min)	7	86.1	31.57	61.6	135.3	7	80.8	20.8	60.7	115.1
Productive time (min)	7	71.2	8.49	61.6	87.7	7	64.2	5.09	57.1	72.6
Payload (gt) [a]	7	29.3	3.03	24.7	34.4	7	31.6	1.64	29.2	33.9
Production (gt/pmh) [a]	7	24.9	2.36	21.0	28.9	7	29.7	2.68	25.9	33.0
# stems/load	7	367.6	54.40	305	445	7	297.7	22.08	263	324
Long fiber										
Gross time (min)	3	47.2	1.52	45.7	48.7					
Productive time (min)	3	47.2	1.52	45.7	48.7					
Payload (gt) [a]	3	30.1	1.45	29.1	31.8					
Production (gt/pmh) [a]	3	38.2	2.27	35.8	40.3					
# stems/load	3	310.0	55.05	260	369					

[a] gt=green tons, gt/pmh=green tons/productive machine hour

The difference between the mean production times of the clean and dirty short fibers was significant (p-value = 0.0037, $\alpha=0.05$). The mean production time for the dirty short fibers was

24.9 gt/pmh. Production time for the clean (delimbed) short fibers was 29.7 gt/pmh. The knives were changed during the last observation of the whole tree short fiber chips because they had been dulled in a test using an excavator to feed the grinder rather than a loader. The duller knives may have contributed to the slower production on the whole tree dirty fiber observations. (Production study data collection did not include any cycles where the excavator fed the H-3045). The mean production rate of the long fiber was the highest observed rate, at 38.2 gt/pmh.

Researchers collected observational data for 57 hours. This study time does not include the initial time spent observing the operation prior to data collection. The utilization of equipment on this study was low. There were lengthy delays waiting for empty chip vans to return from the power plant (120 miles round trip). Only three walking floor trailers were used and not all were available every day of the study. In addition, the skidder driver did not work on one of the study days. So, there were additional delays due to the interactions between the loader and skidder that day. The overall utilization observed during the study was 34%. However, because of the unrealistic utilization due to trucking, higher utilization rates were used in the cost analysis. During the time when trucks were available on site to be loaded and production data was collected, utilization rates of the loader and chipper were more realistic. The utilization rate of the loader averaged 80% and the chipper averaged 83%. These rates are different because when the loader completed the stem feeding cycle, the chipper was still processing stems.

Table 2. Machines Rates for Equipment Used in Study

	Precision-Husky ProGrind H-3045	Prentice 210D Loader	John Deere 648 GIII Skidder	Hydro-Ax 670 Feller-Buncher
Purchase Price	285,000	145,000	175,224	215,000
horsepower	520	142	180	205
Utilization (%)	83	80	60	65
Ownership Costs ($/smh[1])	37.20	16.65	23.90	34.12
Operating Costs ($/pmh[2])	116.38	22.42	36.34	45.29
Labor & Benefits($/smh[1])	0	19.27	19.27	19.27
Total Cost ($/pmh[1])	161.20	67.32	108.30	127.42

[1] scheduled machine hour
[2] productive machine hour

A machine rate for operating the Precision-Husky ProGrind was calculated with the utilization rate observed during data collection (83%). Off-highway fuel prices during the study were $2.85/gal. The cost of $161.20/productive machine hour (pmh) was calculated without an operator, as the operator is included in the cost of the loader. System costs are displayed in Table 2. The cost for the entire system was $464.24/pmh.

In this study, the biomass removal operation was a stand alone operation. No other products were removed. However, if biomass removal is incorporated into a harvesting operation where other products are removed, portions of the costs of the loader, skidder and feller-buncher could be assigned to the other products.

4.0 Conclusion

Stringent biomass size specifications were desired in this project. Chip output was examined from a variety of equipment types, and the Precision-Husky H-3045 was successful in producing a chip that met these specifications. The H-3045 produced short fiber whole-tree chips at an average rate of 24.9 gt/pmh. When the cutting blades were adjusted to create longer fibers, the production rate increased to an average 38.2 gt/pmh. The machine rate calculated for the grinder was $161.20/pmh. For the longer fiber chips, the cost was $4.22/gt. The cost for removing biomass using this harvesting operation was high because biomass was the sole product removed.

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Changes in the Southern Logging Workforce over Twenty Years

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ABSTRACT

We have surveyed Georgia's logging contractors every five years since 1987. The data from these surveys provide extensive information on changes in the composition of the logging crews across the state in this time period. The increase in the prevalence of partial harvest contractors since 1987 has been noteworthy (from 18% to 68%), and this shift has impacted the characteristics of the overall logging workforce. Production trends in clearcut versus thinning crews show that average weekly production is approaching equality. Labor and capital efficiency are not widely divergent, while average capital investment remains higher for clearcut crews. Harvest size for clearcut crews has reduced to 100 acres, while thinning acreages have increased to roughly 150 acres.

INTRODUCTION

Every five years since 1987, researchers at the Center for Forest Business in the University of Georgia have sent mail surveys to all logging contractors in the state of Georgia. These surveys have been used to gather details on the characteristics of the contractors themselves, the logging crews operated within their business, and their typical harvesting practices. Data from these surveys provide a long-term view of how logging business in Georgia have changed over the past twenty years.

A number of revealing trends were found in the data, many of which were summarized by Baker and Greene (2008). Among the most intriguing of these trends; however, was the substantial reduction in contractors harvesting predominantly clearcuts compared with those harvesting predominantly thinnings and partial cuts. This paper will compare key characteristics of clearcut and thinning contractors across this twenty year period to assess how each has changed.

METHODS

We developed a questionnaire to gather information from independent logging contractors that contained four sections: general timber harvesting questions, logging company questions, owner/manager questions, and miscellaneous questions. The majority of the questions in each of the first three sections were taken from previous surveys to allow for direct comparisons with previous results. The original survey form from 1987 was expanded in 1992 to include greater detail, and only data from 1992 forward were analyzed for this paper. General timber harvesting questions asked for information on the types of stands and products harvested by the contractor.

Company questions sought information on the employees and equipment of the firm and business practices employed on their operations. We often made a few modifications for each survey to allow for updates in technology (e.g., removing "fax machine" as a technology adopted by companies). Owner/manager questions asked for demographic information from the individual respondent. We generated miscellaneous questions based on discussions with industry specialists to provide insight into current areas of special concern within the logging industry in Georgia (e.g., questions regarding increased log truck inspections). We purposefully kept the questionnaire to two pages in length to encourage participation.

Since 1997, we have generated the mailing list using a list available from the Georgia Master Timber Harvester program (Gallaher and Jackson 1997). This list included everyone who had completed the state's logger training program for the Sustainable Forestry Initiative and had a valid mailing address recorded in the system. We removed obvious non-loggers and pared the list down to one representative per logging firm. When possible, we selected the owner as the recipient, and if an owner was not evident, we used managers or other employees. In January of 2007, we mailed 878 surveys to logging firms across the state of Georgia and sent a follow-up mailing to non-respondents in February of 2007.

Respondent weekly production levels were converted to tons using 2.7 tons per cord and 25 tons per load depending upon how production was reported. We estimated capital investment in the company using depreciated values for equipment owned by the logging contractor. Equipment costs were estimated based on average costs of new equipment in 2007 gathered from discussions with equipment manufacturers and users. Data from contractors with multiple crews were converted to per-crew averages for equal comparison between firms. Median values are reported here to account for highly skewed data and Wilcoxon rank-sum tests were used to calculate statistical differences between clearcut and thinning values in a given year (Hollander and Wolfe 1999).

RESULTS

We had 211 logger respondents, yielding a response rate of 24.0%, which was our highest rate since the initial survey was sent in 1987 (Baker and Greene 2008). Responses arrived from all regions of the state, and while harvesting conditions differ by region, previous research has shown that logging business characteristics are not substantially different in these areas, justifying an aggregate analysis for the state as a whole (Greene et al. 2001). Detailed summary data of the entire respondent population is available from Baker and Greene (2008).

In 1987, 82 percent of respondents reported performing primarily clearcut harvests. By 2007, only 32 percent were in this category, with the remainder performing primarily partial cuts and/or thinnings. Weekly production levels for thinning crews have been lower than for clearcut crews (Figure 1); however, the scale of this difference has now shrunk to statistical parity ($p = 0.24$). While most thinning crews are performing not only thinnings but also residential harvests and other partial cuts, the recent increase in productivity shows a distinct shrinking of the traditional gap between crews harvesting primarily clearcuts and those geared towards thinning and partial cuts. Changes in capital investment level of harvesting crews have shadowed this trend as well (Figure 2). In 1992, there was wide disparity in capital invested in clearcut crews compared with thinning crews (*p* < 0.001). By 2002, investment level was essentially equal (*p* = 0.64). In 2007, investment level was again significantly different (*p* < 0.05), but the gap was still less substantial than in 1992.

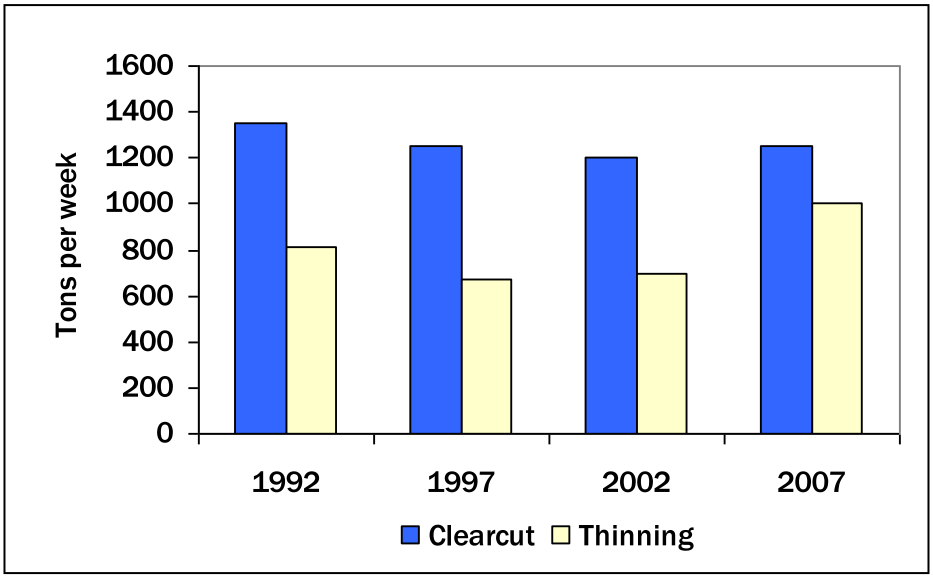

Figure 1. Average weekly production of harvesting contractors cutting predominantly clearcuts and those cutting thinning/partial cuts in Georgia from 1992-2007.

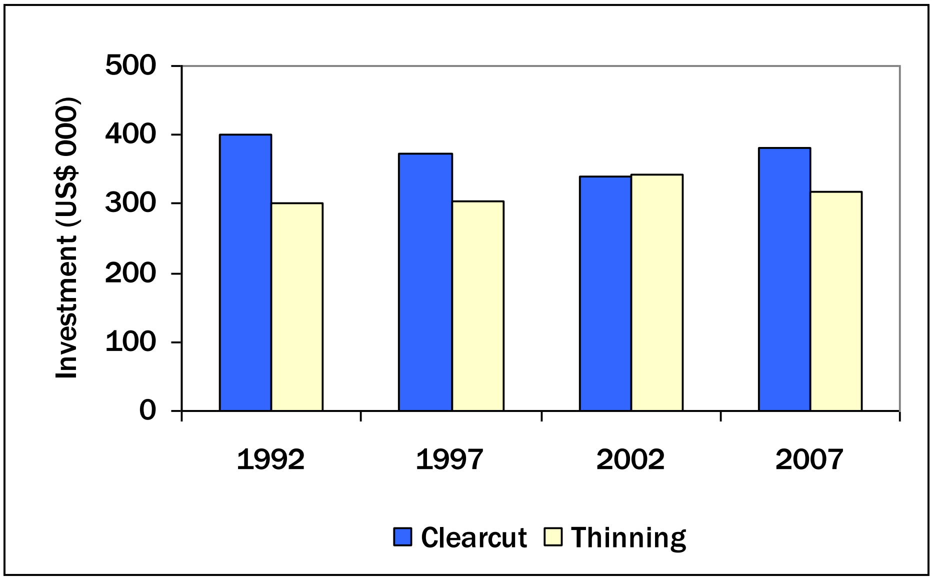

Figure 2. Average capital investment of harvesting contractors cutting predominantly clearcuts and those cutting thinning/partial cuts in Georgia from 1992-2007.

Productivity measures beyond weekly production levels also point toward substantial improvements in thinning crews. Production per $1000 capital investment increased substantially in 2007, driven mainly by growth in weekly production mentioned above (Figure 3). This increase was preceded by steady declines in capital efficiency through 2002. Production per $1000 on clearcut crews has remained relatively level since 1992.

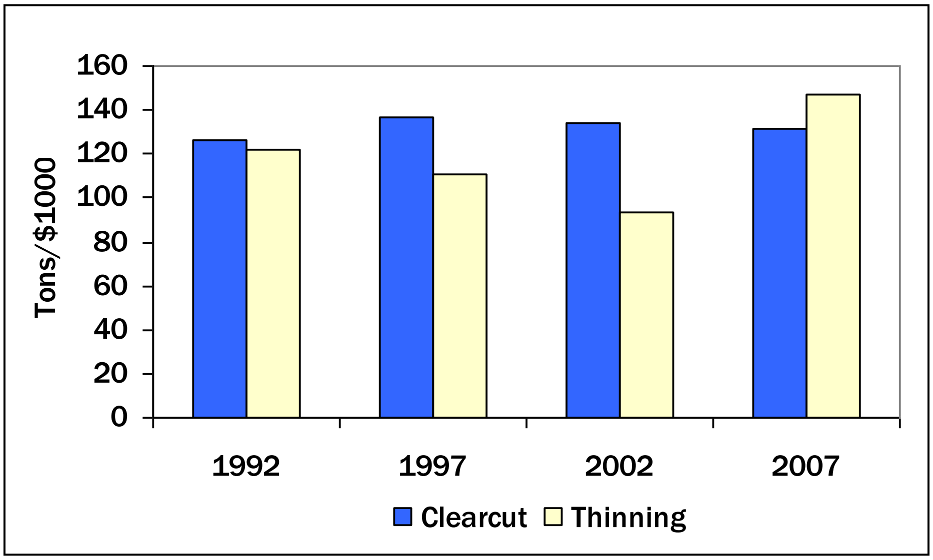

Figure 3. Tons harvested per US$1000 invested by harvesting contractors cutting predominantly clearcuts and those cutting thinning/partial cuts in Georgia from 1992-2007.

The improvements in productivity per man-hour reported by Baker and Greene (2008) are mirrored by both clearcut and thinning crews (Figure 4). Clearcut crews continue to yield slightly higher production per man-hour; however, thinning contractors have grown in size and now maintain an equal number of employees as clearcut contractors (Figure 5).

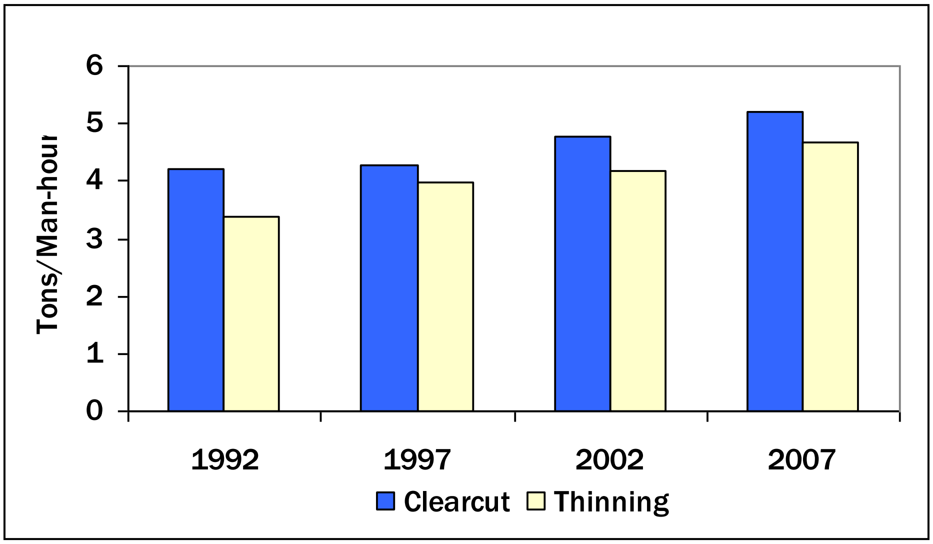

Figure 4. Tons harvested per man-hour worked on harvesting crews cutting predominantly clearcuts and those cutting thinning/partial cuts in Georgia from 1992-2007.

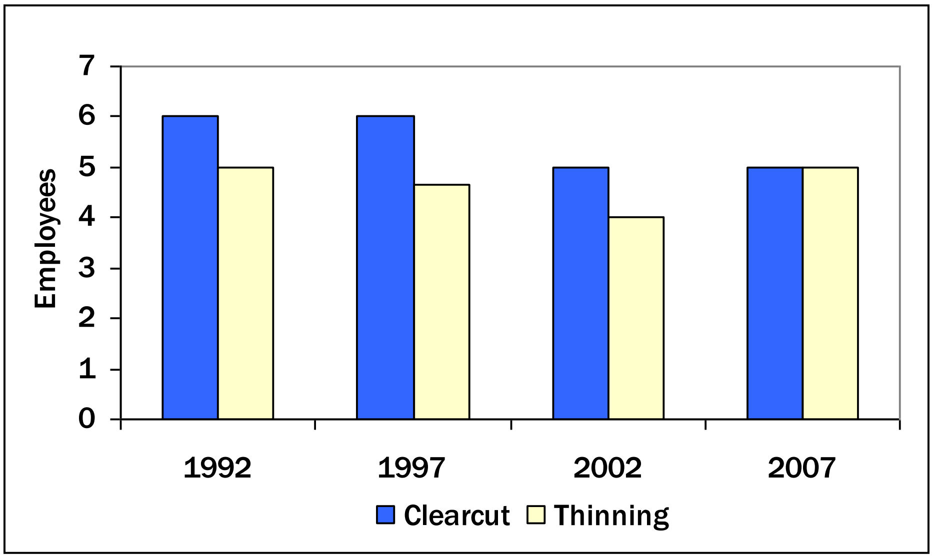

Figure 5. Total number of employees (excluding truck drivers) employed on harvesting crews cutting predominantly clearcuts and those cutting thinning/partial cuts in Georgia from 1992-2007.

Also noteworthy is the acreage harvested by both clearcut and thinning contractors. While the Sustainable Forestry Initiative has helped drive the average harvest acreage of clearcuts down to roughly 100 acres, thinning and partial harvests are not affected by this policy and average harvest acreage for these harvest types has grown steadily (Figure 6).

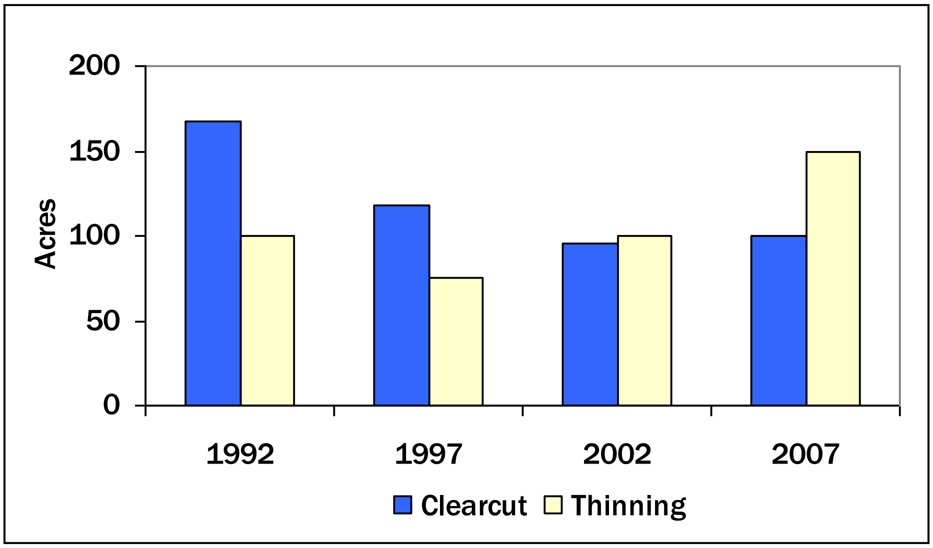

Figure 6. Average acreage per timber sale for harvesting crews cutting predominantly clearcuts and those cutting thinning/partial cuts in Georgia from 1992-2007.

DISCUSSION

The substantial shift in the number of harvesting contractors primarily performing thinning and partial cuts since the late 1980's has been mirrored by changes in their productive and economic performance relative to clearcut contractors. A number of potential correlations between the results seen here are possible, and warrant further investigation. The increase in weekly production in 2007 occurred simultaneously with an increase in average harvest acreage. Weekly production could have increased somewhat due to less frequent moves by contractors. Regrettably, data are unavailable detailing total tons harvested per tract, but as the gap between total acres harvested by thinning versus clearcut crews widens, the total tons harvested would be expected to become similar.

Clearcut crews maintained their employee level from 2002. Thinning crews maintained growth in production per man-hour while increasing total workers which resulted in an increase in weekly production relative to clearcut crews. This growth in labor was not reflected in an equal growth in capital.

Many of the young stands thinned in the past ten years were a result of extensive CRP plantings and intensive forest management by integrated forest products companies. As these stands transition to older stands, it is possible that the predominant harvesting crew characteristics will shift back towards clearcutting.

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Forest entrepreneurs in Quebec: current and future challenges

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Abstract

In Quebec, as in most jurisdictions around the world, contracting firms provide the bulk of all logging services to wood buying mills. The owner-supervisors of these small and medium enterprises (SME) are often referred to as forest entrepreneurs in Quebec, and logging contractors or logging business owners in much of the US. The services they provide account for an important share of fibre procurement cost. It is therefore useful to understand the structure of these SMEs and the motivations of their managers. In the fall of 2006 and winter of 2007, Quebec's forest entrepreneurs were studied through focus groups and a mail survey.

Among other things, results indicate that 50% of the surveyed entrepreneurs were 50 years and older. As a high number of retirements and departures are foreseen within the next five years, and since a majority of contractors do not encourage their children to become contractors despite a familial attachment to logging, it is uncertain that Quebec's forest industry will be able to count on a recruitment pool large enough to maintain the current business paradigm.

Introduction

Since the end of the 1970s, industrial forestry in Quebec has evolved from a structure where large pulp and paper companies had total ownership of their logging equipment, toward a system characterized by the generalized use of logging (sub)contractors. Therefore, many of today's forestry entrepreneurs have gone from being company employees to being the heads of a small to medium sized companies. Despite their important contribution to the forest sector and local economy, it remains difficult to obtain a reliable description of these entrepreneurs and their businesses.

The Canadian forest economy is currently experiencing a crisis of a magnitude rarely seen before. Due to a strong Canadian dollar, slumping North American housing markets, and spiking fuel costs, forest entrepreneurs are especially vulnerable, and the future of Quebec's wood supply system is a cause of concern. This study is an attempt to properly document Quebec's forest machine owners (FMO). Our objectives were firstly to establish a portrait of the FMOs using reliable sociodemographic data and, secondly, to identify the issues facing them. This article mainly addresses the issue of continuity of forestry entrepreneur businesses.

Literature review

Fortin et Gosselin (1960) provide a description of Quebec's logging work force in the years following WWII . In those years it appears that the most common reasons to choose to become a forest worker rather that another occupation were: the shortage of available work in their parish, a lack of skills to do other work, and a lack of education needed to obtain work in the city. By and large, these results show the same feelings of resignation as found in 1968 in a study of forestry workers in Maine by the Public Affairs Research Center. This study underscores that a lack of education and the impossibility of finding other work in the area were the two most frequent quotes noted.

Another study, carried out among forestry workers in Maine showed that about 25% of them did not think they would remain working in this field for another five years, and that between 28 and 40% of respondants would encourage their children to become a forestry worker (Taggart and Egan 2002). The reasons mentioned by the forestry workers for leaving the business were: there is no money in it; it is no longer profitable; the market is not as good from year to year; the price received for wood does not reflect the increases in the costs of production; a wood shortage; etc. As regards the reasons mentioned to justify not encouraging their children to work in forestry, the most important was the poor pay. Also cited in a study explaining the lack of forestry workers in Maine were the long distances to travel, the need to live away from home during the work week, the seasonal nature of the work, and the poor opportunities for promotion (Goldstein et al. 2005).

In Quebec, a study identified the lack of young workers, the difficulty with recruitment, the aging workforce, personnel turnover and the low level of qualifications among workers as the issues that threaten the future of the sector (CSMOAF 2006). In Ontario, which neighbours Quebec, a non-scientific magazine survey reported that 40% of FMOs had profit margins of between 0% and 4%, and another 40% were unprofitable (Jamieson 2006) Our study was designed to provide reliable information and insights regarding Quebec's FMOs.

Methods

In the fall of 2006, a questionnaire was mailed to FMOs in Quebec. The questionnaire was in part inspired by another survey aimed at forest workers (Egan and Taggart 2004) and adapted to address the specific objectives of the present project. It was refined through a process that involved four logger focus groups meetings.

With 336 questionnaires returned, the response rate was 25.8%, with a target population estimated at 1300 individuals (APMQ 2006). The margin of error of the survey is 4.6%, 19 times out of 20.

The representativity of the sample was analysed by comparing the responses of the early and late respondants, made possible by using multiple mailings (Armstrong and Overton 1977). The various tests carried out on the variables of interest ($x = 0.05$) did not detect any significant differences, indicating that the sample is representative of the overall population.

Results

The average age of FMOs is 48.5 years, and the median age is 50 years. Among them, 9.0% are 34 years old or less, whereas 26.3% are 55 or older. The FMOs have, on average, 26.4 years of experience in the area of forestry operations, which includes 18.2 years as owners of forestry equipment.

In terms of education, 55.7% of entrepreneurs do not have a secondary school diploma, whereas it was the last year of education for 28.2% of them. The average age of FMOs without a high school diploma is 50.6 years, which is significantly higher than those with a secondary school diploma, which is 45.5 years of age ($F = 26.120$; $P < 0.001$).

The median number of employees per FMO is 4 (mean = 6.9). Median annual sales amount to \$580,000 (mean of \$958,000). Median volume harvested is 55,000 m^3 (mean of 65,000 m^3) and FMOs generally own two machines (mean of 2.9). A little more than half of the FMOs indicate that their profit dropped by 50.6% compared to the previous five years. On average, during the last year FMOs worked 37.4 weeks (median of 40 weeks). On average, they must travel for 2.5 hours to get to their work site. In addition, 50.9% of FMOs stay at a forestry camp occasionally or on a regular basis.

When starting their business, the younger FMOs had a tendency to take over an existing company instead of launching a new one ($F = 46.940$; $P < 0.001$). The FMOs who took over an already existing company constitute 15.9% of entrepreneurs. Among the 15.9%, 75% of them received help from another person to learn entrepreneurship, whereas among the group who started a new business, only 31.2% of entrepreneurs received help ($\chi^2 = 35.694$; $P < 0.001$). In 68.1% of cases, the help received was given by a family member. As could be anticipated, the FMOs who received help from someone to learn their trade are significantly younger than those who did not receive help ($F = 33.100$; $P < 0.001$) (Table 1).

Table l: Proportion of FMOs who learned their trade from another person.

Age	< 25	25–34	35–44	45–54	55 +
FMOs who learned their trade with the help of someone (%)	100	79	46	35	21

The FMOs gave their opinions for the reasons they chose to become forestry workers. Almost three-quarters (73.4%) said that they were influenced by the fact that they came from a family of forestry workers, and this result jumps to 90.9% when the FMO was preceded by a generation or more of forestry workers in the family ($\chi^2 = 136.382$; $P < 0.001$). Out of 16 suggested statements, those which most influenced the FMOs in their decision had to do with the positive aspects of their work as entrepreneurs. For example, the five first statements were: I like using my skills to accomplish a task (99.0%), I like this work (96.3%), I like the feeling of freedom that I get (91.4%), I like working as a member of a team (91.4%), I like working outdoors (89.9%). The results where the lowest level of FMOs were found in agreement with the statements, were: It was the best paying work available (36.2%), I am not educated to do other work (29.5%), I couldn't find other work in the area 19.9%). The FMOs in agreement with the last three statements were significantly older ($F = 6.287$; $P = 0.013$; $F = 11.226$; $P = 0.001$; $F = 6.287$; $P < 0.001$).

The advanced age of the FMOs is the primary reason for departures due to retirement, which will prove to be quite important in the next five years. Precisely 33.0% of FMOs maintain that they don't think they will still be working in the field of forestry operations in five years. Of this third, 48% give retirement as the reason[1] (average age = 57 years). The other FMOs instead indicate reasons such as: working conditions and atmosphere (17.6%); current instability and uncertain future of the forest industry (15.7%); financial conditions (remuneration) (8.8%); lack of work (3.9%); anticipation of bankruptcy (2.9%); and the desire to change vocation without other explanation (2.9%).

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[1] Results of an open question having been coded..

Overall, 60.9% of the FMOs do not encourage their children to become forestry entrepreneurs. The reasons[2] justifying their position are: uncertainty and instability caused by the forestry crisis in Quebec (40.4%); difficult working conditions (23.0%); various financial aspects related to the occupation (22.4%); no future seen in the occupation (7.3%); the negative image associated with the occupation (3.7%); and the business context in which the occupation must develop (3.4%). A little more than half of the FMOs indicate that their profit has shrunk (50.6%) compared to their income in the last five years. The quality of the business relationship with their client has an influence on whether or not an FMO will encourage his children to become an entrepreneur (81.2% satisfied). Almost half of FMOs (47.3%) who say they have a good business relationship with their client encourage their children, whereas only 6.8% of FMOs who say they are not satisfied with this relationship encourage their children ($\chi^2 = 32.617$; $P < 0.001$). Knowing that almost half (48.8%) of FMOs do business with a single client, and close to one quarter (23.5%) with two, it is possible that entrepreneurs have little opportunity to find another client when the business relationship is not as good as they would like.

A little more than a third (36.5%) of the FMOs have already identified someone to take over their business. The proportion having identified their replacement is, however, not significantly higher among the FMOs who say they want to get out of the field of forestry operations ($\chi^2 = 0.011$; $P = 0.916$). Among the FMOs having identified someone, the person chosen is a family member in 80.8% of the cases and an employee in 16.7% of cases. In addition, 61% of the FMOs stated that they would be ready to hire an intern to train in the occupation. The FMOs not wishing to hire an intern explain their position in the following ways: additional costs related to a loss of productivity (44%); a lack of time (17%); and another 10% of FMOs state that they would accept an intern if they were financially compensated for their efforts. In addition, the FMOs who encourage their children had more often identified someone to take over their business ($\chi^2 = 37.011$; $P < 0.001$) and are more inclined to hire an intern to pass on the occupational expertise ($\chi^2 = 12.760$; $P < 0.001$).

Among twelve statements explaining various reasons for which an individual would not choose to start a forestry business, the six most important reasons were the uncertainty related to forestry (98.2%), the difficulty in financing business start-up costs (93.6%), distance from family (88.2%), the lack of business opportunities (87.3%), work conditions (86.6%) and the difficulty in attracting qualified workers (84.9%). In relation to the difficulties related to personnel, 45.4% of the FMOs affirm having difficulties to recruit or retain good operators, but 77.5% say that it is more difficult than before.

Discussion

The advanced age of FMOs indicates that several of them will cease working in forestry operations in the next few years. We expect that at least 50% of the FMOs will leave their work within ten years. Can we expect that a sufficient influx of new FMOs will compensate these retirements? First of all, choosing to work in forestry from a feeling of "resignation" seems to be a thing of the past. Youth today generally have more education than their elders, and because of this, have broader career choices. In addition, becoming an FMO seems to be a choice that is greatly influenced by the family. The help received to learn this occupation usually comes from a

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[2] Results of an open question having been coded.

family member, and at the same time, families still produce the great majority of individuals identified to take over the businesses. It is therefore quite disquieting to see the proportion of FMOs who do not encourage their children to become a forestry entrepreneur. However, if we rely on the tendency of youth to more often take over an already established business rather than starting up a new one, and that close to 60% of FMOs are prepared to hire an intern to train them in the occupation, some elements to develop the new generation of FMOs could very well be present. Also, with an average business size of one crew per FMO, it might be possible for some entrepreneurs to handle slightly larger operations.

The relationship between FMOs and their clients is a key variable in encouraging their children to become an FMO. Clients must understand that if they do not act in a supportive manner for the transfer of forestry entrepreneur businesses under their governance, they will pay the price later. Otherwise, the FMO capable of producing enough wood at acceptable prices to the industry will become a rare commodity within less than ten years.

The results presented in this paper are based on answers provided by FMOs in the fall of 2006 and early in 2007. At that time, the Canadian forest industry was in a difficult economic position. Since then the market for Canadian forest products has worsened; several more mills have shut down (temporarily or permanently) and many FMOs have totally ceased operations. The difficult financial situation and poor outlook reported by FMOs in the survey has likely worsened.

Conclusion

The results tell us that the current FMO population is comprised of dedicated and passionate workers who love what they are doing. The forest machine operators who will leave the forest in the next ten years will have been the first generation of FMOs and will have developed throughout their career, at a pace parallel with the evolving machinery. The second generation must quickly master the art of managing a complex business. This is why the transfer of the assets of the forestry entrepreneur businesses should be done at the same time as the transfer of skills. Coaching programs could be established. The FMOs and also their other business partners (clients, banks, dealerships, ...) must be sensitized to this imminent challenge and be given the support and counselling needed for their endeavour.

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Sustainable Forestry? Only with a Sustainable Workforce: The Idaho Timber Workforce Development Project

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Abstract: Concern over the workforce in the forestry sector is a topic on everyone's mind as much as the weather. Like the weather, there is much talk but not much is done until the storm hits. In contrast, the Associated Logging Contractors, the Intermountain Forest Association, and the Idaho Forest Products Commission have undertaken a project to attract, recruit and retain qualified workers in forestry businesses and organizations in logging, trucking, primary sawmilling, forestry services, and forest management. The project is led by Dr. John Garland, PE. There are four parts to the project: a workforce Issues Overview; a Survey of Employers and others; a Report with recommendations; and a Summit of sector leaders. The presentation will show data on the workforce, the survey findings, the Summit results and future actions underway by the Idaho forestry sector.

Overall Project Description

Idaho's sawmills, logging, forestry and transport businesses are looking for ways to better compete for quality workers and keep the industry viable in the future. The Associated Logging Contractors (ALC), the Intermountain Forest Association (IFA) and the Idaho Forest Products Commission (IFPC) teamed up to sponsor a study of forestry workforce issues. The combined organizations are referred to as "**the Group**" when used in this document.

The project consisted of four parts; an overview, a survey, a report and a summit. The overview gathered timely and relevant information on current and future forest workforce issues. The survey solicited opinions, observations and suggestions from employers, employees and others about workforce issues. The report summarized the survey findings and provides a slate of possible recommendations.

The Summit brought together sector leaders to suggest additional approaches, evaluate alternative proposals, and begin implementation of workforce improvement efforts. Dr. John Garland, Consulting Forest Engineer, produced the overview, surveys and report and led the Summit leaders to specific actions for the future.

All of the Project information, overview, and reports have been made available at the Idaho Forest Products Commission website under the "workforce development project" link at www.idahoforests.org.

Overview

The Idaho Timber Workforce Overview brought together known information on the issues and opportunities for workforce improvement for Idaho's logging, transport, forestry and primary sawmilling industries. The Overview used available statistics and information to address the following:

- Jobs that are difficult, dangerous, dirty and declining
- Workforce: State, Regional, National and International Issues
- Aging Workers
- Worker Turnover
- Foreign Workers
- Competition for Workers and Wage Issues
- Work as a Goal
- Gender in the Workforce
- Views of the Sector Workforce: factors of production, people like trees, and trajectories of development
- Actions by: Individuals and Career Choices, the firms, and the sector or subsectors
- Identifying Obstacles (Remove the barriers)
- Subsector/Sector Responses to Potential Improvement Efforts?
- A Possible Future…. or Changing the Trajectory of Individuals, Firms, and the Sector

Data on age of logging workers is of particular interest. See Figure 1 below:

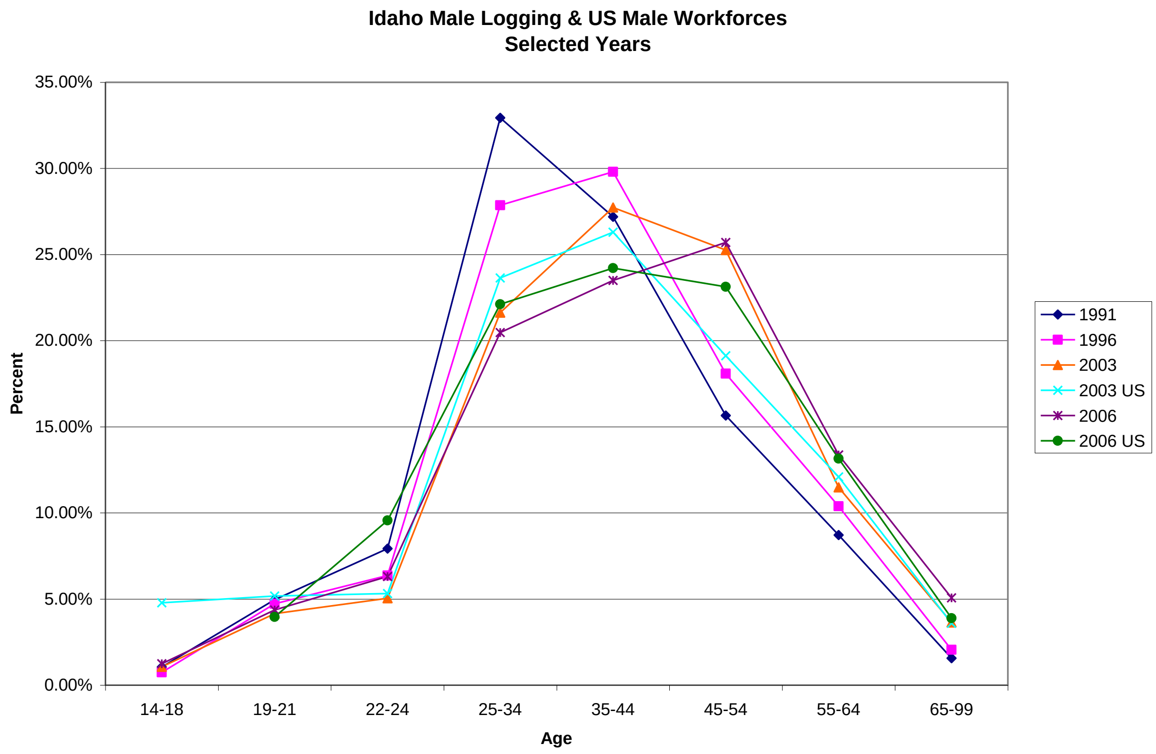

Figure 1. Ages of Idaho loggers and US males

Comparative wages for competing industries show significance for Idaho employers. See Figure 2 below.

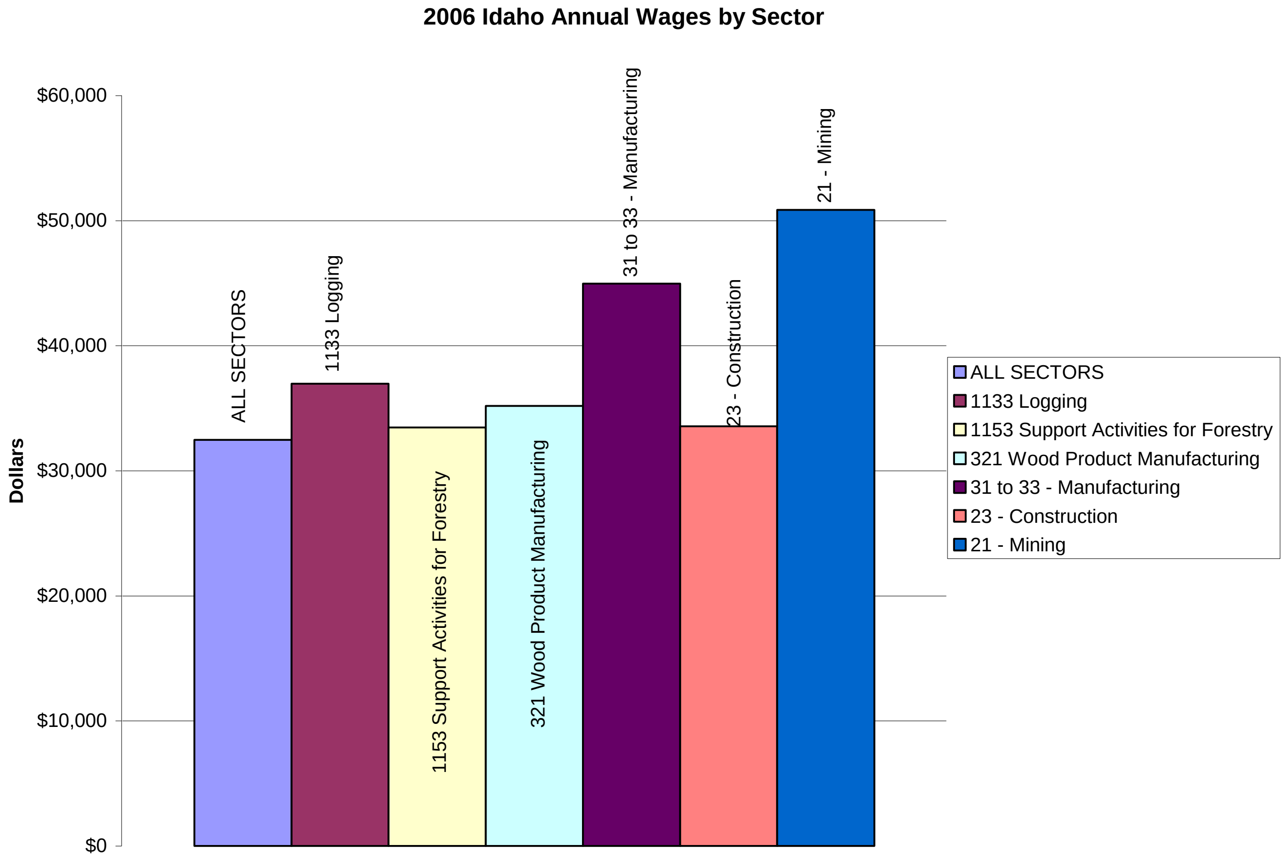

Figure 2. Idaho annual wages by industry 2006

The Overview provided the basis for structuring the Survey of Idaho Timber Workforce employers, employees, and other experts in the Region. The Survey was developed, tested, conducted and summarized in a Report.

Initial Summary of Findings in a Survey of Idaho Timber Workforce Issues

As part of an Idaho Timber Workforce Improvement Project surveys were conducted with selected leaders to gain their insights. Sixty interviews were completed by16 logging firms, 13 milling firms, 3 trucking firms, 4 forestry services firms, 6 large private landowners, 5 public landowners, 3 representing other industries (Construction, Pulp & Paper, & Machinery), and 12 other experts. Six women provided input while the rest were men. The average age of subjects was ~53 years. Summary results and the survey form are included in Report appendices.

The Report identified some Guiding Principles for consideration of improvement efforts.

- Imperative for sector leaders to get everyone behind something—not just react to external forces individually
- Forestry sector is a changing sector not a dying sector (mature, sunset, old-age, low-tech, etc)
- Sector needs to recognize that the new generation will not perform like the current generation of managers and workers
- Sector leadership is questionable if individuals cannot put aside self interest for the common good
- Scrupulous honesty and openness are crucial
- A substantial statement for improvement is needed and the sector must assure success of the first visible effort
- Public interests must be addressed and connections to workforce emphasized, eg, stewardship, environmental protection, rural communities, etc.
- Single, identifiable voice would be best-- one credible with the sector and the public
- Safety and health of workers is a unifying force
- Cheap fix is not a lasting fix—problem is intergenerational
- Future sector leaders need knowledge of workers and their issues, eg from Universities.
- Solutions for individual firms may not affect sector much—need a rising tide to lift all boats
- Pessimism can be overwhelming—a spark of optimism will need fans to ignite the flame

The mass of interview information was reduced to a group of survey themes that are more fully developed in the Report. These include:

Aging Workers
Pay a Major Issue
Single Firm Solutions
Job Leavers…Job Stayers
Challenges and Obstacles
Rural Communities
The Sector is in Doubt—for Everyone?
Generation Gap
Technology—Perceptions and Gaps
Professionalism of Workers not just Pay
Subjects Speak Out

Survey results for job turnover were revealing and more data is needed on why workers leave forestry sector jobs and why some workers stay.

Table 1. Turnover rates in Idaho sample

Turnover Rates	Logging	Mill	Forestry Services
Average	12.1%	32.9%	6.2%
Median	7.3%	19.6%	6.2%

The section on Towards Improvement listed some concepts that might improve the Idaho timber workforce but offered no guarantees of success. The general list is abbreviated below:

- **Maintain knowledge in aging workforce**
- **Address stability issue – forestry is a changing industry not a dying industry**
- **Set up structure to make improvements—Idaho Action Planning Committee**
- **Find permanent funding source**
- **Involve individual workers**
- **Emphasize technology**
- **High school counselors?**
- **Consider paid summer camp**
- **Review training**
- **Consider workers compensation offset**
- **Work with state labor economists**
- **Image and media (tv, radio, web) approaches**
- **Work design for a new generation**
- **Engage a task force to look at the issue of “season length”**
- **Consider more detailed interviews with young**
- **What are options for providing “benefits” (health insurance, retirement plan, etc.)**
- **Discussion of who are the “players” in workforce issues**

During the Summit, the Report on the Survey was used as the basis for discussions.

The Idaho Timber Workforce Summit

The Summit was held May 13, 2008 at Templin's Resort in Post Falls, Idaho. Forty-four industry leaders from sawmilling, logging, trucking, and forestry organizations came together to review the Survey Report, hear what other sectors are doing, discuss options for future action, and chart a way forward to concrete actions. The Group is working on the Idaho Timber Workforce Development Summit outcomes and future actions that will lead to workforce improvements.

More Information

Readers can see full details, references and full reports at:

www.idahoforests.org

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Optimizing the Biomass Supply Network – An Alternative Approach

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Keywords: energy wood potential, forest inventory, logistics, transport optimization, GIS

Abstract:

The climate change forces the politics to subsidize renewable energy. Decision makers see a high potential of fuel wood out in the forest. Hence the strategic planning of supply chains, securing the availability of fuel and calculating the supply costs is of great importance. A new approach to design a wood biomass supply network for a certain region is presented in this paper.

Data of the Austrian National forest inventory was analyzed to estimate fuel wood potential. Using a taper curve and biomass functions the volume were calculated. To give the decision-makers a base for further development, different scenarios of supply for 9 and accordingly 16 plants were designed. The scenarios were developed using a combination of a geographic information system (GIS) and linear programming methods. For every scenario the costs including transport and chipping were calculated separately for each plant.

The total demand of forest chips in the research area for energy purposes stays now at 70.000 m³ of lose volume per year. At the current stage of planning the demand will increase more than 4 times up to 300.000 m³ of lose volume per year.
Regarding the increasing demand and the requirement of a continuous supply especially during the winter and spring time, it is necessary to optimize the supply chain including temporary storage places. A higher demand raises the costs by 14%. Nevertheless the possibility to buffer and dry the fuel might lead to higher value enhancement than the increase of the costs.

Introduction

New regulations to promote bioenergy increase the demand of forest fuel in Austria. One resource is forest chips burned as fuel at combined heating and power plants (CHP). Subsidies are such that a lot of new CHP crop up all over Austria, which will double the forest fuel demand from 2000 to 2010 (Katzensteiner and Nemestothy, 2006).
Use of wood as fuel has a long tradition in Austria, whereas during the last two decades a lot of new district and house heating systems have been installed. As most of them required little fuel, short transport distances with maximum of 30 km were typical. In addition, most of chips

burned in district heating plants are purchased as sawmill by-products. Forest chips had not been competitive, because of high supply costs and varying quality (Stockinger and Obernberger, 1998). Beside costs and quality a constant supply is required during the whole year. Because of weather conditions in winter time, mountainous regions are inaccessible. Therefore wood terminals to store fuel can be an option to secure supply. As CHP plants are mostly located close to settlements chipping or crushing at the plant is sometimes is a problem because of noise and dust emissions. To date supply networks to meet the arising needs do not exist.

The aim of this study is to develop a supply network with optional fuel network via terminals. Optimal material flows and expected costs at plant level for three demand scenarios and supply options are calculated to demonstrate the differences between direct and flow via a terminal. Therefore a survey of demand, fuel wood potential and existing infrastructure of terminals must be documented. To estimate the fuel wood potential the study tries to use the bottom-up principle. As raw data the Austrian national inventory was used. To compute optimal material flows, the linear programming technique will be used.

Material and methods

Study area and data

Beside the political districts, Austria is also divided in forestry districts. The study area involves the three forestry districts "Friesach, Feldkirchen and St. Veit" in southern Austria with a total forest land of 139,300 ha. Compared to the share of forest land in Austria, which is around 48%, these districts are rich in forest. The district "Friesach" has a forest share of 74% (Figure 1).

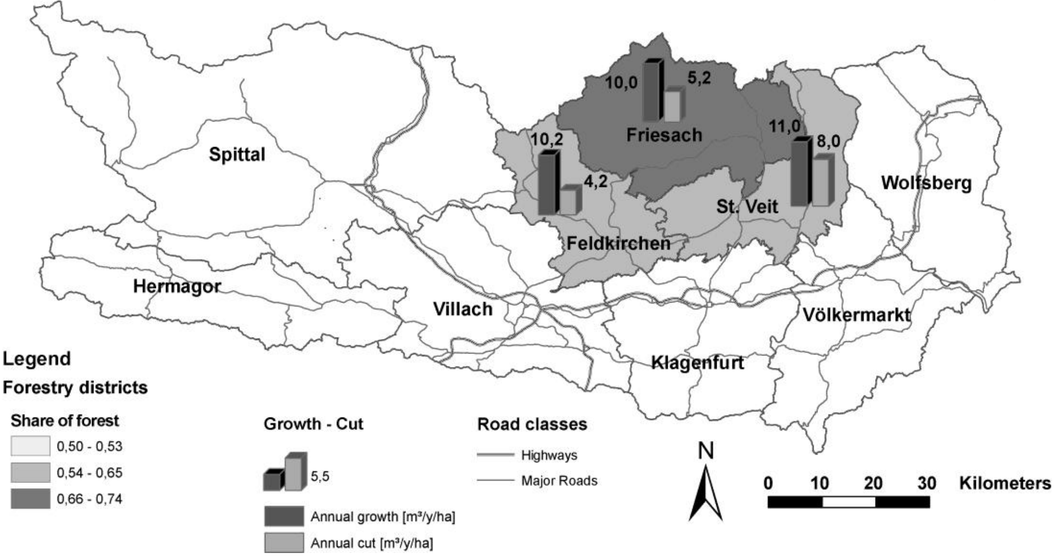

Figure 1: The study area in the southern part of Austria includes three different forestry districts shown in grey colours. The bars symbolise the annual growth and cut in these areas.

Supply network

For the logistics of supplying feedstock to heat plants different supply chains are available, including place to chip as well as the option of using interim terminals. In addition to current demand level of 73,000 m^3/a loose the upgrading of existing plants and new installation are accounted for in scenarios II and III respectively. Scenario II includes upgrading and installation of small and medium seized plants, with a demand less than 50,000 m^3/a loose. In scenario III the realization of a major project, which will increase the demand up to 300,000 m^3/a loose (Table 1), is considered. Three supply options assume different usage of terminals in the supply chain accounted for as a share of the whole yearly demand in the region.

Table 1: Overview of supply chain scenarios and options

Scenarios	Options		
	1	2	3
Demand [m³ loose/a]	Share via Terminals		
	0%	50%	100%
I - 73,000	I - 1	I - 2	I - 3
II - 96,000	II - 1	II - 2	II - 3
III - 306,000	III - 1	III - 2	

Fuel wood potential

The volumes in solid cubic meter of the defined assortments are calculated for each stem in the inventory database separately. For softwood the taper curve from Pöytäniemi (1981) was applied. To calculate the dry mass of softwood branches the biomass functions from Cerny (1990) were used (1, 2). The functions take the DBH (d) in centimeters and the tree high (h) in meters as input parameters. The dry mass was converted by the factor 0.43 g/cm^3 to volume.

$$dry\_mass\_living\_branches[kg] = 0.00045394 * (d^2 * h)^{1.1262} \tag{1}$$

$$dry\_mass\_dead\_branches[kg] = 0.021705 * (d^2 * h)^{0.60715} \tag{2}$$

The volume calculation of the hardwood is based on two functions. For the parts of the stem with a diameter larger than 7 cm the formula after Kennel (1972) und for the parts with a diameter less than 7 cm the equation from Pellinen (1986) was used (3, 4).

$$V_d = \frac{d^2\pi}{40000} h(0.444907 - \frac{107.345}{d^3} + 0.00000610582d^2 + \frac{0.467061}{h} + 0.00126815h) \tag{3}$$

$$V_r = 0.01664061 + 0.00000072179dh^2 + 0.00000252d^3 \tag{4}$$

Model description

The following three flows are considered in the optimization model: (1) direct transport from forest to plant of solid fuel, (2) transport from forest to terminal solid and (3) transport from terminal to plant chipped (Figure 2). The network analysis assumes that all sinks and sources are available in form of locations, therefore terminals and heating plants are geo-referenced. Sources of fuel wood are represented by a square grid of one by one kilometer. Each point will so present 100 ha of forest land.

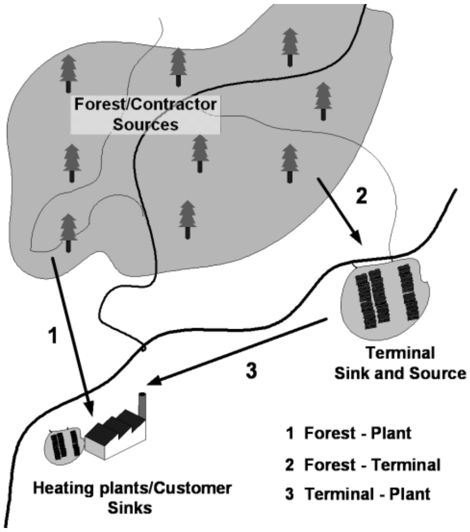

Figure 2: Flow of wood chips from forest to terminal/plant

The calculation of different scenarios and options is done in several steps. Data concerning real supply areas of the plants are not considered. During routing and linear programming theoretical supply areas are calculated.

The variable costs during optimization, which have to be minimized, are the transport costs. The objective function of the analysis computes the transportation costs, whereas defined constraints must be taken into account (Domschke und Drexl, 2005). In the first step the transport from terminal to plant is optimized (1), considering that the demand of plant has to be satisfied (2) and the maximum capacities of terminals has not to be exceeded (3).

$$z = \sum_{i \in I} \sum_{j \in J} c_{ij} x_{ij} \tag{1}$$

$$\sum_{i \in I} x_{ij} = d_j^{plant} p^{share} \qquad \forall j \in J \tag{2}$$

$$\sum_{j \in J} x_i \le v_t^{\max.capacity} \qquad \forall i \in I \tag{3}$$

Transport costs per entity of potential from source to sink (c_{ij}) include driving, loading, unloading, the hourly costs and load volume. Demand (d_j^{plant}) of each plant was collected during interviews, digitized and georeferenced. The potential of sources x_i is determined in a separate study of fuel wood potential in the region. Quantities which have to be transported from source to sink are described with x_{ij}. The maximum capacity of terminals is fixed with $v_t^{max.capacity}$ (Table 2). The amount of chips handled via terminals (p^{share}) depends on chosen option and is 0, 50 and 100% respectively. A matrix with sources and sinks is setup including the information of costs for each sink source combination.

In the second step a cost optimal flow from forest to plant or terminal will be compute. In this case terminals are acting as sinks too, whereas the optimal turnover calculated by step 1 is treated as demand now. To ensure that every source point will be assigned to one sink, the objective function has to be extended by a binary decision variable f_{ij}. (4). Constraint (5) and (6) ensure the limits of fuel wood potential and satisfy the demand.

$$z = \sum_{i \in I} \sum_{j \in J} c_{ij} x_i f_{ij} \qquad f_{ij} = \{0,1\} \tag{4}$$

$$\sum_{i \in I} f_{ij} x_{i\,j} = d_j^{termplant} \qquad \forall j \in J \tag{5}$$

$$\sum_{j \in J} f_{ij} x_i \le x_i \qquad \forall i \in I \tag{6}$$

Table 1: Demand of heating plants (a) Capacities of terminals (b)

(a)

Plant [ ]	Demand [m^3 loose/a]
22	25,000
3	16,800
26	16,470
15	3,000
5	2,800
9	2,500
1	2,500
10	1,750
14	1,450
20	1,000
27	**210,000**
28	**4,400**
29	**2,200**
8	**1,893**
21	**9,600**
31	**1,173**
	302,536

(b)

Terminal [ ]	Area [m^2]	Capacity per Year [m^3 loose/a]
1	4,020	20,100
3	680	3,400
4	1,800	9,000
5	2,500	12,500
6	1,350	6,750
7	11,500	57,500
8	5,000	25,000
9	8,800	44,000
		178,250

Results

Fuel wood potential

Looking at scenario 1, which reflects the actual state, the sum of all defined assortments gives an amount of energy wood of 2.3 m^3 solid per year and hectare ($m^3a^{-1}ha^{-1}$) in average. The highest percentage of the potential is covered by the assortment softwood tops and branches with 39% followed by softwood 8 – 15 cm with 30%. Softwood of poor quality shows with 8% a low proportion. Compared to the distribution of tree species hardwood has an importance as fuel wood with a share of 23% (Figure 3).

If the backlog of omitted tendings and thinnings will be harvested within the next 10 years, the average potential will raise by 30% up to 3.0 $m^3a^{-1}ha^{-1}$. In this case especially a higher proportion of softwood tops and branches as well as the assortment 8 – 15 cm can be expected. At scenario 3 the total amount of fuel wood will be the same as for scenario 1. The slightly different harvesting strategy causes a change of the distribution of fuel wood assortments. The percentage of hardwood increases for the benefit of softwood (Figure 3). It can be assumed that the backlog of tending and thinning effects mostly softwood stands.

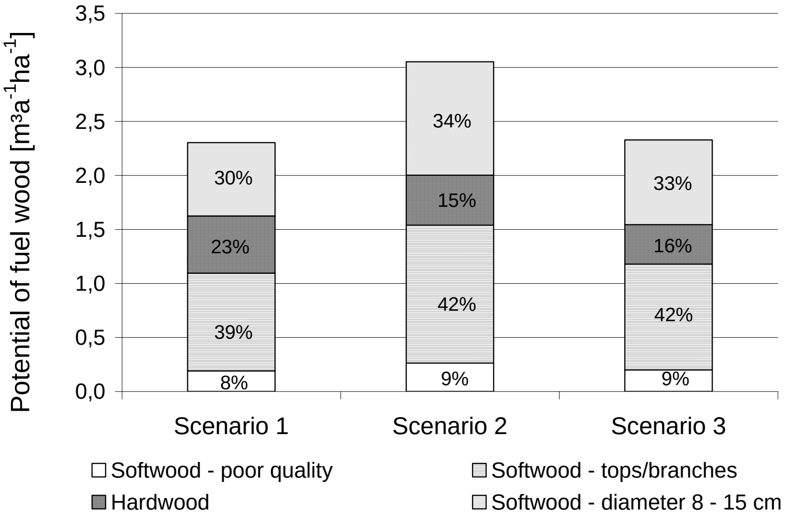

Figure 3: Potential of fuel wood by three different utilization scenarios and aggregated assortments.

Optimization

The computed costs – supply costs at plant level - include chipping, transport and variable terminal costs. This supply costs reflect the viewpoint of forest owners and suppliers respectively, so there are no terminal costs calculated at plant, as they are paid by the plant owner. At a yearly demand level of 73,000 m³ forest chips the optimal supply cost will be 5.80 EUR per cubic meter loose on average, if the material is delivered directly to plant. Fuel flow via terminal creates additional need for transport and the costs for the terminal must be added. Therefore the costs increase to 6.40 and 7.40 $EURm^{-3}$ loose respectively. Another effect appears if demand rises like in scenario II and III. Supply costs of direct transport will increase from 5.80 to 6.60 EUR m^{-3} loose (Table 3).

Table 3: Supply costs of computed scenarios and options in Euro per cubic meter forest chips.

Scenarios	Options - costs [EUR*m^{-3} loose] 1	2	3
Demand [m³ loose/a]	Share via Terminals 0%	50%	100%
I - 73,000	5.80	6.40	7.40
II - 96,000	5.90	6.50	7.40
III - 306,000	6.60	6.90	

Beside the optimal cost allocation of sources, also the material flow from terminals to plant is optimized. To answer the question which terminals should be used the scenario III variant 2 would be taken as example. The optimization assigns a high yearly turnover to Terminal 7, which is located at the center of the study area. A total volume of 57,400 m³ loose should distribute to plants 3, 26, 5, 1, 10 and 27 with optimal flows of 8,500; 8,200; 1,900; 1,200; 1,000 and 36,600 m³ loose per year. All terminals except number 8 operate in full capacity, which implies that this location is less competitive against the others. As this terminal position is close to border of the research area, high transport costs arise. Comparing all other scenarios and options terminals 5, 7 and 9 seems to be promising locations for terminals.
As each source point was allocate to one sink, optimal trading areas can be displayed. The areas are more or less located around the plants along major roads. Because of the given potential and the low demand only small supply areas appear (Figure 4). If the demand rises, like at scenario III where a new CHP will consume most of the forest fuel, the supply areas of existing plants will move. For example the fuel for plant 22 will only be delivered from the east. To fulfill the consumption of heating plant 27 nearly the source of the whole research area must be taken (Figure 5).

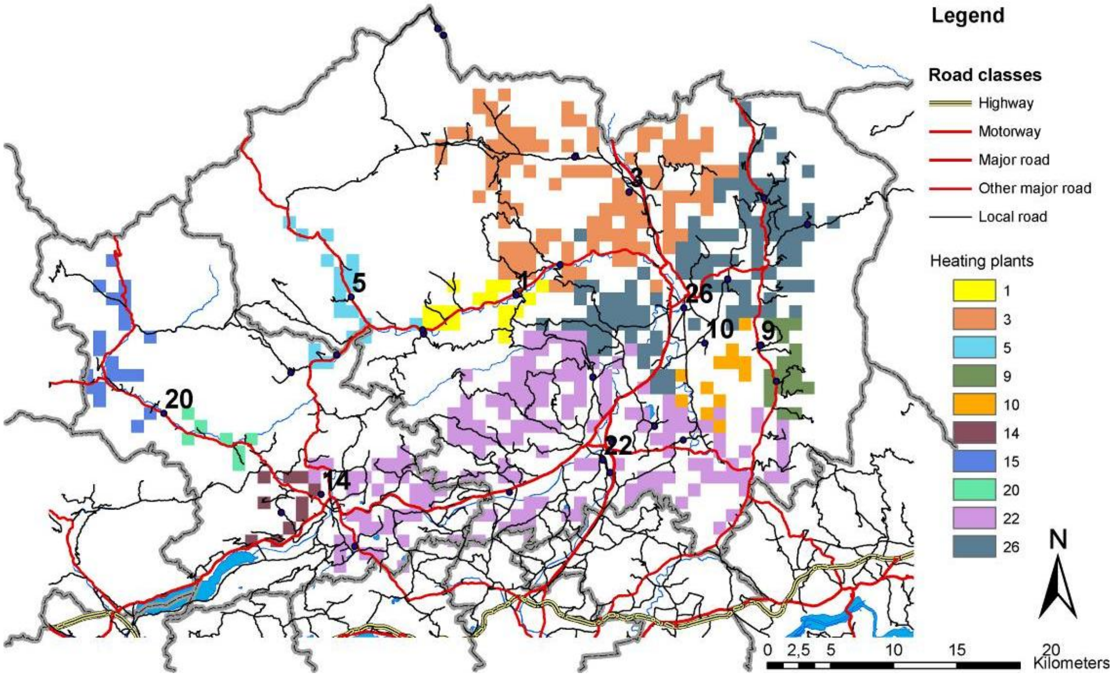

Figure 1: Optimal supply areas at scenario I variant 1 and cost optimal allocation of potential respectively.

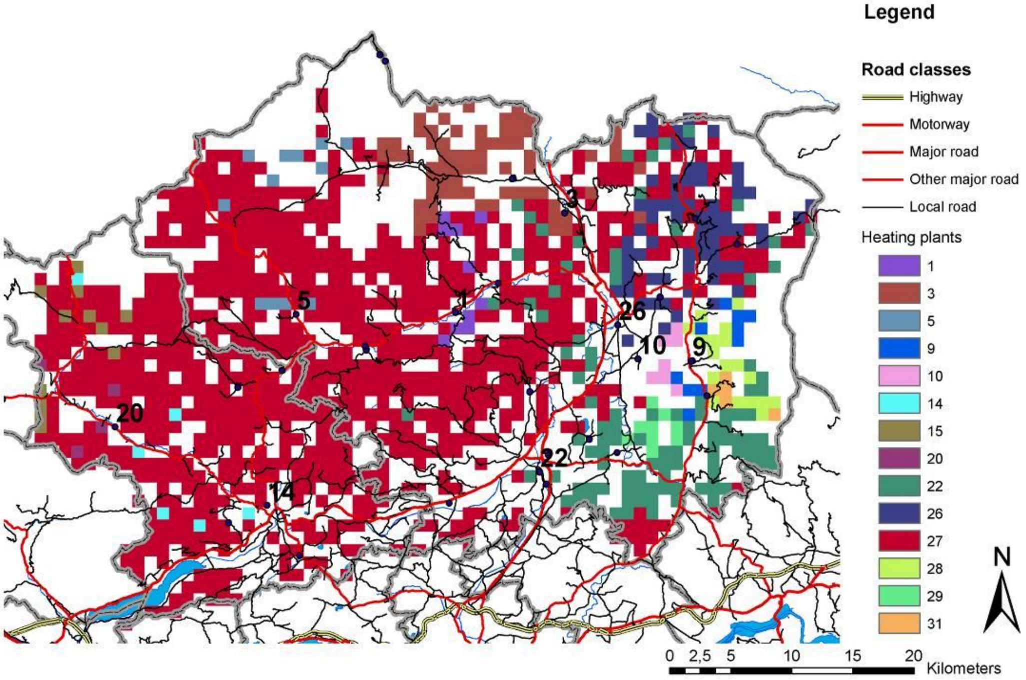

Figure 2: Optimal supply areas at scenario III variant shows that most of the potential will be allocated to heating plant 27.

Discussion

With this simple approach, material flows from forest to plant and optional via terminal can be optimized based on traceable calculations and different scenarios as well as supply options can be evaluated quiet quickly. The outcomes can be seen as a benchmark for the region. Keep in mind that the results ignore market behavior. Simulation of market behavior in biomass supply is done by Gronalt and Rauch (2006) via different assumptions. Nevertheless the findings are computed by models and a comparison to real world is still missing. The main reason for that is that plant owners do not want to share sensitive data, because of suspected disadvantages against competitors.

Due to the chosen stepwise procedure, the model provides only local optimums. A global optimal solution must take all components along the supply chain, which are causing costs, in consideration. Also the limits of spreadsheet calculations will be reached quite quickly, if expanded objective functions must be implemented. Data exchange between a GIS system and spreadsheet calculations needs improvement and so on. Professional solver platforms overcome those barriers and offer a wide range of interfaces as well as tailor to solve mathematical problems scripting and programming language respectively.

Further development of the approach has been carried out, whereby global optimums for material flows and terminal locations can be achieved.

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Economic Modeling of Woody Biomass Utilization for Biofuels: A Case Study in West Virginia

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Abstract: West Virginia is the third most heavily forested state in the U.S. and produces 2.41 million dry tons of wood residues annually. These wood wastes can be used as feedstock for biofuels, bio-gas and green electricity. Efficient harvesting, extraction, and transportation of woody biomass are the key to the economic success of wood residue utilization. The cost components of collecting, processing, and delivering woody biomass are not well documented, which hinders further research on the economic feasibility of woody biomass-based biorefineries in West Virginia. An economic analysis model was developed to evaluate woody biomass utilization for biofuels, including the costs for woody biomass harvesting/extraction, storage, loading/unloading, transportation, and wood chipping under different harvesting system configurations. A mix integer programming (MIP) model was specifically developed using General Algebraic Modeling System (GAMS) to optimize potential woody biomass-based biorefinery locations with the objective of minimizing the total annual delivered cost of available woody biomass and resource constraints. The model was applied in West Virginia and analyzed in terms of sensitivity analysis under different resource and operational scenarios, such as woody biomass availability, demand levels, and inventory at plant. The results would be useful to facilitate the research and economic development of woody biomass for biofuels in the region.

Keywords: Woody Biomass, System Modeling, Cost Analysis, Bioenergy.

1. Introduction

West Virginia has abundant woody biomass resources and produces 2.41 million dry tons of wood residues yearly. Even though 68% of mill residues were utilized in 2006, most of the logging residues, the largest proportion of wood residues, were underutilized (Wang et al. 2006). In recent years, the interest of using woody biomass as feedstock of bioenergy in the U.S. has been increasing due to the concerns of reducing energy dependence on foreign oil. Ethanol as one of the products made from wood residues has attracted much attention. The utilization of abundant wood residues as feedstock for ethanol or other biofuels or bioproducts may provide West Virginia a significant opportunity in economic development and energy independence. Efficient harvesting, extraction, and transportation of woody biomass are the keys to the economic success of woody biomass utilization. However, the optimized costs for collecting, processing, and delivering woody biomass under different resource constraints and operational circumstances are not well addressed, which hinders further research on the economic feasibility of woody biomass-based biorefineries. The purpose of this paper is to develop a MIP model to analyze the woody biomass utilization for biofuels in West Virginia.

2. Model development

The objective of the model is to minimize the total annual delivered cost of woody biomass from the supply locations to demand locations, which is expressed as follows:

$$\begin{aligned} Min \quad z = \sum_{m=1}^{M}\Bigg[& \sum_{i=1}^{I}\sum_{h=1}^{H}(\alpha_h + sc)xh_{ihm} + \sum_{i=1}^{I}\sum_{h=1}^{H}\varphi xps_{ihm} + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{h=1}^{H}(cs_h + \tau_{ijh} + cp_h)xt_{ijhm} \\ & + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{r=1}^{R}(mc_r + mt_{ij})xm_{ijrm}\Bigg] + Lct \end{aligned} \qquad (1)$$

Five cost components were modeled including logging residue extraction cost, on-site storage cost, hauling and loading cost, chipping cost in the field or at mill, mill residue purchased cost and stumpage cost of logging residue. Logging residue was assumed available all the year, thereby ready for collection at any time. Seven woody biomass handling systems which included extraction, storage, transportation and comminution activities were considered in the model based on extraction methods and forms of biomass delivered, including cable skidder-loose material, cable skidder-chip, grapple skidder-loose material, grapple skidder-chip, forwarder-loose material, forwarder-chip, and forwarder-bundle. The notations for variables and symbols in the model are explained in the Appendix. Except for forwarder-bundle system, logging residues can be shipped out either immediately after collection or stored in the field for a period of time. The storage assumption for forwarder-bundle system was described in the later constraints.

Several constraints were considered in the model. It was assumed that there was one extraction system at each supply location (Equation 2). The handling system index h ranged from 1 to 7. Here, it was set to 1, which means that cable skidder-loose material system was selected in the model.

$$\begin{cases} \sum_{h=1}^{H} Alfa_{ih} = 1, \forall i, \\ Alfa_{ih} = 1, \forall i, where\ h = 1. \end{cases} \qquad (2)$$

The amount of logging residues annually extracted using system h at supply location i should be no greater than the available logging residues at that location (Inequality 3). The slope constraint was also considered for cable skidder, grapple skidder, and forwarder extraction systems to further limit logging residue availability. All the extraction machines and slash bundler were assumed to be able to operate on sites with slope 35% or less. Besides this constraint, the amount of logging residues extracted is also subject to the availability of logging residue for a specific time period (or a month) (Inequality 4) and extraction ability of loggers (Inequality 5). An average rate was applied to logging residue availability in each month. For instance, we assumed the logging residue extracted can not exceed 1/12 of the total available if extracted in January. The working time of each extraction machine was assumed as 6 hours per day and 5 days a week, therefore a total of 120 working hours per machine was assumed in a month. The amount of mill residues shipped out of each county is also subject to the total mill residues available in that county (Inequality 6).

$$\begin{cases} \sum_{m=1}^{M} xh_{ihm} - Alfa_{ih} BP_i BIV_i \le 0, & \forall i, h, \\ \sum_{m=1}^{M} xh_{ihm} - Alfa_{ih} BP_i BVS_i \le 0, & \forall i, h. \end{cases} \tag{3}$$

$$xh_{ihm} - Ext_m BP_i BVS_i \le 0, \quad \forall i, h, m. \tag{4}$$

$$xh_{ihm} - 120 P_h \cdot NL_i \cdot NM_h \le 0, \quad \forall i, h, m. \tag{5}$$

$$\sum_{j=1}^{J} xm_{ijrm} - MP_{ir} MIV_{ir} \le 0, \quad \forall i, r, m. \tag{6}$$

The total logging residue extracted using system h at supply location i in month m plus the usable parts of stored logging residue should balance with the sum of logging residue shipped to demand locations and stored in the field (Equation 7). Tembo et al. (2003) indicated that the amount of biomass shipped out plus biomass lost in-field storage balance with total biomass produced in the year. Then, the logging residue storage balance in one year can be derived. If summing equation (7) for one year, we get equation (8). Rearranging this equation, we get equation (9). Equation (10) was used to model the relationship among logging residues extracted, logging residues entering storage and removed from storage, and logging residues transported to demand locations. The storage for logging residue was to balance the whole logistics of logging residue handling process.

$$xh_{ihm} + \theta_i xs_{ihm-1} - \sum_{j=1}^{J} xt_{ijhm} - xs_{ihm} = 0, \quad \forall i, h, m. \tag{7}$$

$$\sum_{m=1}^{M}\sum_{h=1}^{H} xh_{ihm} + \theta_i \sum_{h=1}^{H} xs_{ih12} + \left(\theta_i - 1\right)\sum_{m=1}^{11}\sum_{h=1}^{H} xs_{ihm} - \sum_{h=1}^{H} xs_{ih12} - \sum_{j=1}^{J}\sum_{h=1}^{H}\sum_{m=1}^{M} xt_{ijhm} = 0, \quad \forall i. \tag{8}$$

$$\sum_{m=1}^{M}\sum_{h=1}^{H} xh_{ihm} - \left(1 - \theta_i\right)\sum_{m=1}^{M}\sum_{h=1}^{H} xs_{ihm} - \sum_{j=1}^{J}\sum_{h=1}^{H}\sum_{m=1}^{M} xt_{ijhm} = 0, \quad \forall i. \tag{9}$$

$$xh_{ihm} - xps_{ihm} + xsn_{ihm} - \sum_{j=1}^{J} xt_{ijhm} = 0, \ \forall i, h, m. \tag{10}$$

Regarding forwarder-bundle system, residue bundles are assumed to deliver to a storage site for drying and transportation (Equation 11). The quantities of slash bundles (in tons) transported to demand locations should be no greater than the usable portion of bundles stored before current month in the field.

$$\begin{cases} xps_{ihm} - xh_{ihm} = 0, \ \forall i, h, m, where\ h = 7. \\ xsn_{ihm} - \theta_i xs_{ihm-1} \le 0, \ \forall i, h, m, where\ h = 7. \end{cases} \tag{11}$$

The total woody biomass delivered to a plant plus the usable biomass stored in previous month at the plant should be no less than the storage and feedstock demand at the plant (Inequality 12). We also assumed plant scheduled working days per month as 30 days and 50% moisture content of woody biomass. Therefore, the monthly feedstock demand in wet tons will be 60 times of daily demand in dry tons.

$$\sum_{i=1}^{I}\sum_{h=1}^{H}(1 - tloss) xt_{ijhm} + \sum_{i=1}^{I}\sum_{r=1}^{R} xm_{ijrm} + \phi xss_{jm-1} - xss_{jm} - 60 * CP\beta_j \ge 0, \ \forall j, m. \tag{12}$$

The minimum inventory of woody biomass at a plant was defined to ensure smooth production and zero inventory was assumed in the base case (Mapemba 2006):

$$xss_{jm} - MNBIN \cdot \beta_j \geq 0, \forall j,m. \tag{13}$$

The number of plants that can be built was also considered as a constraint (Mapemba 2006). It was set to one in the base model.

$$\sum_{j=1}^{J} \beta_j = 1 \tag{14}$$

2.1 Woody biomass transportation

Transportation cost of woody biomass can be affected by hauling distance, payload size, biomass dimension and density. The trucking cost model incorporating road networks were based on Wood Transportation and Resource Analysis (WTRANS) (Jensen et al. 2002) and machine rate (Miyata 1980). The trucking cost model (Equation 15) consists of fuel cost, driver wages, and overhead and maintenance costs, which is also a function of payload and hauling distance from supply to demand locations.

$$T_{ij} = \frac{2d_{ij}}{mpg} fpg + \frac{2d_{ij}}{mph} dwh + \frac{\frac{(tp-ts)}{N} + \left(\frac{(tp-ts)(N+1)}{2N} + ts\right) IITR}{SMH \cdot UT} \frac{2d_{ij}}{mph} + \frac{(tp-ts)MR}{N \cdot SMH \cdot UT} \frac{2d_{ij}}{mph} \tag{15}$$

Where, T_{ij} -total trucking cost per load from location i and demand location j (\$); d_{ij} -hauling distance between location i and demand location j (miles); mpg -truck miles per gallon (miles/gal); mph -truck miles per hour (miles/h); fpg -fuel (diesel) price per gallon (\$/gal); dwh -driver's wages per hour, including a fringe of benefit rate of 40% (\$/h); tp -purchased price of truck (\$); ts -truck salvage value, calculated as a percentage of truck purchased price (%); N -economic life of trucks (years); SMH -scheduled trucking hours per year, assumed 2000 hours/year (hours); $IITR$ -Interest, insurance, and taxes rate (%); MR -maintenance & repair rate, expressed as a percentage of depreciation (%); UT -average annual utilization rate of trucks (%).

Considering different forms of woody biomass delivered (loose residues, wood chips, bundles), transportation cost rate (\$/ton) including loading/unloading cost corresponding to each extraction system was computed by dividing trucking cost per load by truck loads.

2.2 Within-county transportation

Since woody biomass supply counties are represented by centroids of the counties in the general transportation cost model (Equation 15), the transportation cost within supply locations are not fully considered especially when the supply location and demand location are in the same county, which results in underestimating the total delivered cost. We calculated the total ton-mile to transport woody biomass for supply location i given the density of biomass as Dornburg and Faaij (2001):

$$sm_i = 1.073\left(\sum_{j=1}^{J}\sum_{h=1}^{H}\sum_{m=1}^{M} xt_{ijhm}\right)^{1.5} (D_b \pi)^{-0.5} \tag{16}$$

Here, sm_i is the average ton-mile for delivering biomass (tons mile per year) in supply location i, and D_b is biomass density (tons mile^{-2}). If there is only one woody biomass handling system and one optimal plant location, equation (16) is equivalent to:

$$sm_i = \sum_{j=1}^{J}\sum_{h=1}^{H} sm_{ijh} = \sum_{j=1}^{J}\sum_{h=1}^{H} 1.073\left(\sum_{m=1}^{M} xt_{ijhm}\right)^{1.5} (D_b \pi)^{-0.5} \qquad (17)$$

The nonlinear function (Equation 17) was approximated by a piecewise linear function using a separable programming approach. The range of the amount of logging residue annually shipped out of each supply location should be determined, over which the breakpoints were defined at a_n, $n = 0,1,\cdots,N$. Let xtl_{ijhn} be the increment of amount of logging residue annually shipped out of supply county i in the range (a_{n-1}, a_n), and subject to the following constraints:

$$\sum_{n=1}^{N} xtl_{ijhn} = \sum_{m=1}^{M} xt_{ijhm} \qquad (18)$$

$$0 \le xtl_{ijhn} \le a_n - a_{n-1},\ \ n = 1,2,\cdots,N \qquad (19)$$

Then, equation (17) is transformed to:

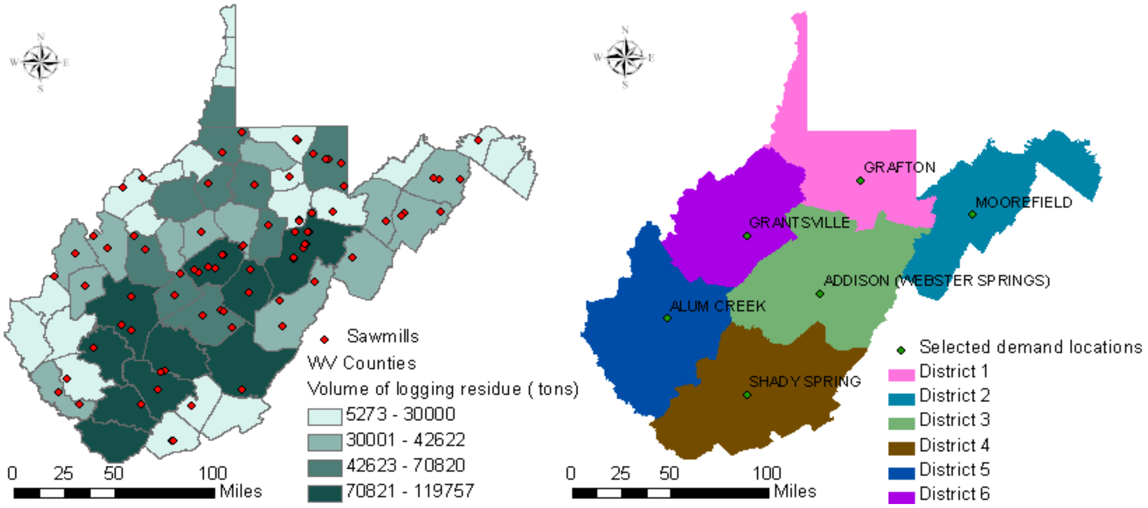
$$sm_i = \sum_{j=1}^{J}\sum_{h=1}^{H}\sum_{n=1}^{N} fc_n xtl_{ijhn} \qquad (20)$$

The transportation cost within supply counties was considered in the total delivered cost if the distance between supply location and demand location (d_{ij}) was no greater than one half of the longest straight-line distance of the supply county (rs_i). The within-county transportation cost can be calculated as:

$$Lct = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{h=1}^{H}\sum_{n=1}^{N} t_h fc_n xtl_{ijhn},\ \ where\ d_{ij} \le rs_i \qquad (21)$$

3. Model application

The model was applied in the central Appalachian region within the state of West Virginia. Thirty three out of 55 counties were chosen as woody biomass supply locations based on logging residues yields $\geq 30{,}000$ tons/year. Six woody biomass demand locations located in the center of each forest district in West Virginia were selected (Figure 1). A medium size of woody biomass-based plant with demand of 1,000 dry tons of wood chips per day together with the following assumptions were assumed as base case for comparison of delivered cost among woody biomass handling systems and further sensitivity analysis.



(a) Logging residue and sawmills. (b) Woody biomass demand locations.

Figure 1 Woody biomass supply and demand locations

3.1 Woody biomass availability and accessibility

The production of wood residues has been surveyed for several years in West Virginia (Wang et al. 2006). The annual harvesting acreage was derived from West Virginia Logging Sediment Control Act (LSCA) 2005 statistics. Considering the terrain constraints and environment protection, the general recovery rate of logging residues was assumed at 65% in the base case. Zero stumpage cost was assumed. The mill residue is assumed non-available in some of the counties such as Braxton, Gilmer, Fayette, Randolph, Raleigh, Upshur and Webster due to the competitiveness from pellet companies. Ninety percent mill residues in the other counties were assumed available at an average cost of $10/ton.

3.2 Logging residue handling productivities and costs

Based on the productivity models for logging residue extraction developed in the region (Li et al. 2006, Grushecky et al. 2007), in the base case, we assumed average extraction distance to be 750 feet. The payload size was 106 ft^3 for cable skidder, 107.87 ft^3 for grapple skidder, and 304.62 ft^3 for forwarder. The payload size for forwarding slash bundles was assumed to be 480.39 ft^3 per cycle (Rummer et al. 2004).

Wang (2007) reported that loading productivity varied from 3.40 MBF/PMH for loading pulp logs, to 7.56 MBF/PMH for peeler logs, and to 12.24 MBF/PMH for sawlogs. The models fitted for saw log and pulp wood were used to estimate loading productivity for forest bundles and loose residues, respectively.

Costs of logging residue extraction were calculated by using machine rate method (Miyata 1980), which include fixed or ownership costs, variable or operating costs, and labor costs (Table 1).

Table 1. Assumptions for logging residue extraction/handling machines.

Items	*Cable skidder*	*Grapple skidder*	*Forwarder*	*Slash bundler*	*loader*
Purchased price ($)	150,000	190,000	220,000	450,000	130,000
Savage value (% of price)	25	25	25	25	25
Economic life (years)	5	5	5	5	5
Interest, insurance, and tax (%)	20	20	20	20	20
Labor cost ($/hour)	10	10	10	10	10
Labor fringe (% of labor cost)	35	35	35	35	35
Maintenance and repair (% of depreciation)	90	90	90	90	90
Mechanical availability (%)	65	65	65	65	80
Horse power (hp)	100-110	110-120	110	182	140-150
Fuel consumption (gal/hp.hr)	0.028	0.028	0.0248	0.027	0.0217
Lubricant (% of fuel cost)	36.77	36.77	36.77	36.77	36.77
Scheduled machine hours/year	2000	2000	2000	2000	2000

The fuel (diesel) price was assumed to be $3.26/gallon. Lubricant cost was estimated at 36.77% of fuel cost. Scheduled machine hours were 2000 hours per year for all the machines. Thus, the hourly cost estimation were: cable skidder: $82.54/PMH; grapple skidder: $96.49/PMH; forwarder: $104.85/PMH; loader: $67.11/PMH. The cost for the slash bundler was calculated as $190.60/PMH without considering twine cost. Each bundle uses about 270 feet of baling twine (Rummer 2004). Baling twine cost was estimated as $5/PMH given the productivity of 20 bundles per hour. So the cost for slash bundler was estimated as $195.60/PMH.

The extraction/loading cost of logging residues in dollar per ton was computed dividing machine cost by productivity rate.

Johansson et al. (2006) estimated that the chipping cost of loose material at landing and forest bundles at plant as 4.23 Euro/MWh (megawatt hour) and 1.52Euro/MWh, respectively. Converted to US dollars, the chipping cost will be $7.60/ton for loose material and $2.73/ton for forest bundles assuming that one bundle (0.4-0.7 dry ton) with 50% moisture content contains 1MWh energy. EECA (2007) also presented a similar estimation for chipping cost. In our case, the chipping costs under different systems were assumed as follows: chipping at plants at $3.57/ton, chipping at landings at $7.14/ton and crushing bundles at $2.84/ ton.

Regarding to the general transportation, the following assumptions were assumed. Tractor-trailer and chip van were used for transporting loose residue and chips, respectively. Both of the purchased costs were $135,000. The economic life was 8 years with salvage value as of 20% of the purchased cost. MPG and MPH were assumed to be 8 miles/gallon and 35 miles/hour for intercounty transportation and 5 miles/gallon and 25 miles/hour for intracounty transportation. Fuel price was $3.26/gallon. Driver wages plus fringe benefits were $14 per hour. Scheduled operating hours were 2000 hours per year and utilization rate was 90%. Maintenance and repair was 90% of depreciation. Interest, insurance and taxes were 20% of yearly investment. The truck capacity was assumed to be 25 tons. Considering woody biomass density in different forms, the loads under different systems were assumed: loose residues shipped to plant: 16 tons, chips to plant: 20 tons and forest bundles: 25 tons.

Considering the difference of logging residue availability in different supply counties, the amount of logging residue that can be shipped out of each supply county per year was assumed ranging from 0 to 75,000 tons, over which a total of ten breakpoints were defined at a_n,

$n = 0,1,\cdots,9$, a_n ={0,1000, 3000, 5000, 10000, 20000, 30000, 40000, 50000, 75000}. The average density of logging residue in West Virginia was estimated as 56.45 tons/mile^2 assuming 65% of logging residues available. Then, the separable linear functions over the domain of total logging residues shipped out of location i each year can be derived. Substitute the parameters into equation (21), we get the applied within-county transportation cost model as:

$$Lct = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{h=1}^{H} t_h \begin{pmatrix} 2.55xtl_{ijh1} + 5.35xtl_{ijh2} + 7.63xtl_{ijh3} + 10.42xtl_{ijh4} + 14.74xtl_{ijh5} \\ +19.08xtl_{ijh6} + 22.60xtl_{ijh7} + 25.63xtl_{ijh8} + 30.17xtl_{ijh9} \end{pmatrix}, \text{where } d_{ij} \le rs_i \qquad (22)$$

4 Results

4.1 Base case

The results indicated that the optimum location for a plant with minimum delivered cost in all the systems was near Addison in Forest District 3. The total delivered cost increased from forwarder-loose material system to cable skidder-chip system. The averaged cost was calculated by dividing the total delivered cost by the annual demand (Figure 2). The transportation cost and purchased cost (including mill residue purchased cost and logging residue stumpage cost) were the major cost components, accounting for 39.90% and 30.97% of the total cost, respectively. Extraction cost accounted for 20.50% of the total and followed by the chipping cost. The comparisons among handling systems demonstrated that chipping cost at mills was cheaper than that in the field. No storage cost was incurred because we assumed that there was either no storage cost or no storage needed.

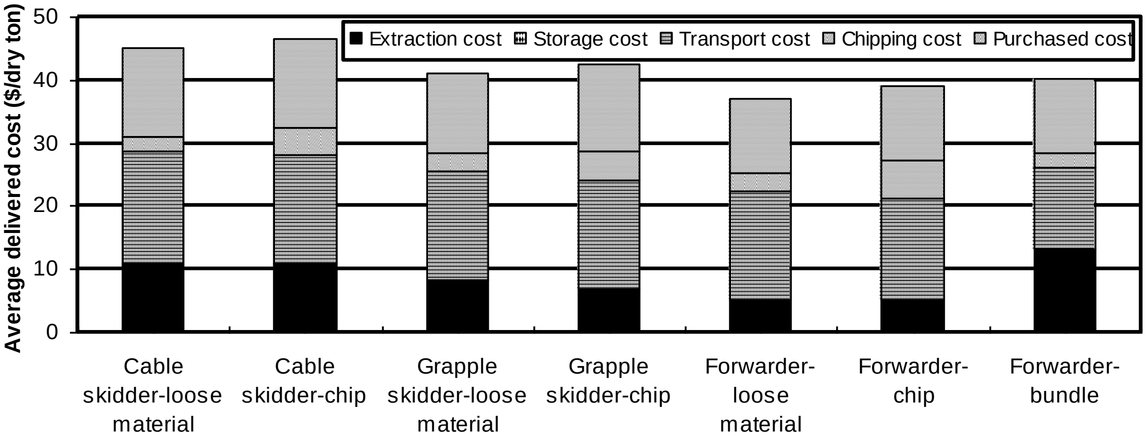


Figure 2. Delivered cost composition by handling systems.

4.2 Sensitivity analyses

(1) Woody biomass availability

The effects of wood residue availability on the average delivered cost of woody biomass were analyzed (Figures 3 and 4). The cost varied slightly as logging residue available proportion changed. Compared to the base case (65% of logging residue available), the delivered cost at 20% of logging residue available increased $1.93/dry ton for forwarder-bundle handling system, $2.08/dry ton for cable skidder and grapple skidder-chip systems, $2.61/dry ton for cable skidder and grapple skidder-loose material systems, $2.60/dry ton for forwarder-chip system, and

$3.56/dry ton for forwarder-loose material system. However, the average delivered cost of woody biomass was sensitive to the variation of mill residue availability. If the available proportion of mill residue decreased from 90% to 20%, the cost increased $20.35/dry ton for cable skidder-based handling systems, $13.17/dry ton for grapple skidder-based handling systems, and $8.76/dry ton for forwarder-based handling systems. Among all the woody biomass delivered, about 59-69% were mill residues and the rest was logging residues. Mill residue availability had great impacts on the average delivered cost at current demand level in comparisons with logging residue.

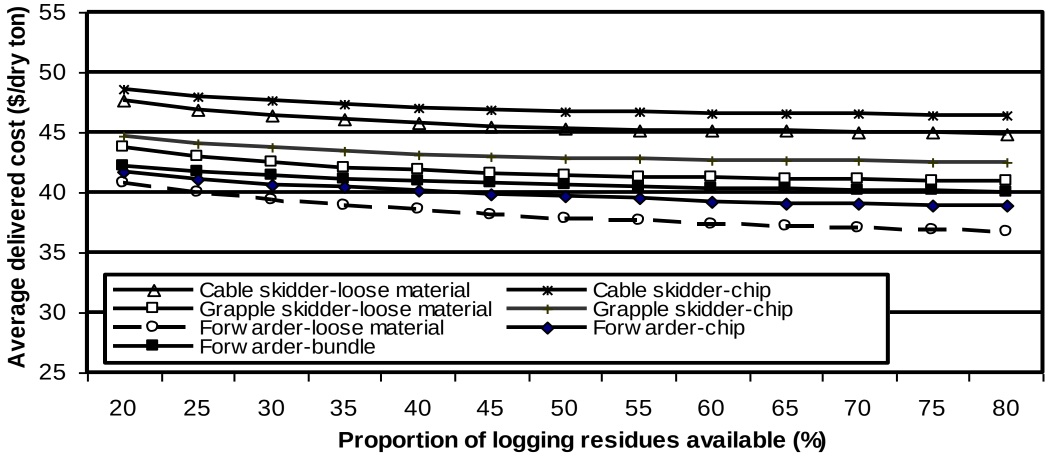


Figure 3. Average delivered cost vs. logging residues availability.

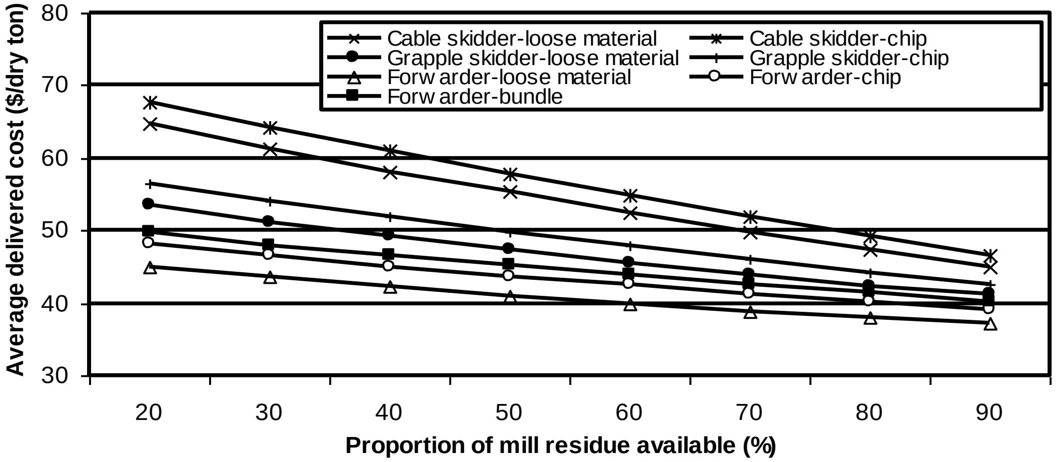


Figure 4. Average delivered cost vs. mill residues availability

(2) Woody biomass demand

The average delivered cost increased dramatically as the demand at a plant increased among woody biomass handling systems (Figure 5). As shown in the previous figures, the costs for grapple skidder and forwarder-based handling systems were relatively lower than that for cable skidder-based handling systems. Due to the biomass resource constraints defined such as 65% of logging residue available and 90% of mill residue available and slope constraints for extraction machine operation, the available woody biomass can satisfy the feedstock demand at plant up to 1,800 dry tons/day. Compared to the base case, the average delivered cost corresponding to the demand of 1,800 dry tons/day increased $14.46/dry ton for cable skidder-based handling systems, $10.37/dry ton for grapple skidder-based handling systems, and $7.82/dry ton for forwarder-based handling systems.

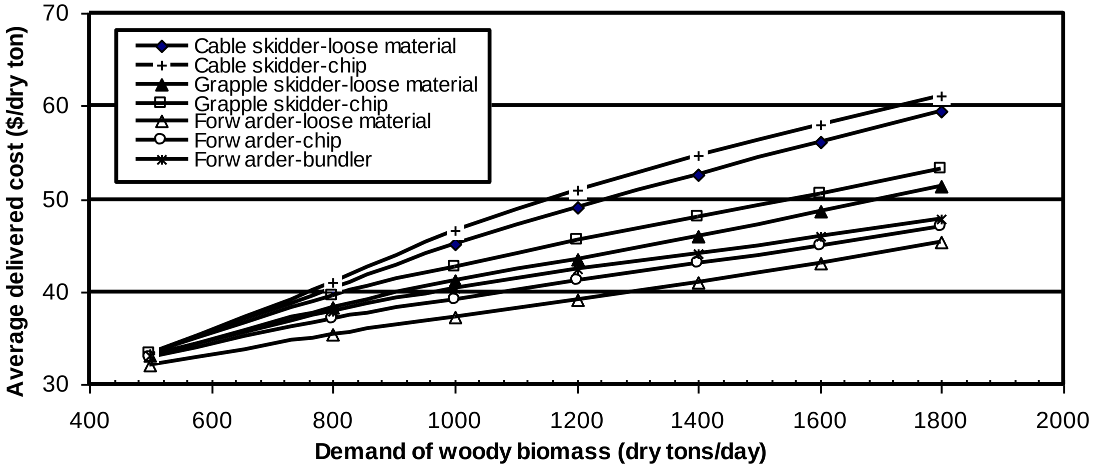


Figure 5. Woody biomass delivered cost vs. feedstock demand

(3) Woody biomass inventory at plant

The inventory level of woody biomass at a plant is critical to ensure the smooth production of biofuels or bioproducts, especially in some seasons when woody biomass collection is not possible. However, it is costly to maintain a higher level of inventory. Even though the inventory cost at plant was not a part of delivered cost, the inventory level would indirectly impact all the activities involved in woody biomass handling. In addition to the base case for comparison, three different levels of inventory by weeks were analyzed. The average delivered cost increased as the inventory level at plant increased among woody biomass handling systems (Figure 6). The highest cost occurred with cable skidder handling systems followed by grapple skidder handling systems. At current demand level of 1,000 dry tons/day, the inventory at plant should be no more than 3 weeks in terms of available woody biomass resources.

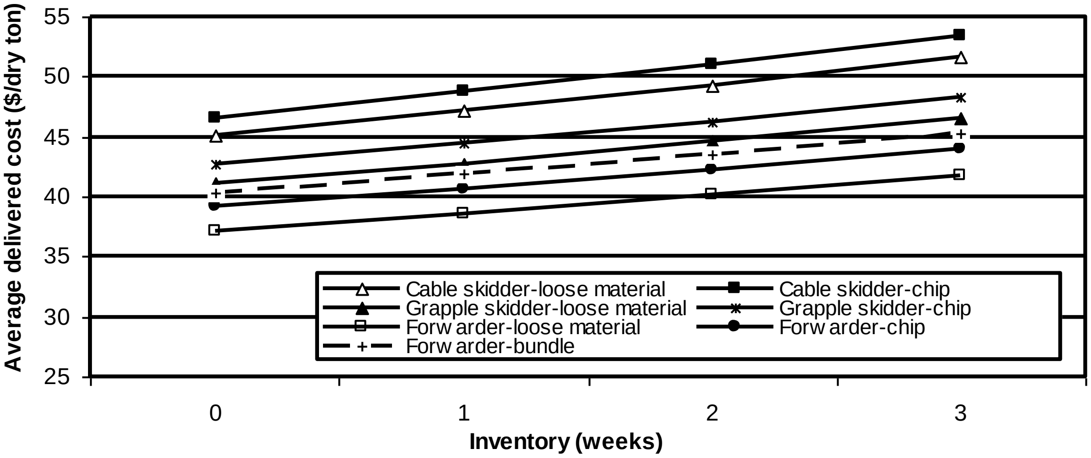


Figure 6. Woody biomass delivered cost vs. inventory at plant

5. Conclusion and discussion

The economic model developed can be used to facilitate woody biomass handling cost analysis and locating potential woody biomass utilization plant under certain supply, demand and other factors. The base case study indicated that the optimum plant location with different woody biomass handling systems was coincidently near Addison, in Webster County (Forest District 3), which is located near the center of West Virginia and surrounded by abundant woody biomass. It is noticed that all the potential plant locations were given by forest districts in the application. Actually, many factors could affect location of a woody biomass-based plant, such as possibility of utilizing existing facilities, accessibility to road networks and utilities, target market for biofuels or bioproducts, and others. All these factors will be considered in the future research and the derived feasible plant locations will be plugged into the model to achieve more accurate and reasonable results.

The average delivered cost of woody biomass for a medium size plant with demand of 1, 000 dry tons/day of wood chips ranged from $37.19 to $46.58/dry ton with different woody biomass handling systems, which was a little higher than DOE (US Department of Energy) target cost of $35/dry ton at which level the production of biofuels from woody biomass could be profitable. In addition, zero inventories were assumed in the base case. If the inventory at plant were increased, the average delivered cost of woody biomass will be higher.

Sensitivity analysis also showed that the availability and purchased cost of mill residues, and demand levels had great impacts on the average delivered cost. Since the feedstock supply stabilization is really important, it is necessary to find niche supply markets for wood residues either by signing long-term contracts or developing cooperation relationship with landowners and major forest products companies. The average delivered cost varied significantly as the demand at plant changed. To determine a reasonable demand, factors such as available funds, plant investment, industrial lands availability, feedstock supply stabilization also need to be addressed.

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Appendix: Nomenclature

I -Set of woody biomass locations;
J -Set of feasible plant locations;
M -Month of the whole year, $m = 1, 2, 3, \ldots 12$;
H -Woody biomass handling system;
R -Mill residue types, $r = \{\text{bark, chips, sawdust}\}$;
α_h -Logging residue extracting cost (\$/ton);
sc -Stumpage cost of logging residue (\$/ton);
φ -Logging residue storage cost in the field (\$/ton);
τ_{ijh} -Round trip transportation cost from supply location i to plant j for system h (\$/ton);
l_h -Loading cost of woody biomass corresponding to system h (\$/ton);
cs_h -Chipping cost in the field corresponding to handling system h (\$/ton);
cp_h -Chipping cost at plant corresponding to system h;
t_h -Within-county transportation cost for system h (\$/ton/mile);
mc_r -Purchased cost for mill residue type r (\$/ton);
mt_{ij} - Mill residue transportation cost from location i to location j (\$/ton);
BP_i -Proportion of logging residue available for extraction at supply location i;
BIV_i -Volume of logging residue at supply location i (tons);

BVS_i - Volume of logging residue on sites with slope 35% or less at supply location i (tons);

Ext_m - Limitation of logging residue extracted in month m as a percentage of the total year (%);

MP_{ir} -Proportion of mill residue r available at supply location i;

MIV_{ir} -Volume of mill residue r at supply location i;

$tloss$ -Loss rate of woody biomass due to transportation (%);

CP -Woody biomass demand at plant (dry tons/day);

Lct -Within-county transportation cost ($);

NL_i -Number of loggers in supply location i;

NM_h -Average number of extraction machines that each logger owns;

n -Breakpoint index;

a_n -Breakpoints over the value of annually delivered logging residue from supply location i;

fc_n -Slope of the line segment in the range (a_{n-1}, a_n);

xh_{ihm} -Quantity of logging residues extracted in month m at location i using system h (tons);

xt_{ijhm} -Quantity of logging residue that are extracted using system h delivered from location i to plant j in month m (tons);

xps_{ihm} -Quantity of logging residue that are extracted using system h entered into storage at supply location i in month m (tons);

xm_{ijrm} -Quantity of mill residue r delivered from location i to plant j in month m (tons);

xs_{ihm} -Quantity of logging residue that are extracted using system h stored at location i in month m (tons);

xsn_{ihm} -Quantity of logging residue that are extracted using system h removed from storage at location i in month m (tons);

xss_{jm} -Quantity of woody biomass stored at plant j in month m (tons);

xtl_{ijhn} - The increment of logging residue annually shipped out of location i in the range (a_{n-1}, a_n) ;

β_j -A binary variable related to plant j.

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When Did the Industrial Revolution in the Woods Begin and End?

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We compare the change in tree harvesting systems in Eastern Canada and the American Southeast to ascertain both the timing and the pace of the industrial revolution in tree harvesting that transformed woods work after World War II in these regions.

What do we mean by an Industrial Revolution?

“Industry” is a term with many uses, sometimes referring to a specific economic activity (the forest industry, the tourism industry) and sometimes to manufacturing as opposed to resource extraction or service provision. We use it to designate the transformation of the work (labour) process in whatever economic activity.

Pre-industrial craft production, though carried out by wage labourers, used methods originating in the pre-capitalist era. Typically workers utilized hand tools requiring relatively high degrees of skill in production processes devised by the workers themselves.[1] The transition from craft work to industrial production began when employers took control of the work process from workers, imposing production processes designed to increase worker productivity, lower unit costs, and – with the addition of new technology – expand the scale of production. The transition reached maturity when these imposed production processes featured the introduction of machinery, transforming the role of workers to machine operators and tenders. Because mechanization is often accompanied by increased specialization in the division of labour, this transition changes – often diminishes – the skills required of workers, removing the autonomy they had previously enjoyed.

Industrial development is the process by which a succession of more and more efficient production systems are developed and *deployed in the workplace*.

An industrial revolution is a situation where the pace of industrial development is so rapid that it constitutes a dramatic and thoroughgoing transformation of the work process.

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[1] For an account of one such harvesting system, see Michael Clow and Peter MacDonald, “The Rise and Decline of Trailcutting on the Miramichi 1960 - 1990: A Perspective Based on Oral History”, *Acadiensis* (XXVI 1) 1996, 76-91.

Did an Industrial Revolution Occur in the Woods after World War II?

Until well after World War II tree harvesting in Eastern North America was organized around wage-labour, depending on large numbers of off-seasonal agricultural workers employing draft animals, hand tools and craft work techniques. This situation was transformed in the space of a lifetime: woods work is now conducted with various highly mechanized industrialized production systems.

This process did not begin with the widespread diffusion of the chainsaw for they are not machines but *powered tools*, completely depend on the skill of the operator. Indeed, their introduction creates *motor-manual* production systems. Rather, industrial development begins with the introduction of a machine to replace the horse, either a frame-steered forwarder or skidder.[2] These machines established the means of locomotion required for all subsequent mobile felling and processing machines.

Whether or not an industrial revolution occurred involves a judgment about the pace of change. The pace of change in Eastern Canada and the Southeast was very different, as was the timing of the introduction of the various felling, delimbing, and slashing machines.

This leads to the question posed in our title. Below we suggest there are different answers for each of our two regions.

Industrial Development in Eastern Canada[3]

Industrial development in Eastern Canada was initiated by the Woodlands Section of the Canadian Pulp and Paper Association with its creation of the Mechanization Steering Committee. Under its aegis Project 'e', established in 1950, developed the various iterations of the Bonnard Prehauler. This later culminated in the Dowty forwarder. The appearance of a genuine forwarder together with the now ubiquitous chainsaw provided for the trailcutter harvesting system, common in Eastern Canada throughout the 1960s. This system provided the foundation for the shortwood path of development. Its developmental stages together with their defining properties are identified in Figure I. Note that topography refers to the location of the processing activities while the division of labour designates the extent of its specialization.

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[2] For an analysis of the developmental implications of skidders versus forwarders, see Peter MacDonald and Michael Clow, "What a Difference a Skidder Makes: the Role of Technology in the Origins of the Industrialization of Tree Harvesting", *History and Technology (* 19 2) 2003, 127-149.

[3] What follows is a summary of Peter MacDonald and Michael Clow, "The Industrialization of Tree Harvesting Systems in the Eastern Canadian Forest, 1955-1995", *Labour/Le Travail* 58 (Fall 2006), 145-167.

Figure I: Stages of the Shortwood Path of Development in Eastern Canada

Developmental Stages	Topography	Division of Labour	Mechanization
Manual	Stump	Unified	Lo
Trailcutter	Stump	Unified	Intermediate
Shortwood Harvester	Stump	Unified	Hi
Double-grip Harvester	Stump	Intermediate	Hi
Single-grip Harvester	Stump	Unified	Hi

The diffusion of the frame-steered skidder at approximately the same time gave rise to the skid and slash harvesting system, itself providing the foundation for the longwood path of development (comprised of tree length and subsequently full tree systems). Here the division of labour becomes progressively specialized and processing is relocated to roadside. These developmental stages are identified in Figures II and III.

Figure II: Stages in the Tree Length Path of Development in Eastern Canada

Developmental Stages	Topography	Division of Labour	Mechanization
Manual	Stump	Unified	Lo
Skid & Slash	Intermediate	Intermediate	Intermediate
Tree Length Harvesters	Intermediate	Intermediate	Hi

Figure III: Stages in the Full Tree Path of Development in Eastern Canada

Developmental Stages	Topography	Division of Labour	Mechanization
Feller-forwarder	Roadside	Intermediate	Hi
Feller-buncher	Roadside	Specialized	Hi

Finally, in Table 1 we present data that provide an indication of the pace of industrial development as measured by the quantity of wood harvested by the variety of developmental paths.

Table Two: Percentage of Total Volume of Wood Harvested By Type of Tree Harvesting Systems in Eastern Canada

Year	Shortwood	Tree Length	Full Tree
1950[a]	95	5	0
1955[b]	90	10	0
1960[b]	80	20	0
1965[a]	45	50	5
1970[a]	30	65	5
1975[a]	20	70	10
1977[c]	14	68	18
1986[c]	12	35	53
1989[d]	6	15	79
1991	15	13	72
1997[f]	25	15	60

[a] J.A. McNally, "Mechanization in the Woods: from the 1930s to the 1970s", paper presented at the 59th Annual Meeting of the Woodlands Section, Canadian Pulp and Paper Association, Montreal, 1978, p.5.

[b] J.R. Erickson, "Mechanization in the Timber-Producing Industry", *Forest Products Journal*, V.18, No. 7, 1968, p.21.

[c] J.-F. Gingras, "Forest Mechanization Trends in Eastern Canada", paper presented at the 11th Annual Council of Forest Engineering Meeting, Quebec, Que, September, 1988, p.9.

[d] J.-F. Gringras, “Harvesting Small Trees - the Eastern Canadian Story”, in Bruce J. Stokes (ed.) *Harvesting Small Trees and Forest Residues*, USDA Forest Services, Auburn, Alabama, 1989, p. 121. Unlike the other figures in this Table, these are an aggregate of some of the kinds of harvesting system within each category.

[e] J.-F. Gingras and M. Ryans, "Future Woodlands Equipment Needs in Eastern Canada: 1992-2001" Technical Note TN-193, December, 1992, FERIC Library, p.3.

[f] Note that this figure includes only single-grip harvesters; therefore, it understates the total per centage of wood harvested by shortwood systems. Equally, the figure for tree length harvesting systems is overstated.

In light of the above, we feel that a true industrial revolution, beginning in the 1960s, occurred as various developmental stages followed one another in use in rapid progression. It ends in the 1990s – not with the monopoly of a single system representing the triumph of one developmental path – but with the most advanced Scandinavian single-grip harvesting system (from the shortwood path) sharing dominance with the swing-to-tree feller-buncher system (representing the most advanced iteration of the longwood developmental path). These have proven the culmination of industrial development in the sense that no new, subsequent developmental stages have since appeared.

Industrial Development in the American Southeast

The American Southeast did not experience the same prolonged and continuous turnover in new production systems that is so striking in Eastern Canada. Tree harvesting development in the Southeast is characterized by the two developmental paths, but in both cases they were relatively truncated.

For the shortwood path, that prototypical Southeastern harvesting system – the bobtail truck – began early and easily, and was ubiquitous and long lasting.[4] Though it represented the start of industrial development, there was scarcely any subsequent development at all. The technical innovation that did occur ironically served to preserve this system rather than provoking development. Here we refer to the Big Stick Loader, the use of pallets, and so on. Forwarders (such as the Jarck Go Getter) and shortwood harvesters (the Busch Combine), though both were developed in the Southeast, proved to be rare machines indeed. Accordingly, the shortwood path of development can be characterized as in Figure IV.

Figure IV: Stages in the Shortwood Path of Development in American Southeast

Developmental Stages	Topography	Division of Labour	Mechanization
Manual	Stump	Unified	Lo
Bobtail Truck	Stump	Unified	Lo

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[4] Our discussion is based on two important field studies of the bobtail truck harvesting system. The first is Robert L. Schnell, "Harvesting Pine Pulpwood in the Tennessee Valley", Report No. 238-61, Division of Forest relations, Tennessee Valley Authority, Norris, Tennessee, 1961, pp. 1-20. The harvesting operations studied included 12 in Tennessee, 5 in Alabama, 3 in North Carolina, 3 in Georgia, and 1 in Mississippi. This document is located in the archives of the Forest History Society. The second is H.R. Hamilton et. al., "Phase Report on Factors Affecting Pulpwood Production Costs and Technology in the Southeastern United States to the American Pulpwood Association", Battelle Memorial Institute, Columbus, Ohio, 1961. Both sources present systematic industrial engineering analyses of the bobtail truck system.

In developmental terms, the status of the bobtail truck system as an industrial production system is disputable for it did not engender a transformation in the work processes of woods workers. Nor did it provide the foundation for the subsequent development of this path; notably, forwarders, shortwood harvesters and single-grip harvesters were all but absent in the Southeastern history of industrialization. Rather, the bobtail truck system supported a loosely structured and flexible team approach to harvesting that gave considerable freedom to workers to decide their work-tasks, and resembled the flexible craft division of labour. As noted above, technological innovation was not only slow to appear but it also was largely restricted to simple loading devices like the Big Stick Loader. These innovations represented only incremental changes that served to sustain the persistence of this system.

The industrial transformation of the work process in the Southeast really begins with the diffusion of tree-length harvesting systems into pulpwood production in the 1970s. Beginning with the motor-manual felling and cable skidder harvesting system, it did evolve with the introduction of mechanized felling. Again, this was something of an incremental development achieved through the addition of shears to the skidder. This tree-length component of the longwood development path is schematized in Figure V.

Figure V: Stages in the Tree Length Path of Development in American Southeast

Developmental Stages	Topography	Division of Labour	Mechanization
Manual	Stump	Unified	Lo
Manual Felling/ Cable Skidder	Intermediate	Intermediate	Intermediate
Mechanized Felling/ Cable Skidder	Intermediate	Intermediate	Hi

Finally, specialized felling machines were developed, emerging from the skidders with the attached shears. An important moment in this process was the development by the Harvesting Research Project of skid-steer machines with attached felling shears that functioned as feller-bunchers;[5] this culminated in the modern drive-to-tree feller-buncher first utilizing shears and later disc saw heads. This full tree component of the longwood development path is depicted in Figure VI.

Figure VI: Stages in the Full Tree Path of Development in American Southeast

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[5] J.E. Blonsky. "The Draw Shear (Development, Testing & Specifications)". American Pulpwood Association, Harvesting Research Project, Atlanta, Georgia, 1971.

Developmental Stages	Topography	Division of Labour	Mechanization
Feller-Buncher/ Grapple Skidder	Roadside	Specialized	Hi

In order to ascertain the pace of development, we present in Table II the prevalence of the variety of Southeastern harvesting systems based on various censuses of harvesting machines carried out over the years.

Table II: The Pace of Development in the American Southeast[6]

Developmental Stage	% of all Producers (1979)	% of all Producers (1987)	% of all Producers (1997)
Shortwood (Bobtail Truck)	75.5	21.2	0
Tree Length (Cable Skidder)	25.7	37.1	16
Full Tree (Feller-Buncher)	9.1	42.1	86

The Southeastern experience of the 1940s into the 1970s was one in which a pre-industrial system remained dominant for more than three decades, during which time in Canada a plethora of systems came and went over the same period in the race to improve productivity and completely mechanize woods work. It might thus be argued that the "industrial revolution" in tree harvesting in the Southeast begins only sometime in the 1970s, with the coming of simple tree length systems. Moreover, these tree length systems remained at the "simple" level, with only felling being mechanized, and the mature tree length harvester all but absent. The industrial revolution ends sometime in the early 1990s when the drive-to-tree feller-buncher becomes as ubiquitous as the bobtail truck had once been.

Discussion

We argue the industrial revolution in tree harvesting in the Southeast was late, short, truncated, and derivative. Late because the bobtail truck system persisted for so long, with the changes it experienced being incremental rather than revolutionary. Short because once fundamental change commences with the move to tree length systems, it ends only 15-20 years later with the rapid ascendancy of a full tree system. Truncated because only a very few important systems were used in the Southeast; many of those so important in Eastern Canadian development (e.g. tree length harvesters, shortwood harvesters, single-grip harvesters) were missing. And derivative because, with the exception of the Busch combine, the industrial systems employed in the Southeast were ones whose principal machines and work processes were pioneered elsewhere.[7]

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[6] These figures are provided by the following sources: G.H. Weaver et. al., "1979 Pulpwood Producer Census: Southwest and Southeast Technical Divisions of the American Pulpwood Association", Mississippi State University, 1981; W.F. Watson et. al., "1987 Pulpwood Logging Contractor Survey: Southwest and Southeast Technical Divisions of the American Pulpwood Association", Mississippi State University, Technical Bulletin 162, 1989; and W. Dale Greene, Ben D. Jackson, and Jack D. Culpepper, "Georgia's Logging Businesses. 1987 to 1997", *Forest Products Journal* (51 1) 2001: 25-28. As these are censuses of machines rather than harvesting systems, we have been forced to use specific machines as proxies for systems; that is why the figures do not total to 100%.

[7] Cable skidder based systems were common in the early 1960s in Canada, though the mechanized felling version appears to be a Southern adaptation of shear-head technology. The adaptation of the shear to skid-steer machines appears to presage the drive-to-tree feller buncher. Purely Southeastern contributions also include delimbing gates and pull-through delimbers, though the delimbing gate is a very "simple" machine indeed.

We do not wish to suggest that the Southeast did not possess the engineering resources to develop and promote new technology, or had some unusual penchant for avoiding change. Instead, it appears to us that most mill-owning corporations – regardless of where they were and are located – eschew investment in harvesting operations. Seeing their mills as their profit centres and the woodlands as an expensive sinkhole, forestry corporations would prefer to outsource wood provision, purchasing it as a bulk commodity much like their chemicals. But socio-economic conditions sometimes preclude this preferred option.

What provoked mills to support and invest in the very costly process of invention, development, and utilization of increasingly capital-intensive harvesting systems, as they did in Eastern Canada? Though the answer is multifaceted and complex, we wish to identify as most important the availability of cheap labour, and the shape of the wood supply system.[8]

Highly successful post-World War II planning was targeted to industrial and urban development in the Windsor to Montreal corridor, leading to the rapid erosion in Ontario and Quebec of subsistence agriculture (which, as elsewhere, had provided the off-season labour for woods work). The coincident commercialization of agriculture led to the tractor replacing the horse. Faced by the rapid evaporation of its supply of cheap labour and of horses, pulp and paper corporations knew "mechanization" to be a necessity for upgrading the status and wages of woods work, for providing locomotion, and for expanding the supply of wood to their mills to meet increasing post-War demand. Though there are small woodlots in some places in eastern Canada, forested land is dominated by large contiguous company-owned holdings and Crown land in the back-of-the-beyond. The combined opportunities to shed labour and reduce camp costs in remote areas, to move to year round operations, and to achieve economies of scale all favoured the development and use of highly mechanized, high-volume systems. Existing contractors could not finance the development and use of these costly new machines and systems. Only the mill-owners could. It thus made economic sense for forestry corporations in Eastern Canada to take the lead, to invest in the invention, development and direct employment of progressively more productive tree harvesting equipment, and to create a cadre of dependent contractors able to operate increasingly capital-intensive systems far from settled communities.

Conditions in the American Southeast led to a very different history. The post-War boom took a long time to reach the rural South and erode the old agriculture-forestry nexus. Thus alternative employment was slow to develop for rural Southern Blacks. And alternative business opportunities to woods contracting were slow to develop for Southern rural Whites. The fact the forest resource was growing on many small woodlots owned by unorganized, non-industrial landowners scattered throughout the countryside presented serious problems to mill managers coming in from away. Under these conditions mill owners had a strong incentives to outsource the provision of wood to a network of wood dealers with strong local connections.[9] These local intermediaries handled the task of connecting many small, poorly capitalized local contractors and

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[8] This notion of "shape" comes from Lars. Laestadius, "A Comparative Analysis of Wood-Supply Systems From a Cross-Cultural Perspective", Ph.D. Dissertation, Virginia Polytechnic Institute and State University, 1990.

[9] For an account of the wood dealer system, see Warren A. Flick, "The wood Dealer System in Missippi: An Essay on Regional Economics and Culture", *Journal of Forest History* (July) 1985, 131-138; and John C. Bliss and Warren A. Flick, "With a Saw and a Truck: Alabama Pulpwood Producers", *Forest & Conservation History* (April 38), 1994, 79-89.

their workers with landowners willing to have their woodlots harvested. These contractors had few resources to innovate, but as long as their numbers, and those of their workers, were sufficient such a system delivered wood at very low prices to the mills without their need to provide strong financial support or to coordinate harvesting operations. Incremental innovation served to sustain, not transform, the bobtail truck system.

The bobtail truck system could not continue forever – relatively prosperity and alternative job and business opportunities did eventually come to the rural Southeast. Mills themselves added to these external pressures, as some began in the early 1970s to move to tree length delivery, to merchandize higher-value logs at their wood yards. The better contractors, undoubtedly those singled out as 'core contractors' with more abundant contracts and more financial assistance from wood dealers, moved to simple tree length systems. By the 1980s a full-tree system cheap enough that the best and most successful contractors could operate had emerged; single grip harvesters remain too expensive to match the low wood prices of the Southeast.

Questions for Further Research

What was the pattern of system use in the Great Lakes States, with their Canadian-like terrain and climate, and a strong history of technological innovation? What kind of wood supply system developed and why?

Why did Sweden, where experimentation was early and intense remain, dependent on horses for so long, change to mechanized operations overnight, and then contribute so significantly to cut-to-length development?

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