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Discriminating between Landslide Sites and Potentially Unstable Terrain using Topographic Variables

By
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ABSTRACT - Land managers face significant challenges to locate landslide prone areas and define potentially unstable terrain. A landslide inventory, statistical analyses, and Geographic Information Systems (GIS) are used to produce Topographic Indices (TIs) to discriminate landslide sites from similar and adjoining areas (non-slide sites) in the Oregon Coast Range. A spectrum of TIs are computed using topographic variables including local slope (ground surface) and contributing area (drainage). The topographic variables are derived from Digital Elevation Models (DEMs). TI performance is determined as ratios of landslides to area (i.e., densities). A logistic regression is used to test site similarity and promotes the use of an optimized TI. Landslide sites are found to be topographically dissimilar from non-slide sites. Further, some TIs appear to discriminate better than others. Measurement of relative TI performance is partially confounded by DEM error, and GIS technique. The latter issues not withstanding, optimization of TIs using a detailed landslide inventory and accurate DEMs offer increased possibilities for discriminating slope stability hazard.

Introduction

During the winter of 1996, two landslide-producing rainfalls affected most of Western and Northeastern Oregon. The Oregon Department of Forestry (ODF) conducted a relationship study between forest practices and storm impacts on water quality and aquatic habitat [1]. ODF's work resulted in a ground-based landslide inventory, with detailed attribute data. They investigated the utility of locating landslides using topographic data and ground-slope comparisons. Landslide occurrence was analyzed with respect to slopes, contributing area, land form, and watershed location.

We build on ODF's previous work using Digital Elevation Models (DEMs) to derive topographic variables. Geographic Information Systems (GIS) are used to generate Topographic Indices (TIs) for a statistical analysis of landslide occurrence with respect to local topography.

Objectives

The primary objective is to discriminate between sites, i.e., contrast the distributions of TIs in areas where landslides have occurred compared to where they have not occurred. Auxiliary objectives are to optimize the utility of available landslide data sets and to perform a check on the propagation of elevation errors inherent in DEMs.

Potentially Unstable Terrain

Definitions surrounding potentially unstable terrain are often very specific in context. For example, many observers use *site similarity* to define potentially unstable terrain. Existing landslide sites and adjacent terrain are assumed to have similar landslide hazard qualities, because they appear similar (e.g. slope, geology, landform). This assumption is manifest in the protocol of many field assessments of landslide hazard. Reference to *potentially unstable terrain*, in the context of this research is defined as up-slope ground areas with a high probability of shallow landslide occurrence, given a catastrophic rainfall (1996).

Study Area

The study area is located in Lane, County Oregon in a portion of the Mapleton Watershed (**Figure 1**). The area has a high density of first and second order, ephemeral streams dissecting non-glaciated Tyee Sandstone, with an average slope of 45 percent. Colluvial soil depth varies with sub-basin from 3 to 5 ft.

Landslides

The present analysis has a reduced scope relative to the original ODF investigation in order to limit the potentially complex environmental processes and forest management treatment effects involved. Landslides are defined as *shallow* meaning they have a small depth compared to length and width.

Further, landslides are characterized as:

- initiation points with a discrete failure surface,
- resulting in debris flows impacting well defined channels down-slope,

- located in an up-slope position,
- in response to a catastrophic rainfall (i.e., 1996 winter flood), and
- non-road related.

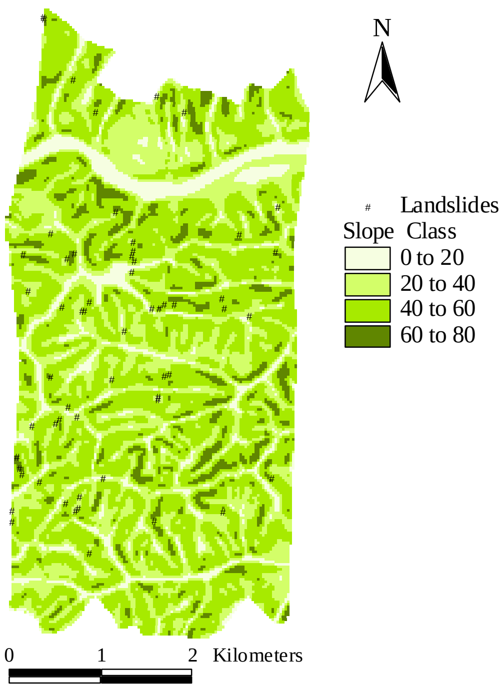

Figure 1. Mapleton study area with associated landslides displaying slope index θ_1 using a USGS 30m resolution grid. The landslides represent a binary response variable, i.e., 1 for landslide cells and 0 for non-landslides.

Topographic Analysis

We extracted topographic data from a U.S. Geological Survey DEM with 30m cell resolution. Local slope and contributing area (drainage) are derived using a commercially available GIS [2][3]. Several computer algorithms are tested for comparison of GIS technique. The slope and contributing area variables are treated as TIs of landslide occurrence, ranging from low order (single variable) to higher order combinations (**Table 1**).

Table 1 Topographic Indices by Group

Group	Type	Description	Ref.
1	Slopes	Tan θ_1: geometric mean Tan θ_2: finite diff. estimator Tan θ_3: maximum value	[4] [5] [6]
2	Contributing Area	a_1:multiple flow direction a_2:single flow direction a_3:multiple flow direction	[4] [6] [7]
3	Topographic ratios	$\ln(a_1/\mathrm{Tan}\theta_1)$, $\ln(a_1/\mathrm{Sin}\theta_1)$	
4	Infinite Slope Models	q/T: linked to Group 1 and 2 Sindex: linked to Group 1 and 2	[4] [8]
5	Statistics	Expected value from regressions	

Group one and *Group two* encompass some differences in numerical methods applied to grid calculations common to GIS. *Group three* are collectively known as topographic ratios, and parallel some of the indexing made popular in hydrological modeling. The infinite-slope type models in *Group four* use slope and contributing area variables to link geomorphology to an estimate for factor of safety against failure. The statistical models in *Group five* are used as an index and to test differences between similar and adjoining sites.

The distributions of TIs with landslide occurrence are contrasted with the total study area to assess their discriminatory ability (e.g., **Figure 2**).

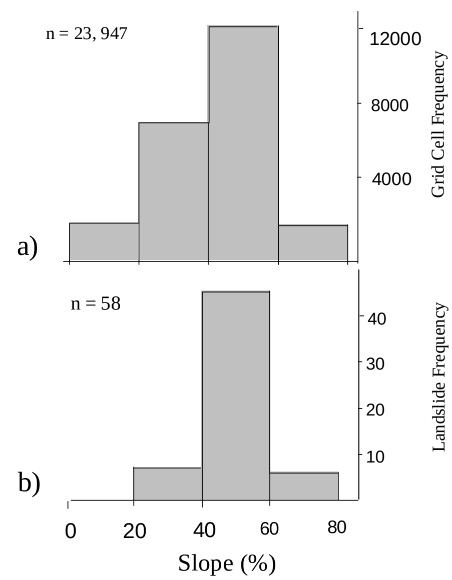

Figure 2. Frequency histograms for slope index θ_1 in Mapleton study area using a USGS 30m resolution grid; a) all grid cells, and b) up-slope landslides only.

A matrix plot (e.g., **Figure 3**) provides an effective means to map between TI domain, cumulative landslides, cumulative area, and densities. The performance of a TI is traditionally measured in two ways: i) *landslide density*, measured as the number of landslides per unit area, and ii) *areal density* measured as the ratio of potentially unstable terrain to the total study area. This research uses a special type of *density*, defined on a continuous domain of the TIs. The smallest and greatest values of the TI define the respective domains of the landslide population and total area. TIs are effectively continuous variables when discretized at a 30m scale (e.g., Figure 3a). However, landslide occurrence is a binary variable (i.e., 0 or 1). Therefore, landslide accumulations create step plots as opposed to continuous curves. Good TI qualities include a high sensitivity to landslide occurrence (e.g., average slope in Figure 3b) and high landslide density (e.g., average slope in Figure 3c).

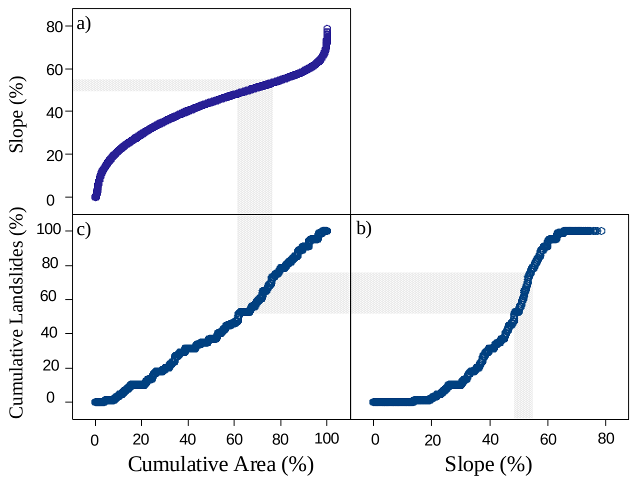

Figure 3. Performance data of slope index θ_1 in Mapleton study area using a USGS 30m resolution grid. Rates of change on each curve represent; a) terrain character, b) sensitivity of landslide occurrence to the index, and c) landslide density. Stippled area is an example definition for potentially unstable terrain in the θ_1 domain. The width of the stippled area measured on the horizontal axis of c) defines the areal density on a continuous domain of the index.

Landslide density provides a common metric between TIs, when the cumulative area is held constant. A pragmatic approach is to search for maximum rates of change across an area referred to here as a *density ratio* (e.g., cumulative % landslides per 10% cumulative area). TI distributions are mostly non-linear therefore, comparisons (not done here) of density across equal intervals of a TI domain require normalization of the respective areas.

TI distributions for the landslide population are contrasted against similar and adjoining terrain using the slope index θ_1, and contributing area index a_1. Random sampling was performed with various domain and location restrictions.

Results

The density ratios for eleven different TIs, and three different intervals of cumulative area are shown in **Figure 4**. The relative differences in density ratio between all TIs are 15 to 20% cumulative landslides. The EVI index is the top performer followed closely by contributing areas, slopes, infinite slope models, and topographic ratios. Results from statistical tests of no difference between distributions of slope index θ_1, contributing area index a_1, and expected value indices are shown in **Table 2**, **Table 3**, and **Table 4** respectively.

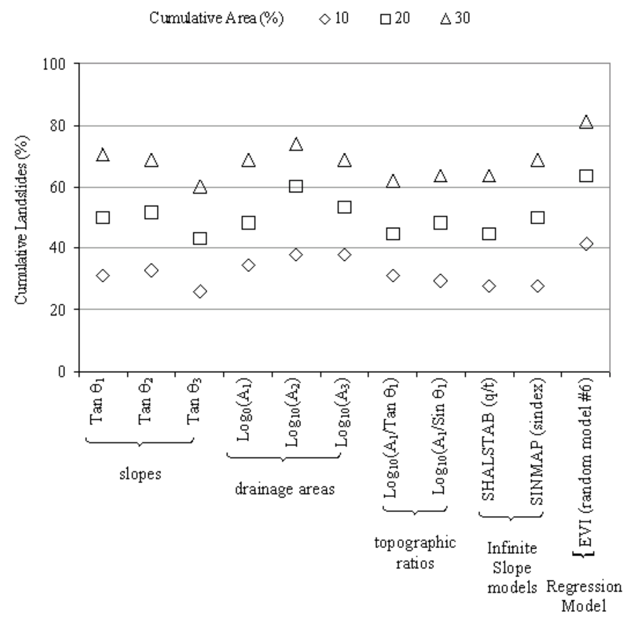

Figure 4. Comparison of topographic indices from the Mapleton study area using a USGS 30m grid. Index performance is evaluated using a maximum landslide density measured on three different area scales. The topographic indices are factored into five distinct types ranked from lowest to highest order.

Table 2 Slope Index θ_1

Scope	Comments
Slope domain similar to landslides	*Suggestive evidence*, 2 sided p-value of 0.14, t-test
Contributing area domain similar to landslides	*Suggestive to no evidence*, 2 sided p-value of 0.21, t-test
5 and 10 grid cell area adjoining landslides	*Suggestive to no evidence*, 2 sided p-values of 0.14 to 0.36, t-test

Table 3 Contributing Area Index a_1

Scope	Comments
Slope domain similar to landslides	*Strong evidence*, 2 sided p-value of 0.03, t-test
Contributing area domain similar to landslides	*No evidence*, 2 sided p-value of 0.36, t-test
5 and 10 grid cell area adjoining landslides	*Strong evidence*, 2 sided p-value < 0.01, t-test

Table 4 Expected Value Index EVI

Scope	Comments
Slope domain similar to landslides	*Strong evidence*, p-value of 0.05, logistic regression of θ_1, and a_1.
Contributing area domain similar to landslides	*No evidence*, p-value of 0.30, logistic regression of θ_1, and a_1.
5 and 10 grid cell area adjoining landslides	*Strong evidence*, p-value < 0.01, logistic regression of θ_1, and a_1.

Discussion and Conclusions

The statistical analyses suggest that landslide occurrence is highly sensitive to changes in contributing area on sites that are similar to and adjoining landslides. This is also true for slope, but to a lesser degree (see sensitivity in Figure 3c). This may be explained by the higher rate of change in the contributing area index opposed to the slope index in areas similar to and adjoining landslide sites. Further, the adjoining terrain is topographically more dissimilar (i.e., lower p-values) than sites which are merely within the same index domain. Therefore, we may to varying degrees successfully discriminate between sites where landslides have and have not occurred.

The different algorithms used for slope and contributing area variables create bias which should appear in the density ratios. The topographic ratios suffer from mathematical division creating equal outcomes, therefore, a relatively high density ratio is not expected. The infinite-slope type ratios may arguably be considered as constants multiplied by simple variables. This would suggest they are of the same order as the simple variables with respect to landslide discrimination. The parameters in the SINMAP [8] program may be manually iterated to increase landslide density. Neither SINMAP [8] or SHALSTAB [4] programs have objective oriented optimization routines built in. However, the EVI index has the ability to optimize the density ratios using the maximum likelihood algorithms employed in logistic regression. We can think of TI and DEM combinations as being informed i.e., landslide inventory is available. The EVI index is using additional information for optimization of density ratios.

The difference in density ratios between informed and non-informed TI and DEM combinations may represent the value of adding a landslide inventory. The most conservative comparison between the EVI and a_2 indices shows an increase in the range of 2 to 5% cumulative landslides. Figure 4 also shows this difference increases in magnitude with increasing cumulative area. The added benefit of the landslide inventory seems low, however, this is likely due to issues surrounding landslide location error, DEM error, and grid resolution.

We analyzed uncertainty in density ratios in a parallel study [9] in the Oregon Coast Range using a similar DEM, and landslide data set. Uncertainty in density ratios shown in Figure 4 using a 10% cumulative area are estimated at +/- 1% cumulative landslides (95% C.I.). We speculate the uncertainty decreases when measured over larger areas. The magnitude and spatial structure of elevation error was measured with a more accurate DEM, and simulated in a probabilistic analysis. These methods have not been thoroughly tested and are the subject of ongoing research. It remains to be seen how far the topographic boundaries migrate as a result of error propagation.

There are serious limitations to TIs. The U.S.G.S. DEMs were created from high altitude photography, and therefore contain a relatively large amount of error. We caution the use of an index as a surrogate for field measurements. However, slope and contributing area indices may be used to calibrate a coarse DEM. Further, density ratios may be used to arbitrarily define landslide hazard and the location of potentially unstable terrain.

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Challenges, Rewards, and Requirements for Working Globally

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ABSTRACT – As the world becomes smaller through technological advances in travel, communication, and data control, opportunities for working in the global market increase. Because of this increase and an interest in harvesting forests in other countries, many forest engineers are looking at opportunities abroad. Several things should be considered before embarking on an overseas assignment. Whereas the terrain conditions encountered in the United States (such as slope, rainfall, and climate) may be similar overseas, other conditions may be completely different. Engineering options may be similar, but social conditions may be very different. The challenge is to apply applicable engineering knowledge to the situation while working within the social structure in a productive way. Recognition and acceptance of physical and social constraints can be difficult unless one understands that not all things should necessarily be done as they are in the United States. This paper will present some of the challenges encountered, and the methods utilized to overcome those challenges, by a company that has worked on overseas projects for over 20 years. Some of the accomplishments, as well as some of the problems, will be discussed. Also, a few recommendations will be given to engineers interested in overseas assignments.

INTRODUCTION

Forest Engineering Inc. has spent over 20 years working on projects overseas. These projects have been primarily devoted to engineering, such as logging planning; but in nearly all cases, they required some element of technology transfer through training. Some of the projects were very simple, such as teaching workers to splice cable, and some were more complex, consisting of developing GPS hubs or designing multi-span bridges.

Diversity of species and forest composition is a condition relatively uncommon in Northwest United States forests but a major factor in tropical forests. Vines and bole composition can present a whole new problem area in the falling stage.


Figure 1. Tropical Forest.

The terrain conditions encountered ranged from flat, swampy areas to very rocky, mountainous slopes exceeding 125%. The temperatures encountered ranged from plus 33 degrees Celsius (+92°F) to minus 50 degrees Celsius (-58°F). Rainfall in many cases exceeded 3,000 mm (118 inches) per year. Elevations went from sea level to over 4,545 meters (15,000 feet), sometimes being that diverse within one project area.

All of the projects required a solution to a problem or situation. A general "blue-sky" verbal recommendation was often not acceptable. Clients wanted you to show them what to do, not just say what should be done. This was true whether it was something as simple as falling a tree or as complicated as developing a strategic harvesting plan.

CHALLENGES

Politics and Policies

The challenges of working globally can be formidable, but they can be very rewarding. Perhaps the most frustrating projects are the ones that had previously been developed based upon someone's concern but with limited knowledge or accountability. Often these are a result of advice given by people outside their level of expertise. It is very common to find out that the harvesting or engineering solutions recommended have been given by previous "consultants" who do not know what they are talking about. Often these are Ph.D. silviculturists or even engineers with limited experience on the ground in their own country, let alone in a foreign setting.

Politics (and the resulting policies) is prevalent in all countries (the United States included) and its impact varies from country to country. Some policies can be very positive, since they allow for quick changes, and others can cause permanent problems that must be recognized.

An example of a poorly applied policy was finding out that cable logging on steep slopes was prohibited in Indonesia based mainly on advice given by so-called experts who knew little or nothing about cable harvesting. Fortunately, once the "powers that be" had the correct information, changes were made quickly.

Other restrictions can be harder to overcome. The prohibition of bringing GPS units into Russia made things harder, but the enforcement of restricting maps to 1:100,000 scale, rather than the 1:5,000 scale normally used, made useful planning very difficult. Some policies can be changed and others have to be coped with the best way possible.

Language

Most people anticipating working overseas are concerned about the language differences. Although being able to converse in a common language is very beneficial, it is not the handicap imagined. First of all, if a foreign company is going to hire someone to do a technical job, they are more interested in their technical knowledge rather than their language skills and will usually provide the necessary interpreter. Also, most companies have people at the technical level that can speak English. It is the universal business language.

However, being able to speak the appropriate language is important at the operations level where you are communicating with workers who are not necessarily university educated. Being able to talk to excavator operators or members of the rigging crew is always a positive move and should be encouraged. The problem in many countries, however, is that although there is a national language, there may be many local dialects that are used in the bush. If the projects are long enough, it pays to learn at least some of the everyday phrases if for no other reason than to be courteous.

Logistics

One of the major problems of foreign projects is the remoteness of many forest operations, especially in developing countries such as Southeast Asia and China. Even in North America remote logging camps and long drives can be common. However, a 2-hour flight on a Beaver from Ketchikan to Rowan Bay is a "piece of cake" compared to traveling from Balikpapan, Indonesia, to Camp 83 on the Boh River. This trip can consist of 2 hours by car to the Mahakam River, 12 hours by speedboat (3 days by river taxi) to the Long Bagun base camp, and 5 hours by truck to the camp on the Boh. If you plan to ship equipment, you are looking at a minimum of 4 days on the river.

The communications network is improving to the point where it is possible to have satellite telephone coverage, but it is often not dependable. Some countries are better equipped than others with these conveniences.

Equipment decisions can be critical in overseas locations due to the time lost waiting for replacement parts. How much inventory to keep becomes a major decision which impacts cost-control and operations analysis if production is of importance.

Culture

One of the major rewards of working in a foreign country is working with a group of people who have a different culture and lifestyle than you encounter in North America. Their customs and desires may be very different and may seem strange when first encountered. The trick is to recognize that they have different beliefs of what is important and different ways of accomplishing the same tasks.

Religious beliefs must be recognized and accepted in the operations and worked into any schedule. These can vary from holding prayer sessions on certain days to prohibiting the practice of using a machine to cut down a tree.

Traditions that have been developed over a long period of time from economic conditions or cultures should be evaluated carefully before trying to apply new systems or techniques. There may be a very valid reason for using animals for skidding that are not always based on economics or lack of knowledge.

It is not a good idea to make quick judgments about how things should be done because what you may find is that local workers may have tried your way but found theirs to be better. Do not be too quick to replace the oxen with a skidder until you find out how hard it is to get parts and diesel fuel.

Talk to the operators (even if you need an interpreter) and ask them questions. If you want to get to know someone, ASK the person for advice. It is much more productive than TELLING them what they should do. Working together from a common knowledge base usually gets good results. Of course, this is usually true in North America as well.

COMPETENCY

Although there may be opportunities to work overseas through some governmental program such as the USFS International Forestry program or USAID, most countries are more concerned with employing their own citizens than hiring someone from outside. That means that your chance of getting employment overseas so you can learn a given trade is limited. Therefore, it can be difficult to get work at a starting position. Most industrial organizations want to hire someone with more knowledge than those they already have in place.

Although academic degrees may give you the opportunity at some levels to talk about solutions, they alone are usually not sufficient if a problem needs to be solved. You need to know what you are doing before you get on the plane. As Les Calder, a renowned logging engineer, once said, "A college education is seldom harmful if you are willing to learn something after you graduate." You need to be able to do the job and not just talk about it. This is especially true in the industrial operational levels. Government organizations are sometimes more forgiving, perhaps because they appear not to be as concerned about solutions.

Some of the projects our company has been involved with overseas involved reworking recommendations that were made by "consultants" advising outside their level of expertise. Therefore, know what you are doing and do not try to pass yourself off as an expert outside your discipline. The old adage that you are an expert once you are more than 50 miles from home does not work for very long. You need to get positive results, whether it is falling a tree or designing a multi-million dollar operation.

Figure 2. Living conditions are not always ideal.

If you feel comfortable with your knowledge in your subject area, have an understanding spouse, and an urge for adventure, good or bad, take a shot at an overseas assignment. It will probably be the same job you would have in North America but often under more adverse conditions, especially in the developing countries. It will seldom be boring. It is somewhat like being in the military. It is hell when you are in it, but it is fun to talk about when it is over and you are happy you had the experience.

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Why and how should French foresters face the question of site disturbances in logging operations?

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ABSTRACT – Nature preservation is now a great and very common expectation among French people. In the last decade, forestry laws have integrated the concepts of biodiversity and sustainability. So we expect that in the near future loggers will have to be more careful how they manage harvesting operations. Especially, the aim will be to reduce or minimize site disturbances due to harvesters, forwarders or skidders traffic. During the last three years, AFOCEL has studied soil perturbations on 10 sites where clear cuts or thinnings have been carried out with different methods and machinery (chainsaw operator + forwarder, chainsaw operator + forwarder + skidder, harvester + forwarder…). In this paper, we first give a few precisions on the French context. Then we present the main results of this AFOCEL project on harvesting operations impacts. We finally discuss the further needs in research to find practical solutions that could be used easily and economically by contractors.

INTRODUCTION

Nature preservation is now a great and very common expectation among French people. As plenty of others in the last decade, forestry laws have integrated the concepts of biodiversity and sustainability. More particularly, special regulations or recommendations concerning logging operations impacts have been produced: forest managers and loggers will have to grasp problems such as water quality or soil damage. In the meantime, certification standards and regional model codes of forest harvesting practice are spreading across the country. They all take into account the aspect of environmental impacts. So we expect that in the near future loggers will have to be more careful to the way they manage harvesting operations. Especially, the aim will be to reduce or minimize site disturbances due to harvesters, forwarders or skidders traffic. During the last three years, AFOCEL has studied soil perturbations on 10 sites where clear cuts or thinnings have been carried out with different methods and machinery (chainsaw operator + forwarder, chainsaw operator + forwarder + skidder, harvester + forwarder…).

PRECISIONS ABOUT THE ENVIRONMENTAL CONSTRAINST FOR LOGGERS IN FRANCE

Legislation

In France, the first laws concerning forest management and wood harvesting were written in the Middle Age, with the aim that forests and woodlands should be kept endlessly in good condition. Since then, it has been a long story. Nevertheless, and even with the creation of the European Union, the current French legal framework can be considered as the heritage of the very old past.

Many foresters nowadays tend to consider that the law is becoming increasingly restrictive. However, often, it is just that the existing law is becoming better applied. Before December 2000, the rules regarding environmental aspects and especially logging operations were already very numerous but spread in different Codes of laws (Rural Code, Forestry Code…). After this date, they have been grouped into a special new Code, the Environment Code. It has to be said that this Code focuses on wildlife habitat and water quality (see a few examples in table 1) but give no special rules concerning the ground surface or the soil compaction after logging operations.

Certification

The worldwide emergence of certification has lead, for logging operations, to different kind of systems.

With systems such as ISO 14001, real standards characterized by a list of quantitative and qualitative criteria describing the level of site disturbances (soil, water, ecosystem, landscape, risk of fire…) to achieve have been defined. In France, SEBSO and SOFOEST (LA ROCHETTE group, now TEMBEC group) are the two first roundwood supply companies to be certified ISO 14001 (respectively 1999 and 2001). Several other such big companies are undertaking the same process.

In systems such as PEFC, at the moment, loggers "just" contract to work according specifications regionally defined but no quantitative criteria are defined (examples: "the logger contracts to do everything he can in order to limit impacts on fragile soils" "the logger contracts to keep in good condition water quality and stream way"). We presume that in 2003, 80% of French forest will be certified. Meanwhile, we expect that a next step in the process will be achieved : the definition of objective and quantitative criteria to be able to control that the job has been done in the right way.

So, whatever the system of certification, there is a need to know more about what can be considered as "low impact", and how to achieve this result, depending on the type of harvesting operation to be done, the site characteristics but also the men and material forces available. We also need information about the consequences of site disturbance.

Table 1. A few examples of damages considered as violations to the law and incurring penalties

Damage	Violation	Max. Penalty
Wood harvesting in special wildlife habitat without authorization	Degradation of a specific wild and protected bird or mammal habitat	6 months imprisonment + 9000 €
Crossing a stream or leaving slash in a stream	Perturbation of the aquatic ecosystem	2 years imprisonment + 18 000 €
Spreading oil in the forest	Risk of perturbation for natural ecosystems by dangerous substances	2 years imprisonment + 18 000 €

A PROJECT TO STUDY LOGGING OPERATIONS IMPACTS

Objectives

From 1999 to 2001, AFOCEL managed a research project on harvesting operations impact, the aims of which were:

- to analyse and evaluate the impacts of forest exploitation and their short term consequences on biodiversity, soil properties and stand development,
- to compare different harvesting systems (motor-manual or fully mechanized harvesting, skidding or/and forwarding) in terms of impacts on forest environment,
- to test several tools and guidelines to limit soil disturbances.

In fact, the study focused on the forwarding, which is the most disturbing operation.

The Choice of the logging sites

We had several criteria to choose the sites and the working methods to study in this project (see table 2). The main of those was to have no other forest operation after the wood extraction in order to follow natural flora and soil evolution during the three years of the study. This is why, excepted one, all the sites were in deciduous forests: conifer stands are mainly regenerated by plantation in the area of the study. We also wanted to compare different types of work (clear-cut or thinning, different intensities of thinning), of machinery, of forwarding guidelines (concentration or dispersion of the skid trails, driving or not over slash). Of course, all these modalities had to be technically and economically feasible. Finally, 9 logging sites were studied: for 6 of them, we have been able to compare 2 modalities of harvesting. Five of them were concerned by storm damages.

Table 2: Characteristics of the studied logging sites

Logging site	Operation	Logging system	Modalities	Storm damages
I - Salon-la-Tour	Clear-cut	Chainsaw operator + forwarder	1/ Driving over logging residues 2/ Not driving over logging residues	No
II - Les Baléares	Clear-cut	Chainsaw operator + forwarder	1/ Concentration of skid trails 2/ Dispersion of skid trails	No
III - Echourgnac	Thinning (pine stand)	Harvester + forwarder	1/ Driving over logging residues 2/ Driving outside logging residues	No
IV - Chœurs	Thinning	Chainsaw operator + skidder + forwarder	2 different intensities of thinning	No
V - Brigueuil	Clear-cut	Harvester + forwarder	Wheeled forwarder not equipped with tracks	Yes
VI - Chaptelat	Clear-cut	Harvester + forwarder	Wheeled forwarder equipped with tracks	Yes
VII - Le Palais	Clear-cut	Harvester + forwarder	Wheeled forwarder equipped with tracks	Yes
VIII - Ancerville	Clear-cut	Chainsaw operator + skidder	1/ Wheeled skidder equipped with chains 2/ Wheeled skidder not equipped with chains	Yes
IX - Trois Fontaines	Clear-cut and thinning	Chainsaw operator + skidder	1/ Concentration of skid trails 2/ Dispersion of skid trails	Yes (3 intensities of storm damages: none, 25% and 100%)

Measures

On every site, we have used the European harmonized protocol (Concerted Action n°AIR3-CT94-2097) to carry out on a sample area the assessment of soil disturbances and tree damages (300 observations/0.25ha). We have also measured the soil compaction (bulk density and penetrability) and made floristic analysis.

All these surveys have been carried out before the starting of harvesting, after every operation (processing, forwarding, skidding) and every year during three years after the harvesting accomplishment. So it was possible to follow the natural evolution of flora and soil properties (persistence of soil compaction or natural recovery).

An additional measure was also carried out after every machine passage (harvester, forwarder, skidder): the surface area of the trail occupancy (expressed in percentage of the total logging site surface). For this purpose, we made maps of the logging sites (on plots of 0.25ha) with all the skid trails (see figure 1). These maps helped us to understand the organisation of the harvesting and the forwarding.

Main results

Ground surface disturbances

The European protocol makes a difference between surface and deep disturbances. The firsts are just a mixing of the litter and the top soil. The second are ruts up to more than 30cm deep. **We have found in our studies that the disturbances (deep + surface disturbances + soil deposit) cover a relatively important surface area: 38% in thinnings and 54% in clear-cuts** (see figure 2).

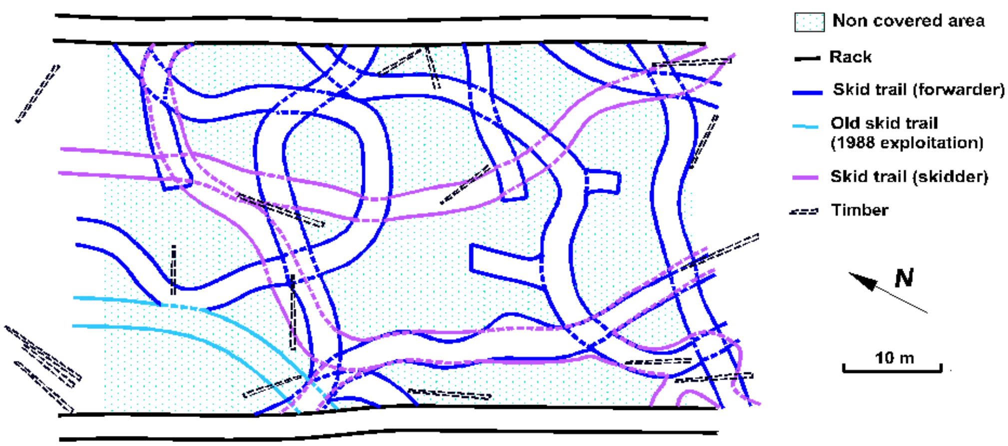

Figure 1: Map of the logging site IV (thinning) for the modality "chainsaw operator + forwarder + skidder"

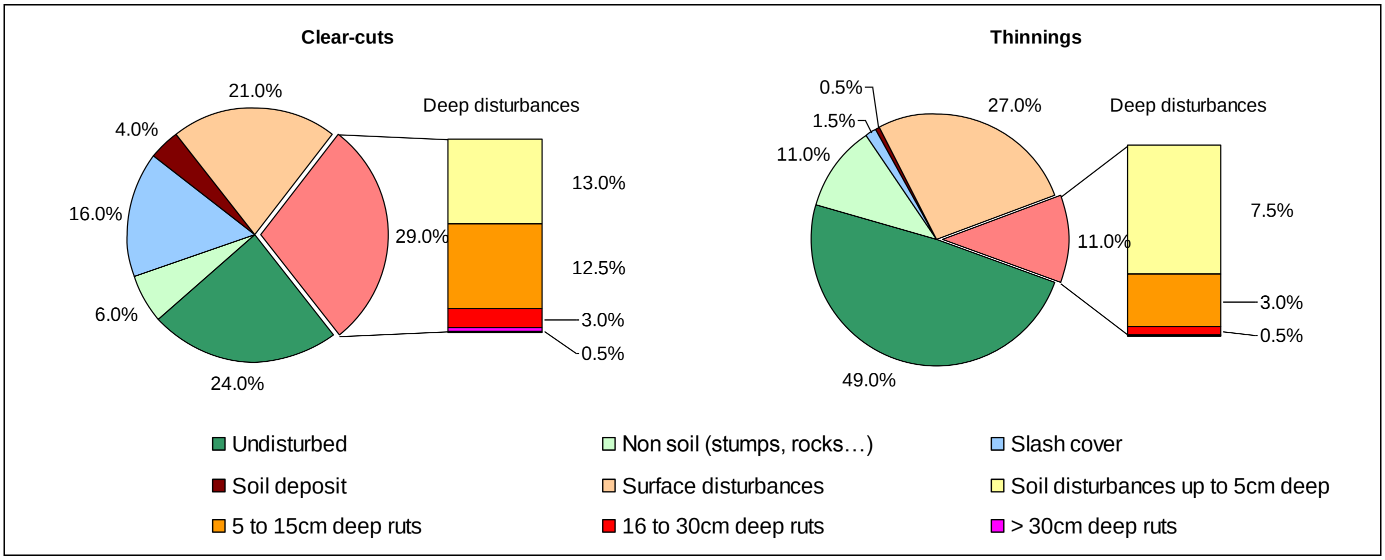

Figure 2: State of ground surface in logging sites after forwarding in clear-cuts and thinnings

Machinery trails occupancy

The maps of the skid trails reveal that the organization of the forwarding is not always rationalized. The drivers do not take the time before starting to work and drive to look at the timber, the obstacles, the sensitive areas… So **the surface area affected by machinery trails is relatively important: from 30% to 67% of the harvested area,** excepted in particular operations in storm damaged forest (see figure 3). **For both economical and ecological reasons, the organisation of the forwarding should be rationalized.**

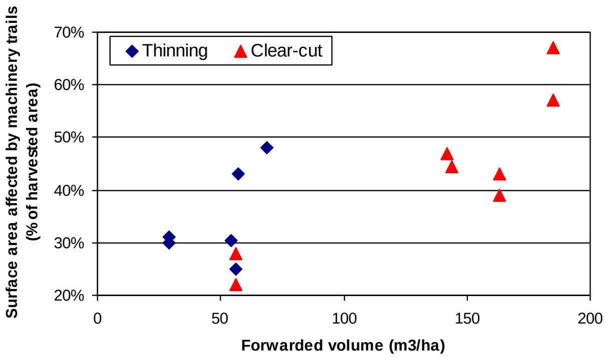

Figure 3: Relation between trail occupancy level and volume forwarded.

Soil compaction

The soil compaction assessments have been carried out taking into account the position of the skid trails and the ground surface disturbances. All the logging sites have silty soil (more or less sandy), with various moisture conditions during the logging operations. The skid trails and disturbances on the logging site are not innocuous. Indeed, we showed that **bulk density and soil strength increased under, beside the machine tracks, and under deep disturbances. Moreover all the horizons (0 to 50cm depth) are concerned by this change of soil properties and in most cases soil compaction is still persistent after 3 years.** A great percentage of the surface of the logging site is affected by these alterations: up to 67 %.

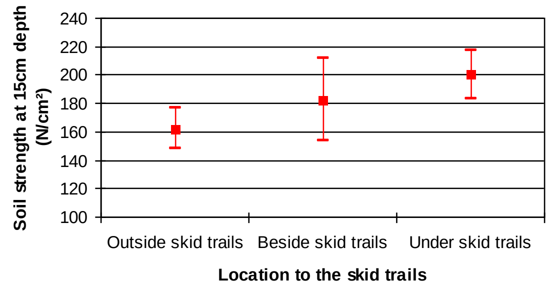

Figure 4: soil properties modification and machinery traffic (example of alteration)

Flora and tree injuries

We have not enough measures to make definitive conclusions about flora and tree injuries. All we can say is that **we have noted a large increase of the number of species (mainly heliophilic species) and we have not observed a total floristic recovery**. We have not also enough measures to see if there is an influence of soil compaction on stand development. However, the bibliography is not hopeful about that.

Advice for forwarding organisation

The comparisons between different modalities (in terms of impacts) lead us to recommend some usual and already well-known methods or tools, but that are not used enough by professionals. To summarize, we can give this **simple advice to limit site disturbances**:

- **a good general organisation for every operation and a good coordination between operations**,
- **a rational organisation of the forwarding** (driving over the logging residues to limit rutting and soil compaction, concentrating the skid trails over few surface to reduce the area occupied by skid trails …),
- **a use of specific tools such as chains or tracks when necessary** because of the climatic and soil conditions.

The advice is quite similar for storm damaged forests.

CONCLUSION

This 3 years research project have brought us :

- a validated protocol to assess easily the effects on environment (soil disturbances, compaction, machinery traffic…) of wood harvesting at the scale of the logging site.
- some practical advice to limit or reduce disturbances.

But more studies are necessary:

- to determine the long term effects of soil compaction on stand development and flora evolution (some information exist but they are too spatially limited,
- to build a national database on the state of logging site after exploitation. This database is necessary to know the present situation and to fix the objectives in relation with PEFC and ISO 14001 criteria.

Moreover some ways have to be prospected to reduce forest exploitation impacts (machinery overrun), such as a better organization for forwarding operations. We have established that progress is possible to reduce impact and probably also to increase productivity. In this objective, we start studies using GPS for analysing the traffic of forwarder on logging sites.

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Productivity of a Ponsse Ergo Harvester Working on Steep Terrain

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ABSTRACT – The objective of this study was to analyze the productivity of a Ponsse Ergo harvester using a H73 head working in a mixed pine and hardwood forest on steep slopes in north Georgia. Productivity data were collected on the harvester from five one square chain plots. Each plot represented a different stand and slope condition. Slopes ranged from 0 to –46 percent. The harvester was videotaped performing the operations of felling, limbing, and bucking. Time and tree data were extracted for an elemental time study. Estimated quantities were defined in units of time per tree and included move time, swing time, fell time, process time, and total productive time. The possible predictor variables were identified as DBH, total height, number of bucks, tons per acre, trees per acre, slope, and species. Slope was found to be a significant variable for predicting move time, swing time, and total productive time. The variables of DBH^2, total height, slope, and trees per acre with a square-root inverse transformation were found to be significant for predicting total productive time per tree when total height was known. Number of bucks, tons per acre, and species were found to be non-significant variables for predicting any of the dependent variables. It was not surprising that slope had an effect on the productivity of the harvester. Interestingly though, the analysis found species variation to be non-significant for predicting any of the analyzed dependent variables. That is to say that even on steep slopes, the Ponsse Ergo harvester harvested upland, hard hardwoods equally as well as pine.

INTRODUCTION

The objective of this study was to analyze the productivity of a Ponsse Ergo harvester using an H73 head working in a mixed pine/hardwood stand in North Georgia on steep terrain.[1]

Equipment History

Ponsse was founded in 1970. Its parent company is based in Finland with offices in Sweden, France, Great Britain, Norway, and the United States.[2] The Ponsse group designs, manufactures, and markets forest machinery as well as information technology solutions for cut-to-length (CTL) harvesting. Ponsse manufactures two harvesters, three forwarders, three harvester heads, and a number of information technology packages.

The H73 head, which was used in this study, is the largest harvester head that Ponsse manufactures. It's very versatile and can handle tree trunks up to 28 inches in diameter.

The Ponsse Ergo Harvester has a standard forest machine control system known as Opticontrol, which integrates the

[1] Funding for this research was made possible by a grant from the U.S. Forest Service and Ponsse USA.
[2] The use of brand or model names is for reader convenience only and does not represent an endorsement by the authors, Auburn University, or the U.S. Forest Service.

diesel engine, measuring device, and crane control systems into an efficient entity.

Figure 1. Ponsse Ergo Harvester

This harvester also has a self-leveling cab feature, which keeps the cab and operator level even on steep slopes.

Cut-To-Length Harvesting Background

Cut-to-length (CTL) harvesting systems have proven to efficiently harvest a variety of tree sizes including first commercial thinnings. Studies have shown CTL to be a low impact form of harvesting. It provides minimal residual stand and site damage and requires less manpower and leaves fewer slash piles than traditional tree-length systems (Lanford and Stokes 1995). This system varies from the typical southern tree-length system because the trees are limbed and bucked into lengths at the stump, leaving limbs and tops evenly distributed throughout the tract (Stokes 1988). CTL provides a logging system which can be adapted to small tracts of timber, offers decreased environmental impact, and may better suit a landowner's long-term management plans (Holtzscher 1995). With social and aesthetic concerns becoming increasingly important, CTL operations stand to become the system of choice for the future.

A solution to the many problems associated with thinning and small diameter tree harvest is CTL logging. CTL has many benefits to offer the landowner, contractor, and mill. This form of timber harvesting is not a new concept it has been practiced in Scandinavia, Canada, and the Northern U.S. for many years (Tufts and Brinker 1993). However, in the southeast the complexity of the machine, high initial cost, availability of financing, lack of service support, and resistance to change by local logging contractors has limited CTL mainly to thinning operations (Holtzscher 1995).

STUDY METHODS

Five one square chain plots were used for data collection. Each plot represented a different stand condition. Plots were selected based on the criterion of area, density, slope, and species. Plot conditions were as shown in Table 1.

The harvester was video taped performing the operations of felling, limbing, and bucking on the five study plots. The videotapes supplied data for an elemental time study. Time elements included move time, swing time, fell time, process time, and number of bucks.

Statistics

Time elements were analyzed statistically using Number Crunching Statistical System (NCSS) 2000. Dependent variables were defined in units of time per tree and are shown in Table 2.

Table 1. Plot Conditions

	Plot Number				
Conditions	1	2	3	4	5
Acreage	0.11	0.10	0.10	0.10	0.10
Number of Trees	65	13	32	38	30
Trees Per Acre	568	130	320	380	300
Pine Trees Per Acre	568	70	300	260	0
Hardwood Trees Per Acre	0	60	20	120	300
Avg DBH (in)	7.7	11.7	7.8	8.7	8.2
Avg Pine DBH (in)	7.7	8.9	7.7	8.9	0
Avg Hardwood DBH (in)	0	14.4	9.2	8.3	8.2
Avg Total Height (ft)	51.3	55.1	44.6	46.8	57.4
Tons Per Acre	126.0	81.7	69.2	110.2	99.9
Pine Tons Per Acre[1]	126.0	22.3	61.1	85.5	0.0
Hardwood Tons Per Acre[2]	0.0	59.4	8.1	24.7	99.9
Slope %	39	46	0	30	8

[1]Clark and Saucier 1990, [2]Clark, Saucier, and McNab 1986

DATA ANALYSIS

Each dependent variable was analyzed separately in order to form a model for its prediction. To give a statistical starting point, each dependent variable was defined as a function of possible independent variables. Basic models were:

<u>Move time/tree =</u>	f (DBH, tons per acre, trees per acre, slope)
<u>Swing time/tree =</u>	f (DBH, tons per acre, trees per acre, slope)
<u>Fell time/tree =</u>	f (DBH, species, total height)
<u>Process time/tree =</u>	f (DBH, total height, number of bucks, species)
<u>Total productive time/tree =</u>	f (DBH, total height, number of bucks, species, tons per acre, trees per acre, slope)

Table 2. Variables Used in Statistical Analysis

Dependent Variables	Independent Variables
Move time	DBH
Swing time	Total height
Fell time	Number of bucks
Process time	Tons per acre
Total productive time	Trees per acre
	Slope
	Species

Move Time Analysis

Significant variables:
1. Trees per acre with a square-root inverse transformation (TPASQIN)
2. Slope

Best model to predict move time (minutes) per tree:
= 3.5577747-61.49611*TPASQIN-8.525437*SLOPE+147.5555*SLOPExTPASQIN

Regression Equation Details

Independent Variable	Coefficient	T-Value	Prob Level
INTERCEPT	3.577	3.15	0.0021
TPASQIN	-61.496	-3.10	0.0025
SLOPE	-8.525	-3.15	0.0022
SLOPExTPASQIN	147.555	3.22	0.0017

Analysis of Variance

Source	DF	SS	MS	F Ratio	Prob Level
Intercept	1	0.9343	0.93438		
Model	3	0.2961	0.09872	6.67	0.0004
Error	89	1.3174	0.01480		
Total	92	1.6136	0.01753		

Swing Time Analysis

Significant variable:
1. Slope

Best model to predict swing time (minutes) per tree:
= 0.07998051+0.06853754*SLOPE

Regression Equation Details

Independent Variable	Coefficient	T-Value	Prob Level
INTERCEPT	0.07998	9.07	0.0000
SLOPE	0.06853	2.34	0.0214

Analysis of Variance

Source	DF	SS	MS	F Ratio	Prob Level
Intercept	1	0.88391	0.883913		
Model	1	0.01104	0.011042	5.42	0.6391
Error	91	0.18337	0.002015		
Total	92	0.19441	0.002113		

Fell Time Analysis

Significant variable:
1. DBH

Species difference after including DBH in the model was not significant.

Best model to predict fell time (minutes) per tree:
= 0.02729352+0.002610831*DBH

Regression Equation Details

Independent Variable	Coefficient	T-Value	Prob Level
INTERCEPT	0.027293	3.53	0.0006
DBH	0.002610	2.79	0.0064

Analysis of Variance

Source	DF	SS	MS	F Ratio	Prob Level
Intercept	1	0.208155	0.2081550		
Model	1	0.005962	0.0059621	7.78	0.0064
Error	91	0.069760	0.0007665		
Total	92	0.075722	0.0008230		

Process Time Analysis When Total Height was Known

Significant variables:
1. DBH^2
2. Total height

Species variation was non-significant.

Best model to predict process time (minutes) per tree when total height was known:
= 0.04359187+0.00005476559-DBH^2xHT

Regression Equation Details

Independent Variable	Coefficient	T-Value	Prob Level
INTERCEPT	0.04359187	1.32	0.1897
DBH^2xHT	0.00005476	11.11	0.0000

Analysis of Variance

Source	DF	SS	MS	F Ratio	Prob Level
Intercept	1	5.85035	5.85035		
Model	1	4.25311	4.25311	123.41	0.0000
Error	62	2.13679	0.03446		
Total	63	6.38990	0.10142		

Process Time Analysis When Total Height was Unknown

Significant variable:

1. DBH^2

Species variation was non-significant.

Best model to predict process time (minutes) per tree when total height was unknown:
$= 0.007510166+0.003662553*DBH^2$

<u>Regression Equation Details</u>

Independent Variable	Coefficient	T-Value	Prob Level
INTERCEPT	0.007510	0.292	0.7714
DBH^2	0.003662	12.98	0.0000

<u>Analysis of Variance</u>

Source	DF	SS	MS	F Ratio	Prob Level
Intercept	1	6.14833	6.1483300		
Model	1	4.49162	4.4916200	168.42	0.0000
Error	90	2.40029	0.0266699		
Total	91	6.89192	0.0757345		

Total Productive Time Analysis When Total Height was Known

Significant variables:
1. DBH^2
2. Total height
3. Slope
4. Trees per acre with a square-root inverse transformation (TPASQIN)

Species variation was non-significant.

Best model to predict total productive time (minutes) per tree when total height was known:
$= 0.2229785+0.0000540762*DBH^2xHT+5.504761*SLOPExTPASQIN$

<u>Regression Equation Details</u>

Independent Variable	Coefficient	T-Value	Prob Level
INTERCEPT	0.2229785	4.45	0.00003
DBH^2xHT	0.0000540	7.52	0.00000
SLOPExTPASQIN	5.5047610	1.96	0.05397

<u>Analysis of Variance</u>

Source	DF	SS	MS	F Ratio	Prob Level
Intercept	1	19.24902	19.24902		
Model	2	5.23522	2.61761	41.47	0.0000
Error	61	3.85030	0.06311		
Total	63	9.08552	0.14421		

Total Productive Time Analysis When Total Height was Unknown

Significant variables:
1. DBH^2
2. Slope
3. Trees per acre with a square-root inverse transformation (TPASQIN)

Species variation was non-significant.

Best model to predict total productive time (minutes) per tree when total height was unknown:
$= 0.1765521+0.003786057*DBH^2+4.936639*SLOPExTPASQIN$

<u>Regression Equation Details</u>

Independent Variable	Coefficient	T-Value	Prob Level
INTERCEPT	0.176552	4.3604	0.00003
DBH^2	0.003786	9.4876	0.00000
SLOPExTPASQIN	4.936639	2.3329	0.03713

<u>Analysis of Variance</u>

Source	DF	SS	MS	F Ratio	Prob Level
Intercept	1	23.19739	23.19739		
Model	2	5.78296	2.89148	61.69	0.0000
Error	89	4.17156	0.04687		
Total	91	9.95453	0.10939		

CONCLUSION

For this study, slopes on the five study plots ranged from 0 to –46 percent. For all plots over 10 percent slope the harvester operator processed downhill. –46 percent slope is very extreme for ground based timber harvesting. Slope was found to be significant for predicting move time, swing time, and total productive time. Number of bucks, tons per acre, and species were not significant for predicting any of the dependent variables. It was not surprising that slope had an effect on the productivity of the harvester. Interestingly though, the analysis found species variation to be non-significant for predicting any of the analyzed dependent variables. That is to say that even on steep slopes, the Ponsse Ergo harvester harvested upland, hard hardwoods equally as well as pine. This might be explained by the fact that the landowner specified that large hardwood limbs did not require processing so that they were left on the site to help prevent erosion. Had those large tops been merchandized, a species effect on processing time might have been significant.

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MultiDAT and Opti-Grade: two knowledge-based electronic solutions for managing forestry operations more efficiently

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ABSTRACT

"You can't manage what you don't measure". Based on a full understanding of this fact, two novel systems (MultiDAT and *Opti-Grade*) were recently developed by FERIC to provide integrated solutions for the monitoring of forestry operations activities and the management of road maintenance activities. MultiDAT lets forest operators maximize their machines' uptime by recording and reporting machine activity and productive time. *Opti-Grade* monitors road roughness and provides work schedules for optimal road grading. Both systems are distributed by FERIC.

INTRODUCTION

In most cases, managing an operation is done by means of a cycle that starts with planning (setting objectives), then continues with monitoring actual performance, comparing it with the planned performance, taking corrective measures, and cycling back to planning to permit continuous improvement. It is essential in this process to develop accurate feedback and information systems because no proper monitoring and management can take place without them. This reality is well summarized in the saying: "You can't manage what you don't measure". Forestry operations do not escape this principle of proper management; although flying by the seat of one's pants is quite a common approach for forestry operators, the most successful operations will be those that adopt more rigorous planning and more organized monitoring.

A common challenge is to track and monitor accurate performance indicators and integrate them within a simple management system. The two examples presented in this paper combine the actual monitoring of performance indicators within the management system and therefore represent integrated solutions. The first, MultiDAT, is a forestry equipment monitoring system that lets machine operators maximize their machine's uptime by recording and reporting machine activity and productive time. The second, *Opti-Grade*, is a road management system that helps managers focus road grading or reprofiling activities where they will have the greatest impact for the money invested. Both systems have been developed by FERIC and are available for purchase from FERIC.

MULTIDAT

The MultiDAT equipment monitoring system was developed with forestry managers in mind. Forestry managers in every region share a common need: to obtain accurate information on machine productivity so they can improve the economics of their operations. In response to this need, FERIC has developed a second-generation datalogger, the MultiDAT, that can be installed on any machine or vehicle involved in forestry operations.

As a datalogger, MultiDAT is a modern-day version of the traditional mechanical activity recorder. The mechanical systems used the vibration of a stylus to record machine activity on a round clockwork-driven chart. The charts were then manually analyzed to extract data, which then had to be processed to produce results. The type of input was limited to machine movement, though this could be supplemented by adding a one-channel electrical stylus to chart another function.

In contrast, MultiDAT can record machine functions, machine movement, machine location, and operator comments. The associated software can analyze the data and produce reports on which optimal decisions can be based.

Record machine functions

When linked with up to four sensors provided by the user, the MultiDAT can record the operation of the related functions. This permits analysis of the duration of a function's activation, the number of activations, and measurement of a frequency at specific intervals (e.g., monitoring a speed sensor).

Record machine movement

The MultiDAT comes equipped with an internal motion sensor that detects movement of the machine and can be calibrated to ignore vibrations of the motor. In many cases, you can quickly determine the true operating time for a machine without requiring any additional sensors.

Record machine location

With the GPS option installed, MultiDAT can collect positional data and determine the areas that have been harvested or treated. These data can be exported for analysis using ArcView (from ESRI) or compatible software.

Record operator comments

The operator can enter codes on the MultiDAT keypad that describe the work in progress or the reason for machine downtime. You can customize the codes for each operation and determine the hours the operator worked, the type of work done by the machine, and the reasons for any work stoppages.

Analyze the data and produce reports

Even the report format is configurable. Using the MultiDAT software, you can select the information to compile and how to compile it (e.g., daily, weekly, by operator) using your personal computer.

MultiDAT can be used in both operational and research contexts. There are many possible applications, including:

Tracking and managing machine productivity:

This is a classic application for MultiDAT. One forestry machine or a fleet of machines can be equipped with MultiDAT units to track productive machine hours, productivities, and delays. A crucial indicator of performance is provided by dividing productive machine hours by scheduled machine hours to define the machine's operational availability. At 75% availability, a forest machine typically just breaks even under eastern Canadian operating conditions. Improvements in availability above 75% rapidly translate into significant profits for the operator, since income increases much more rapidly than costs above that level. Conversely, losses mount up rapidly if uptime can't be maintained. By measuring and understanding where operator time is spent, managers or operators can take corrective measures to decrease delays and maximize the number of productive hours.

Tracking effective work hours

For several types of operations, remuneration is paid based on the actual hours worked. This is particularly common for road construction or excavation equipment. MultiDAT provides a convenient means of measuring the hours when the machine actually performed a productive task rather than simply idling. In some cases, specific sensors must be added or developed to record the task being done. For example, FERIC is completing the development of a sensor that will be mounted on the frame of a grader in order to determine when the blade is actually moving road material.

Detailed timing studies

MultiDAT is a particularly suitable operations research tool. The manager's objective is often to optimize the work cycle of a particular operation. By tracking a machine's every move over a large number of cycles, conclusions can be drawn about any recurring causes for delays or slowdowns and about time-consuming activities. The GPS option provides machine locations and travel speeds, which also lets you correlate the machine's activities with terrain conditions. Conclusions can be drawn on what mechanical changes could make the machine more productive or what operational changes could be implemented to make the work more effective. To date, more than 60 MultiDAT units are working across Canada for 12 forestry companies.

OPTI-GRADE

Opti-Grade is a road management system that helps managers focus road grading or reprofiling activities where they will have the greatest impact for the money invested. Any management system relies on the availability of quality information to make good decisions. A lack of information on the state of an unpaved road network leads to expensive, inappropriate decisions on maintenance scheduling and maintenance activities. To fill this information gap, FERIC developed *Opti-Grade*, a tool that continuously collects important information on the condition of the road network to permit wiser scheduling of maintenance activities. *Opti-Grade* allows precious rehabilitation budgets to be focused where they will have the greatest impact. The result is a better-quality road within the available budget, plus decreased costs for users of the road and increased user satisfaction.

Previous Situation

In the forest industry, road maintenance often receives a relatively low priority and is done solely to keep the road in reasonably usable condition for the haul trucks. This approach leads to interventions after the road's quality has already deteriorated to the point at which it is affecting transportation efficiency. It also assumes that since each section of a road experiences similar traffic levels, each segment should require the same level of maintenance. Thus, managers often schedule graders to follow a repeating schedule that covers the entire road currently in use. In most cases, this requires having one grader available for every 80 to100 km of road being maintained to allow weekly grading of the complete road. The result is overuse of the grader for sections that need little grading and under-use of the grader on the sections that need grading the most.

New Approach

The first step in improving the decision-making aspect of managing grading operations involves collecting information on which to base grading decisions. To achieve this, FERIC has developed an approach based on automatically collecting roughness measurements that reflect the impact of the road's condition on travelers. In this approach, a haul truck or other vehicle traveling on the road network is equipped with an instrument that measures the effects of road condition on the truck and provides a GPS location for each roughness level recorded by the instrument.

In the next step, managers analyze the data. In FERIC's system, the data is stored in a database so it can be displayed graphically and in table format. From this database, reports can be produced. Two reports offer graphic representations or maps that show the location of rough points on the road network. These can be used by the road manager to quickly visualize the location of troublesome sections of the road. The software also produces a histogram that shows the percentage of the road that falls into each of five roughness classes defined by the user. The remaining reports are more comprehensive tables that offer more detail to support decisions concerning routine road maintenance.

This information is used to generate daily grading schedules, which indicate where grading should take place based on user-defined criteria for roughness and operational limits. The grading schedules are followed by the grader operators who actually maintain the road.

A second set of reports provide information on the travel speeds of the vehicle that carries the *Opti-Grade* hardware; these are broadly representative of the speeds of other similar vehicles on the road. Managers can compare the average speed and roughness for a segment of road with the current situation to identify problem areas that are affecting traffic circulation as a result of dust, traffic levels, excessive roughness, etc.

Results

To date, 32 *Opti-Grade* units have been sold to Canadian forest companies. Here are three examples of the results these companies have obtained:

Example 1. Reduced maintenance costs

To reduce grading costs, one forestry company reduced its fleet of graders from three to two. To ensure that this cost-reduction measure would be acceptable to the road's users, the managers withdrew the third grader and began using *Opti-Grade* to manage the two remaining graders. The road's condition remained unchanged, despite using one less grader. Following the grading schedules produced by *Opti-Grade* thus permitted an effective 33% reduction in grader hours while keeping the road in good condition. In addition, the managers appreciated the availability of reports on vehicle travel speeds that were gathered by the system. They use this data to verify cycle times and monitor the average travel speeds on various sections of the road. The software was also used to verify vehicle speed while approaching stream crossings, where truckers must slow down to avoid damaging the bridges. Last but not least, the grading schedule let managers limit maintenance to sections that really required grading; this helps preserve the effectiveness of any dust suppressants that have been applied by avoiding unnecessary disturbance of the road surface during the summer.

Example 2. Increased scope of action for the graders

Another user faced increasing haul and maintenance costs because of ongoing expansion of their main road. This road has now reached a length of 180 km, and sustains heavy traffic; thus, the managers expected that they would soon need to add a new grader. By following the grading schedules produced by *Opti-Grade,* a single grader was easily able to maintain 35 to 45 km/day rather than the 20 to 30 km/day that had formerly been achieved. In effect, this operation decreased its grading time by 25%, reducing the work week from 7 days to 5 days. The managers anticipate a better-quality rolling surface, which should translate into reduced haul costs as a result of this targeted management of road maintenance.

Example 3. Improved effectiveness, quality, and user satisfaction

Using *Opti-Grade*, another company was able to maintain 210 km of main road and nearly 100 km of secondary road (roughly 300 km in total) using only two graders. According to the managers, better management of their graders on the main road let them free up this equipment to assist the crews responsible for maintenance of the secondary roads. In addition, *Opti-Grade* identified a 20-

km section of the main road that required grading each day. This problem section was rehabilitated in the fall of that year. The managers were able to justify budgeting for the application of crushed rock because both the problem and the potential benefits of solving it could be documented using *Opti-Grade*. As well, the forestry workers reported that the road had never been in such good shape.

With typical payback periods of less than 4 months, *Opti-grade* is an easy sell to forest companies.

CONCLUSION

MultiDAT and *Opti-grade* are two examples of specialized technologies (hardware and software) that allow managers to complete the cycle of planning, monitoring, comparing, and correcting. Both tools integrate measuring tools within integrated management systems that allow for continuous improvement of the operations.

For more information on MultiDAT or *Opti-grade* please contact FERIC at 514-694-1140 or E-mail us at admin@mtl.feric.ca.

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Southeastern State BMP Monitoring Needs

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Abstract

A uniform standard is needed when monitoring forestry Best Management Practices (BMPs) throughout the southeastern United States. The level with which individual states monitor forestry BMPs depends upon the states willingness to enforce implementation and the level of funding. Effective monitoring depends upon the ability of the state agencies to inspect harvesting operations. Current methods of monitoring BMP implementation range from on-site inspections, aerial observations, to no observations unless a water quality complaint is issued. Regardless of state BMP monitoring methods, the overall compliance percentage of BMP implementation is, on average, in the 90s. There is an obvious discrepancy in monitoring and reporting BMP compliance in the southeast. This is a direct result of not having a standard monitoring and reporting procedure.

Introduction

Binkley and Brown (1993) estimate forestry operations as the leading polluter for 3 percent of the nations river and stream miles. Potential non-point source pollution (NPS) from forestry operations is sediment and nutrient transport to surface waters which can effect the physical, chemical, and biological integrity of water quality (Brooks, 1997). To manage NPS potential from forestry operations, the Clean Water Act suggested best management practices (BMPs) for development to use as system of methods and measures for pollution prevention (AF&PA, 1993). It is the responsibility of all states, including those in the southeast to conduct BMP compliance monitoring and audits to assess the level with which voluntary and mandatory BMPs are being applied and effective. Southeastern state BMPs are a voluntary measure, unlike Pacific Coast states, which require BMPs to be employed on silvicultural operations.

However, to first conclude if BMPs are effective, states must quantify the level of effort that water quality is being protected during and after forestry activities through compliance monitoring. According to Ellefson et al., (2001) compliance monitoring is the systematic gathering of information to determine whether landowner and timber harvesters are actually applying forest practice guidelines or rules in the intended manner. It is typically difficult to get an accurate picture of BMP effectiveness because NPS pollution is transported as a function of rainfall and snowmelt. Further, site visits are rarely coordinated with such events.

The first of three challenges facing southeastern states is the misunderstanding of terminology used when describing and reporting BMP implementation and compliance. In the southeast, data is misinterpreted as a result of assuming each state has similar definitions of compliance and implementation. Figure 1 provides an area where common language can benefit foresters in the field.

Figure 1. Common language is key when reporting BMP field audits.

The second challenge facing southeastern states is tract access for monitoring BMP implementation on forestry operations. This is a direct result of state's government willingness to give forestry department personnel the right-to-trespass on property to ensure that water quality is protected.

Table 1. Southeastern state BMP monitoring status.

State	Right To Trespass	BMP Monitoring Compliance Rate	BMP Effectiveness Studies	State's With Starting BMP Programs	States With Known Future Effectiveness Studies
Alabama	No	98%		✓	
Arkansas	No	79%		✓	
Florida	No	96%	✓		
Georgia	No	98%			
Kentucky	No	?		✓	
Louisiana	?	?		✓	
Mississippi	No			✓	
North Carolina	No	>90%			
Oklahoma	?	?		✓	
South Carolina	No	91.5%	✓		
Tennessee	?	?		✓	
Texas	No	88.6%			
Virginia	Yes	90%			✓

Outside of Virginia, all southeastern states must contact the landowner for permission to go onto the property or inspect BMP implementation through aerial reconnaissance. All southeast state forestry departments have permission to go onto the property as a response to a water quality complaint. Each of these methods is a function of funding and available state personnel. Although monitoring methods, funding, and the number of personnel vary, southeastern states report BMP implementation compliance percentages in the 90s. As seen in Table 1., the status of southeastern states monitoring BMP implementation varies, while the compliance rate is consistently a high percentage.

The third challenge facing southeastern states is their ability to have an objective uniform BMP monitoring and reporting procedure. In the southeast, the "BMP Water Quality Task Force" was created, through the leadership of George Dissmeyer (retired, U.S. Forest Service), in 1996 as a result of several meetings with hydrologists and water quality specialists from state forestry agencies as well as the U.S. Forest Service and EPA Region IV non-point source specialist (Vowell *et al.* 1997). The Task Force created "Siliviculture Best Management Practices Implementation Monitoring—A Framework For State Forestry Agencies," in 1997. This handbook was created as an outline for southeastern states to implement a statistically sound method for maximizing and improving BMP implementation while being analytically consistent and comparable among the states (Vowell *et al.* 1997).

Although this document was created with the greatest intentions it was not widely accepted as a result of states willingness and resources to implement the monitoring framework. Further, not every state forestry department has the responsibility of monitoring. Therefore, in the southeast, monitoring for BMP implementation compliance differs among each state. For example, according to Ellefson *et al.*, (2001) only two states in the southeast monitor all harvested sites in the state. However, it is important to note that this statistic does not account for the discrepancies in reporting procedures. This poses a large problem when comparing and contrasting BMP implementation and compliance data throughout the southeast.

Discussion

The United States Environmental Protection Agencies (EPA) Coastal Zone Act Reauthorization Amendments (CZARA) of 1990 and Total Maximum Daily Load (TMDL) program are a driving force for state BMP monitoring and effectiveness data. The

TMDL program was designed to address the maximum allowance of pollutants a watershed can receive in one day (USEPA, 1999). Initially developed for point source pollution, the TMDL program has shifted towards NPS sources, such as silviculture operations.

Continuity in reporting and monitoring among southeastern states to provide a more accurate picture of BMP implementation and their effectiveness is needed. To achieve this goal, there should be a low cost uniform objective approach for field site inspections of forestry operations to determine water quality degradation potential and occurrence over time.

The purpose of monitoring BMP programs is to measure the success of state efforts on educating and providing technical assistance for loggers, foresters, and landowners on practices to prevent water pollution.

Conclusion

Although silviculture operations contribute a relative small percentage of NPS pollution when referenced towards other land uses, pressure to manage NPS on forestry operations has increased with the development of EPA's CZARA and TDML programs. Therefore, the need for southeastern states to follow a uniform standard is paramount when comparing BMP program advancement. The following list provides the general overall need for southeastern states:

Basic Standards

1. Common definition of compliance and implementation.
2. Common random sample selection of sites for BMP audits.
3. Common monitoring (recording) and presentation of data as seen in Figure 2.

State Needs

1. Proper notification "several days/weeks" prior to a logging operation.
2. Right to trespass on property to assess BMP implementation/effectiveness.
3. Funding to implement BMP programs and monitoring.

Effectiveness

1. Common means of testing BMP effectiveness.
2. Less expensive objective "on-the-ground" procedure to assess effectiveness and compliance.

Baseline Studies

1. Only a handful of states monitor control watersheds for background data on natural loading rates for sediment and nutrients.
2. Compare and Contrast monitoring results by blocking study areas by region/physiographic province/landowner type.

The above list are suggestions to remedying a current southeastern state need and suggest future examination of both mandatory and voluntary BMP monitoring nationwide.

Figure 2. On-site objective monitoring of BMPs is necessary for accurate BMP implementation compliance surveys.

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Benchmarking the Performance of Logging Crews Using Stochastic Frontier Analysis

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ABSTRACT – Timber harvesting businesses do not have a standard method to quantify performance or determine the capacity of an individual logging crew. Both productivity and efficiency are often used to measure performance. Productivity is the ratio of output to input. Efficiency is a comparison or ratio between an observed performance level and a benchmark, defined as the optimal performance for a given a level of input. This study used a benchmarking technique to estimate production capacity for individual logging crews as a function of labor and capital inputs. We used 3,132 weekly production reports during 2000 and 2001from 63 logging crews. These weekly data serve as a quantitative narrative of the workweek, explaining the number and types of loads hauled, the amount of labor employed, the number of moves, and the extent of use of contract trucking. We used stochastic frontier analysis (SFA) to estimate technical efficiency. A production frontier was estimated based on actual production and measures of labor and capital inputs. Explanatory environmental variables were tested for significance and influence on production.

INTRODUCTION

Performance of a business or industry is often difficult to evaluate because the definition of performance varies between firms and industries. The business of timber harvesting, or logging, suffers from the lack of a standard method to quantify performance. In many cases, productivity and efficiency are applied as measures of performance. Productivity has been defined as the ratio of outputs to inputs (Coelli *et al.* 1998). Efficiency is a comparison or ratio between an observed level of output and a benchmark that is considered the optimal output level for a given a level of input.

The challenge of applying these measures to any industry exists in determining what to include as input and output and how to find, measure, or estimate the benchmark. The benchmark or optimal level of production is the productive capacity or the maximum level of output attainable by a crew with a given equipment array or fixed capital input (LeBel 1993). The benchmark can be estimated in a number of ways. Each machine has a theoretical rating, based on engineering measurements, which gives the maximum output that a machine could produce in a given amount of time. The sum of the machine rates would give a measure of a benchmark. This logic, however, is flawed in that the sum of the parts rarely equates to the whole. Additionally, this method allows for no stochastic or random effects in the production process. More preferred methods to estimate production capacity uses actual production data. Stochastic frontier analysis (SFA) is one widely accepted method of estimating capacity and efficiency that is based on actual production data. It also accounts for random effects in production as well as possible measurement error.

Stochastic frontier analysis estimates "best practice" frontiers, with the efficiency of specific observations measured relative to that frontier (Coelli *et al.* 1998). A functional form for the production frontier is specified, similar in many ways to a production function. A production function assigns the expected or average output for a given set of inputs, whereas the production frontier defines the maximum output for the same set of inputs (Figure 1). Because this method is stochastic, observations may be off the frontier due to inefficiency and/or random effects. The frontier function is hypothesized to contain a separable, two-part error term where one part accounts for inefficiency and the other accounts for random effects. The generic translog specification of a production frontier:

$$Y_j = X_j{*}B + (V_j - U_j) \qquad j = 1,\ldots,N$$

where:

Y = the natural logarithm of output of a firm;
X = the natural logarithm of a vector of inputs to production;
B = a vector of unknown parameters to be estimated;
V = the error term that accounts for random effects;
U = the non-negative error term that accounts for technical inefficiency.

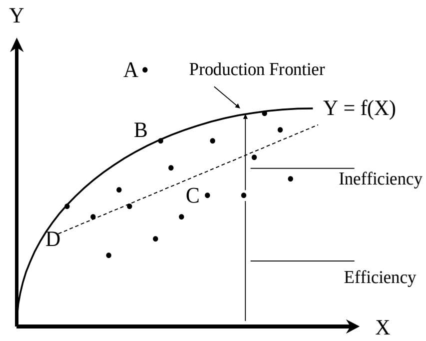

Figure 1. A generic production frontier and an ordinary least squares regression line fit to sample data. Relative efficiency and inefficiency are demonstrated for a single data point.

The distributional assumptions placed on V, the random effects error term, are that they are normally, identically, and independently distributed with a mean of 0 and variance of sigma squared. Additionally, it is assumed to be independent of U, the inefficiency term, which is assumed to be half-normally distributed, truncated at 0, and independently and identically distributed $|N(\mu, \delta_U^2)|$.

By simply using the inputs of the production process, SFA reveals much information regarding the efficiency of each observation. In fact, each observation has a technical efficiency percentage associated with it after SFA is performed. The logical next step is to try to explain these efficiencies using information about the firms and operating conditions that produced the observations. This information, often referred to as environmental variables, includes any information external to the production process, not just characteristics of the physical environment. A number of empirical studies have estimated stochastic frontiers and predicted firm-level efficiencies, and then regressed the efficiencies upon firm specific variables, such as region, firm experience, or business strategies in attempts to identify the reasons for differences in predicted efficiencies between firms within an industry (Coelli 1996). While this is a useful exercise, it is inconsistent in its assumptions regarding independence of the inefficiency error term. Also, this two-stage procedure is unlikely to produce estimates that are as efficient as those obtained using a single stage procedure (Coelli 1996).

By slightly modifying the original stochastic frontier function, we can produce one-stage estimations of the frontier and observation-specific efficiencies, which include the effect of environmental variables. The modification expresses the inefficiency effects, U, as an explicit function of the selected environmental variables. The distributional assumptions on V are the same as the previous model, but the assumptions on U are the key difference. U is still assumed to be independent, identical, truncated at 0, and normally distributed, but unlike before the distribution of U is assumed to have a mean, M, $|N(M_j, \delta_U^2)|$. M is expressed as a function of the selected environmental variables:

$$M_j = Z_j * G$$

where:
Z = a vector of environmental variables;
G = a vector of unknown parameters to be estimated.

PRODUCTION INPUTS AND OUTPUTS

The inputs and outputs of the stochastic frontier models mirror the inputs and outputs of the production process. In our study, the number of loads of wood delivered to market each week represented production output. The total number of man-hours worked by the crew during the workweek measured the labor input. Some measure of weekly expense was also required as capital input. We used all weekly expenses, except labor and trucking, as our measure of capital input. These were based on readily available, published equipment prices and operating costs rather than utilizing proprietary, crew-specific cost data that might not be readily available to future analysts.

Using equipment cost data from Brinker (2000), we generalized the categories of equipment. We combined specific types of woods equipment into ten general equipment categories; skidders, fellers, loaders, delimbers, chippers, tracked fellers, tracked skidders, tracked loaders, harvesters, and forwarders. This measure considered only woods equipment. Trucking was not included. Using Brinker (2000), we calculated average fixed cost per year and average operating cost per scheduled machine hour.

In the logger profile data, crews reported their annual scheduled machine hours. When that information was not available for a crew, we assumed 2000 hours per year. Dividing the average fixed cost per year of each of the categories by the number of scheduled machine hours per year gave an estimate of fixed cost per scheduled machine hour for each category. This calculation expressed the fixed cost in the same units as the variable cost per scheduled machine hour. By summing the fixed and variable costs, we determined the total cost per scheduled machine hour per machine category.

Also from profile data, we knew the type and number of machines that each crew used. The number of machines in each category was multiplied by the average total cost per scheduled machine hour per category. To account for the cost of holding and maintaining spare equipment, their cost was calculated as if it were an active piece of machinery, multiplied by 20%. All costs were summed to obtain the total equipment cost per scheduled machine hour. We multiplied the total equipment cost per scheduled machine hour by the scheduled machine hours per week to attain the capital measure or total cost per week.

RESULTS

During the course of the study, we collected 3,132 logger-weeks of data from 63 loggers, all of whom had submitted profile information and at least 13 weekly activity reports. It was assumed, given the nature of the logging industry, that the technology used to sever, process, and transport wood did not change significantly during the 18 months of this study. Based on this assumption, the data panel was pooled into a single cross section of 3,132 weekly observations to simplify the analysis and present more robust findings.

Using specialized software (Coelli 1996) to estimate stochastic frontiers, we fit the data to a production frontier. The analysis resulted in the following logging production frontier model:

$$Y = -31.4257 + 6.8849{*}K + 1.1523{*}L - 0.3848{*}K^2 - 0.0444L^2$$

where
Y is the natural logarithm of loads per week,
K is the natural logarithm of the capital measure, \$/week
L is the natural logarithm of man-hours per week.

This model yields weekly production capacity that is unadjusted for environmental variables. From this estimated capacity, efficiency scores were generated for each observation. The mean efficiency value is 62.9%, with a minimum of 4.6% and a maximum of 96.4% (Figure 2). The signs (positive or negative) and magnitudes of the coefficients of this frontier relate important information. Because the coefficients for K and L are positive, we know that additional inputs of K and L will increase output, however, because the coefficients for the squared terms are negative, we know that the production process displays diminishing returns.

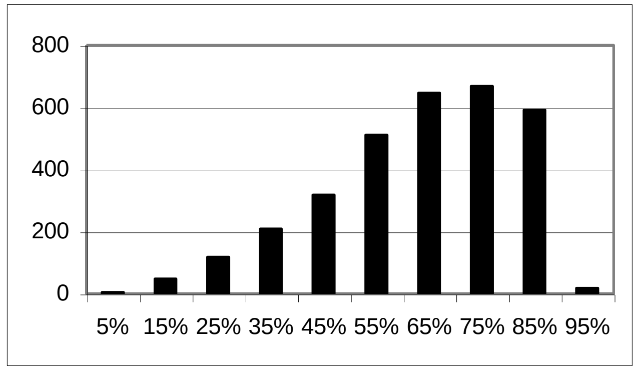

Figure 2. Distribution of observed efficiency (weekly data).

To address the sensitivity of the output frontier to changes in input values, we used the function to predict the production capacity using the mean values for capital and labor. We then increased and decreased each of input by 10% to examine the resulting change in output (Figure 3).

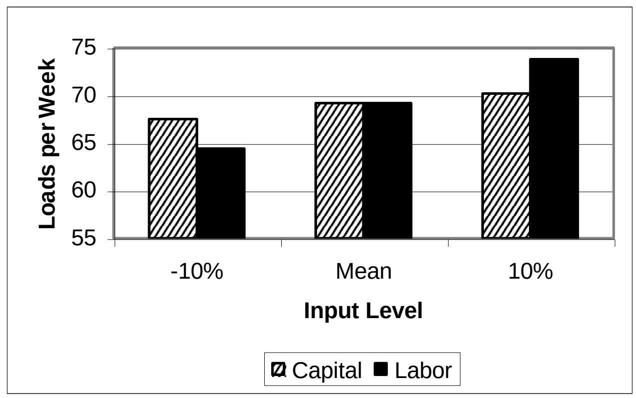

Figure 3. Loads per week for the mean value of inputs and for a 10% increase and decrease of each.

CONSISTENT PRODUCTION

Because the data were collected and expressed in weekly units, we were concerned that the frontier could be biased by "heroic" weekly efforts that would not be generally reproducible on a consistent basis by any crew. This could potentially exaggerate the productive capacity of the harvesting force and the inefficiency associated with it. To address this issue, we collapsed the data from weekly figures into both monthly and quarterly measures and performed similar stochastic frontier analysis on these collapsed datasets. To collapse the data, we simply calculated average weekly values of loads hauled and man-hours for each crew by month and quarter. By averaging the data we sought to dilute the effect of any "heroic" weeks, without completely removing them. Logger-months in which two or fewer weeks were reported were removed from the data set. We expected values for the weekly frontier to be higher than those for a monthly frontier and likewise those for a monthly frontier to be higher than those for a quarterly frontier.

A production frontier was fit to the monthly data (n=734) as described above and resulted in the following equation:

$$Y = -22.8495 + 4.1565{*}K + 2.3657{*}L - 0.2287{*}K^2 - 0.1558L^2$$

where
Y is the natural logarithm of average loads per week,
K is the natural logarithm of the capital measure,
L is the natural logarithm of average man-hours per week.

This function yielded production capacity, expressed as an average weekly value, as determined on a monthly basis that is unadjusted for environmental variables. Based on this frontier, 734 efficiency scores, one for each observation, were produced. The mean efficiency value is 65.9%, with a minimum of 14.6% and a maximum of 92.9% (Figure 4).

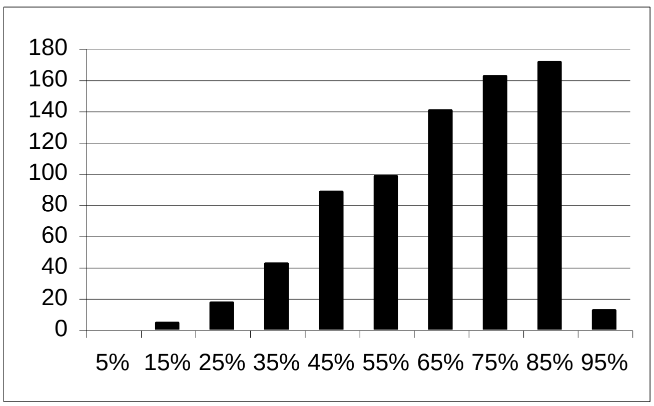

Figure 4. Distribution of efficiency (monthly data).

Quarterly data were obtained using the same process as with monthly data. Logger-quarters with fewer than seven weeks reported were dropped from the data set. We fit a production frontier on the quarterly data (n=259), forming the function:

$$Y = -25.5648 + 5.0329{*}K + 2.0129{*}L - 02802{*}K^2 - 0.1241L^2$$

where
Y is the natural logarithm of average loads per week,
K is the natural logarithm of the capital measure, $/week
L is the natural logarithm of average man-hours per week.

This function yields production capacity expressed as average weekly production, but determined on a quarterly basis and is unadjusted for environmental variables. Based on this frontier, 259 efficiency scores, one for each observation, were produced. The mean efficiency value is 63.8%, with a minimum of 15.5% and a maximum of 92.9% (Figure 5).

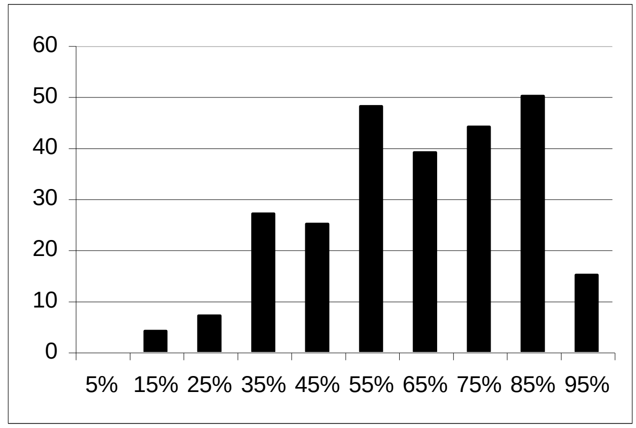

Figure 5. Distribution of efficiency (quarterly data).

ENVIRONMENTAL VARIABLES

Using the same production data and adding to it the corresponding environmental variables, we used FRONTIER (Coelli 1996) to produce a production frontier, including coefficients that describe the effect of the 14 environmental variables (Table 1).

Table 1. The coefficients of the production frontier, including environmental variables.

	Parameter		Coefficient	T-ratio
b_0	Constant		3.2426	1.48
b_1	ln (capital)		-.5559	-1.06
b_2	ln (labor)		.8734	8.56
b_3	(ln capital)^2		.0249	0.83
b_4	(ln labor)^2		-.0251	-2.50
z_1	Preferred Suppier	(0,1)	-.3922	-12.70
z_2	Stumpage via Company	(0,1)	-0.3206	-10.40
z_3	Stumpage via Dealer	(0,1)	.0559	1.30
z_5	Partial cut crew	(0,1)	.7787	26.80
z_6	Hardwood Producer	(0,1)	.4354	14.50
z_7	Contract Trucking	(0,1)	.7751	19.10
z_8	Age of Business		-.0121	-5.03
z_9	Age of Crew		-12.0791	-.550
z_{10}	Sells via dealer	(0,1)	-.4739	-10.40
z_{11}	moves		0.1059	5.90
z_{12}	Piedmont	(0,1)	0.1762	4.60
z_{13}	Mountain	(0,1)	0.4171	8.70

z_{14}	Average haul distance	0.0036	7.30
z_{15}	High Tract rating	0.2128	16.30

Because the environmental variables are analyzed as part of the separable, two-part error term, the coefficients describe the effect that the variable has upon inefficiency. Thus, a negative coefficient implies that the variable tends to reduce inefficiency, thereby increasing efficiency. Of the 14 environmental variables, 12 appear are significant at the 99 percent confidence level (t ratio = 2.576). Only 'stumpage via dealer' and 'age of crew' are not statistically significant.

As we expected, preferred supplier status reduced the inefficiency of the individual crew. This could be due to a more stable level of productivity, caused by the mill allowing the logging contractor to more accurately tailor his operation to that level. Stumpage via company appears to reduce inefficiency as well. This is also likely due to a more stable production level. Partial cut crews tend to be more inefficient. This should be no surprise given the size of the trees being harvested and the care required to remove the harvestable trees while leaving standing stock intact. Contractors that are primarily hardwood producers appear more inefficient than those that are not. This is probably due to the challenging terrain often inherent in hardwood logging operations. Understandably, many loggers prefer that the liability and expense of trucking be borne by a third party, but in terms of production, surrendering control of this aspect of the operation tends to reduce efficiency. Using age of business as a proxy for experience, it seems that experience reduces inefficiency. Selling through a dealer tends to decrease inefficiency. This could be due, in part, to the dealer having a variety of outlets to which he may sell wood, even when the logger is unable to do so. Moves, as expected, seem to increase inefficiency. Operating in the piedmont, versus the coastal plain tends to increase inefficiency, and operating in the mountains tends to increase inefficiency even more. As average haul distance increases, inefficiency increases slightly. High tract rating also has an effect on inefficiency. The better the tract rating (closer to 1), the less inefficient the crew appears. Conversely, the worse the tract rating (closer to 3), the more inefficient the crew appears.

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Optimization of Cable Logging Layout Using a Heuristic Algorithm for Network Programming

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ABSTRACT - This paper describes a methodology for optimizing cable logging layout using a heuristic network algorithm. The methodology formulates a cable logging layout as a network problem. Each grid cell containing timber volume to be harvested is identified as an individual entry node of the network. Mill locations or proposed timber exit locations are identified as destinations. Then, each origin will be connected to one of destinations through alternative links representing different cable roads, harvesting equipment, landing locations, and truck road segments. A computerized model incorporating the methodology is introduced. The model is intended to optimize landing, harvest equipment, logging profile, and road location simultaneously using information from GIS layers. A heuristic method for network programming is used as an optimization technique in the model.

INTRODUCTION

Designing timber harvesting units is one of the most difficult tasks in forest operational planning. The task requires engineers to decide logging equipment, landing site, logging profile, transportation system, and road location based on various considerations including timber volume distribution, economic and environmental outcomes, and physical feasibility of the system. Traditionally, engineers have done the task manually, but it is difficult to consider many alternatives. Thus, it is not easy to find a timber harvest layout which is not only "feasible" but also "good" by the manual method.

With the purpose of assisting engineers in designing timber harvest layout, various computerized methods have been introduced. Dykstra (1976) developed a methodology to assist in the design of timber harvest cutting units and the assignment of logging equipment. PLANS (Preliminary Logging Analysis System) developed by the USDA Forest Service (Twito et al. 1987) has been used for developing timber harvest and road network plans based on large-scale topographic maps. PLANEX (Epstein et al. 1999a, Epstein et al. 1999b) is able to generate an approximately optimal allocation of equipment and road network based on a heuristic algorithm. However, none of the above methods has a complete analysis tool covering from cable road analysis considering topographic profiles to the simultaneous optimization of cable harvesting equipment placement and road location.

The methodology described in this study will combine a cable logging equipment assignment problem with a road location problem and optimize them simultaneously, while incorporating modern computer software languages, Geographic Information Systems (GIS) technologies, and optimization techniques that have become available during the last two decades. The methodology evaluates alternative cable layouts based on feasibility analyses of logging system and road segments, and estimation of operation costs. A heuristic network algorithm is used as an optimization technique. The entire network is divided into two parts of the network. Each part of the network is solved separately using the heuristic network algorithm while being connected to the other by a feedback mechanism. The methodology is implemented in a computerized model, which is currently being developed as a decision support tool. Upon completing the development, the model will be able to assist forest engineers in designing cable logging units by providing "feasible and good" alternatives using cost and environmental criteria.

PROBLEM FORMULATION

Cable logging operations can be considered as a series of operations that start from the stump and end at the mill. Each operation can be represented by a link connecting two consecutive operations with corresponding costs. Then, a series of operations would be a path (a series of links) forming a part of a network system. All possible links starting at each timber source would build an entire network system consisting of multiple origins, multiple paths, and multiple destinations. Then, the network problem is solved using a network solution technique.

Required Data

The methodology requires several GIS layers as input data: a Digital Terrain Model (DTM), a timber volume layer, and layers containing other logging considerations.

A DTM provides spatial and topographic information for logging feasibility analysis and estimating logging operation and road costs. A timber volume layer enables identification of the timber sources spatially, by which we can consider not only clearcut treatments but also group selection cutting systems and individual tree selection operations.

Formulating the Network

Figure 1 shows a series of cable harvesting operations on a DTM. The timber harvesting operations using cable systems may be categorized into two different types of operations: cable logging and truck transportation. The cable logging operation planning requires decisions on cable system, cable road, and landing location, while truck transportation planning requires selection of road locations and transportation routes.

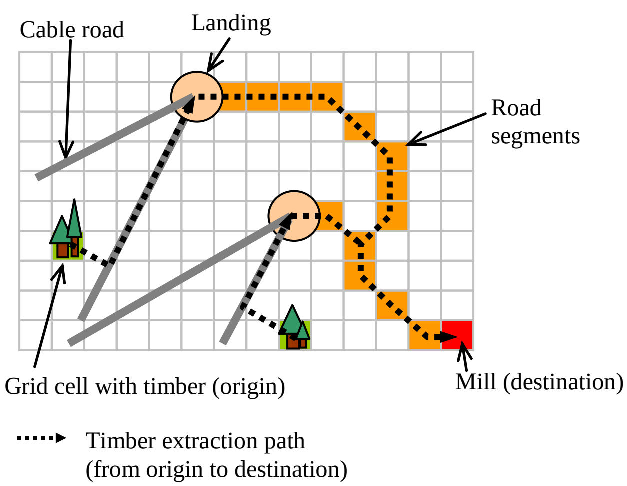


Figure 1. Cable harvesting unit layout as a network problem on a DTM.

Each grid cell containing timber volume to be harvested is identified as an individual entry node of the network. Mill locations or proposed timber exit locations are identified as destinations of the network. Then, each origin will be connected to one of destinations through alternative paths representing different cable roads, harvesting equipment, landing locations, and truck road segments (Figure 2). Each path consists of links incurring variable costs (yarding and truck transport cost) and fixed costs (equipment cost, landing and road construction cost).

In order to solve cable logging operation and road location problems simultaneously, two different link lists are used in the network analysis: a cable road link list and a truck road link list. The cable road link list includes all possible links from the origins to alternative landings and is used to evaluate cable logging operation paths. A truck road link list consists of road links generated from the DTM, and is used to evaluate truck transportation routes from each landing to the destinations.

Once the truck road and cable road network is set up, a network algorithm solves the problem and finds the least cost path from each origin (timber entry) to one of destinations (mills) while simultaneously selecting cable road, cable equipment, landing location, and road segments to be used.

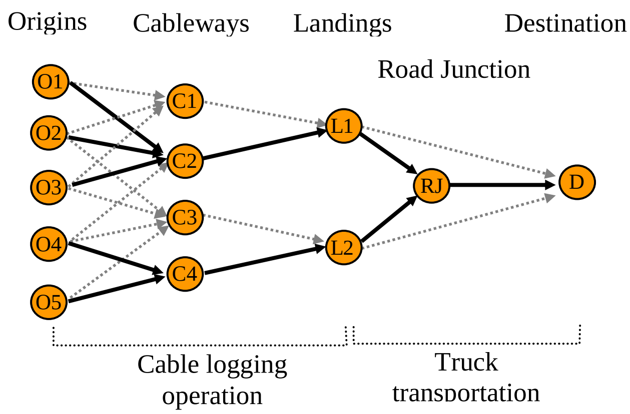


Figure 2. A network represents cable logging operations and truck transportation.

PROBLEM SOLUTION TECHNIQUES

A Heuristic Network Algorithm

Due to their efficiency and ability to handle large-scale optimization problems, network optimization algorithms have been used for solving a wide variety of problems such as transportation, assignment, and resource allocation (Jensen and Barnes 1980). In forestry, a heuristic NETWORK algorithm developed by Sessions (1985) has been applied to forest transportation planning and other applications. This heuristic NETWORK algorithm is similar to the Prorate Algorithm developed by Bill Schnelle of the USDA Forest Service (1980) to solve the fixed charge and variable cost problem. However, the heuristic NETWORK algorithm uses a series of rules to avoid stalling in a local minimum and it also extended applications to multiple periods, multiple product, and value maximization or cost minimization through introduction of special arcs.

In this study, the heuristic NETWORK algorithm developed by Sessions (1985) is used as an optimization technique. The algorithm calculates the minimum cost network by using a shortest path algorithm to solve the variable cost problem similar to that proposed by Dijkstra (1959). The process begins with sorting the grid cells by timber volume (Figure 3), and then solving the shortest path problem without considering the fixed costs (FC). The sum of the volumes, Vol_i, that went over each link are accumulated and so that at the end of the first iteration the sum of all volumes, ΣVol_i, over each link are available. The variable costs for each link, VC_i, are then recalculated using Eq. 1. The volume over all links is then reset to zero and the next iteration started using the new set of variable costs. This process continues until the same solution is repeated for two iterations. To diversify the search, a negative value is substituted for each positive variable cost link not in the solution such that $VC_i < 0$ for all links with $Vol_i = 0$. The solution procedure is then repeated until the solution re-stabilizes. Each time a link with a negative value is used its value returns to its original value. This process rapidly eliminates the substituted negative values while providing an additional opportunity to consider alternative paths.

[Eq. 1] $$VC_i = VC_{INIT\,i} + \frac{FC_i}{\sum Vol_i}$$

where, VC_i : Variable cost for link *i*
VC_{INITi} : Initial variable cost for link *i*
FC_i : Fixed cost for link *i*
Vol_i : Volume transported on link *i*

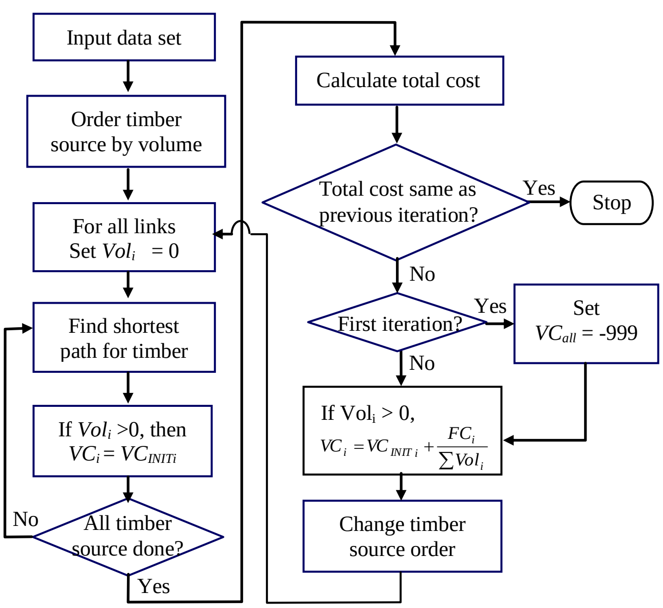


Figure 3. Flowchart for heuristic problem solving approach based on the shortest path algorithm.

Solving Cable Logging Equipment Placement and Road Location Problems

For the purpose of reducing solution time and enhancing solution quality, the methodology in this study divides a large network into two sub-parts: cable logging operation and truck transportation. First, the cable logging operation part of the network is solved in order to select cable roads, cable systems, and landing locations without considering truck transportation (Figure 4). Then, total timber volume arriving at each landing is calculated based on the results of the optimization and sent to the truck transportation part as being entry volume in the road network. After truck transportation routes are optimized, road and transportation costs related to each landing are sent back to the cable logging operation part and added to fixed and variable costs for each landing in the network. In case that several landings share the same road links, the road costs on the links are divided to each landing proportional to its volume transported over the links. Then, the optimization algorithm comes back to the cable logging operation part with updated link costs and resolves the network problem.

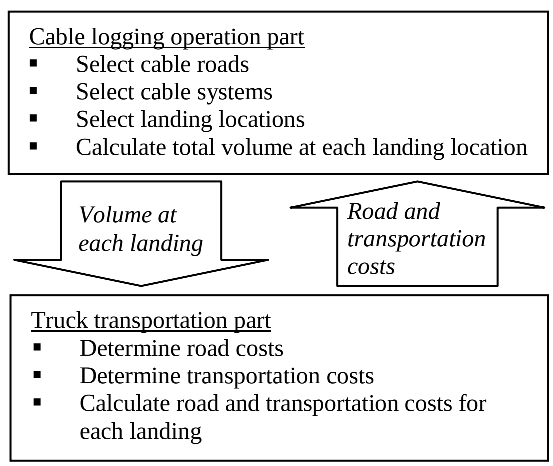


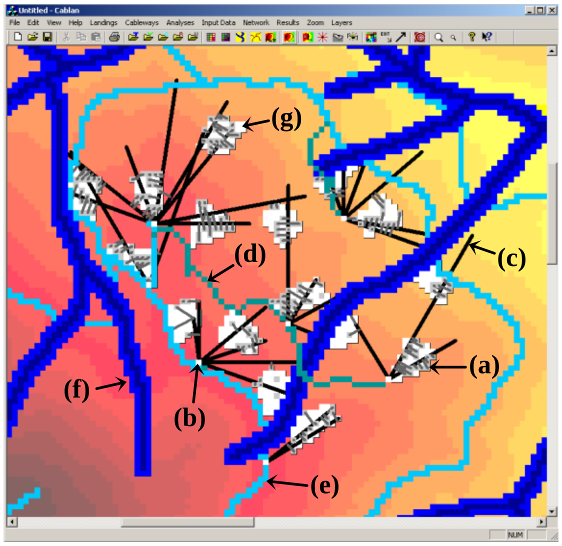
Figure 4. A feedback mechanism between two separated network problems.

A number of iterations of this process are required to get to a steady state where the results from each part remain the same as the previous iteration and the algorithm stops. Depending on the specific problem, the repetition of this process might not converge to a steady state but keep bouncing around within a range. Setting stopping criteria such as limiting the number of repetitions would be necessary to terminate the algorithm in a reasonable time. The best overall solution should be kept over the iterating process.

A PRELIMINARY COMPUTERIZED MODEL

A computerized model implementing the methodology described in this paper is currently in development. The model starts with reading input data and generates two link lists for a network analysis. Based on the link lists, the heuristic network algorithm finds the best path from each timber source to the proposed destination.

Figure 5 shows the preliminary computerized model. As an example, the model was applied to patch-cut harvesting areas in the McDonald-Dunn Oregon State University (OSU) Research Forest and developed an alternative cable logging layout. GIS data provided information on topography, timber location and volume, and the locations of existing roads and riparian zones. The model identified feasible candidate cable roads through the payload analysis while considering terrain conditions and riparian zones. In a network assembled by the model, each timber location was identified as an entry node and the destinations of the network were any grid cells on the existing roads.



(a) timber source, (b) selected landing, (c) selected cable roads, (d) proposed roads, (e) existing roads, (f) stream buffers, (g) patch-cut areas

Figure 5. The preliminary computerized model applied to patch-cut areas on the McDonald-Dunn OSU Research Forest.

DISCUSSION

This paper introduced a methodology for simultaneously optimizing cable equipment placement and road locations using a heuristic network solution technique. This methodology is currently being implemented in a computerized model. Developing a useful model requires a good estimation of operation costs, therefore detailed cable road analysis and road cost modules are included.

Grid pixel size in a DTM directly affects the problem size for the network analysis. High resolution in a DTM would provide topographic details but exponentially increases problem size resulting in increasing solution time and demand for memory capacity. Methods to reduce problem size with a high resolution DTM may need to be explored to shorten solution time and lessen memory requirements. Reducing the number of origins by clumping several timber cells together or eliminating infeasible links from the whole network system might be alternative ways to reduce problem size.

Future improvement of this model should include the considerations of riparian zone management regimes and other environment impact of road construction. Additional constraints may enable us to restrict stream crosses and avoid road construction from unstable soil areas. Verification of the methodology described in this paper should be done in the future studies. The results from this methodology can be compared with a cable layout by manual methods or results from other optimization techniques. Also further studies to improve the efficiency of the solution technique should be taken based on the preliminary results of the planned model.

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Sedimentation Risk From a Road Network in Western Oregon

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ABSTRACT - Sedimentation from forest roads includes both surface erosion and hillslope failures. This paper will investigate the utility of combining the risk of surface erosion and hillslope failure to determine the total risk of sedimentation from a road network in the Coast Range of Oregon. A combination of a topographic index to rate inherent slope stability and road-specific parameters to assess the stability of individual road segments will be investigated to determine the utility of using such an approach to evaluate the risk of hillslope failure associated with forest roads. Data from the Oregon Department of Forestry 1996 Landslide Survey will be used to compare model performance with actual road-related landslide occurrence.

INTRODUCTION

Forest roads are known to be major contributors to landslides in the western United States (Rosenfeld, 1999). However, our ability to predict road-related landslide occurrence is limited by a number of factors, such as:

- The episodic nature of landslide occurrence means that not all road segments that are potentially unstable will fail during a given storm event.
- Many road-specific variables are highly correlated, making it difficult to get at the true relationship between variables and road-related landslides.
- Few comprehensive datasets exists to create and test the prediction ability of road-related landslide estimation models.

Two classes of factors influence the landslide potential of a road segment: topographic features that determine the inherent stability or instability of a hillslope; and specific road attributes that determine the extent to which the inherent slope stability is aggravated by road construction. This study involves the combination of these two classes of factors to create a preliminary model to predict the occurrence of road-related landslides.

DATA

Two large storms during the months of Feburary and March of 1996 delivered long duration, high intensity rainfall to much of western Oregon. These storms triggered numerous landslides. Oregon State University, in cooperation with the Oregon Department of Forestry, initiated a landslide inventory of eight 2x5 mile study sites (Robison et. al., 1999). Three of these study sites were chosen after aerial reconnaissance detected an unusually high occurrence of landslides. Oregon State University Forest Engineering, under the direction of Dr. Arne Skaugset, inventoried all active roads within six of the eight of the Oregon Department of Forestry study sites. This inventory was designed to record all road-related landslides and factors that may have lead to road failure.

Roads were divided into distinct road segments as defined by drainage points. These drainage points were most often culverts or grade reversals. For each road segment, the following information was collected: length, road width, road prism width, cut slope height, fill slope depth, road grade, road construction method, condition of the road surface, surface material, and ditch condition. Additional information was recorded at some of the road segments, such as culvert diameter and condition. This data was recorded in the field and transferred to an Excel database.

METHODS

Data from two survey areas, Mapleton (Coast Range of Oregon) and Vida (Cascade Range of Oregon) were chosen for analysis. These two datasets combined contained 476 total road segments, 43 of which failed due to a landslide. A logistic regression was preformed using 30 randomly selected road segments that failed and 30 randomly selected road segments that did not fail. Road segments that did not experience a landslide were not stratified. This model was then tested using a bootstrap method (Efron, 1993) that included five sets of data chosen at random. These test data sets each contained 30 failed and 30 non-failed road segments.

RESULTS

The following model was fitted to the selected dataset:

$$RoadFailure = \beta_0 + \beta_1(Slope * CutSlopeHeight) + \beta_2(CutSlopeHeight)^3 + \beta_3(PrismWidth)^2 + \beta_4(RoadSurface)$$

Where:

RoadFailure	0 (<0.5) no failure 1 (>0.5) failure
Slope	Hillslope angle, expressed in percent
CutSlopeHeight	Height of the cut slope in feet
PrismWidth	Width of the road prism in feet, including the cut slope, ditch, travel way, and fill slope
RoadSurface	0 if parent material 1 if other (gravel)

Model statistics are shown in Tables 1 and 2.

Table 1: Model Statistics

R	R^2	Adj. R^2	Std. Error
0.756	0.571	0.540	0.3419

Table 2: Parameter Statistics

	β	t	Sig.
(Constant)	7.625E-2	0.600	0.551
*Slope*CutSlopeHeight*	1.822E-3	7.073	0.000
CutSlopeHeight^3	-1.817E-4	-5.060	0.000
PrismWidth^2	-2.845E-4	-2.809	0.007
RoadSurface	0.257	2.079	0.042

Test of Model

This model was tested on five randomly selected, non-stratified sets of data containing 30 road segments known to have experienced a landslide and 30 that did not. From these results it was deemed appropriate to split the response variable at 0.5 so that a response (model output) less than 0.5 indicated a road segment that was predicted to not fail (have a landslide occur within the road prism) and a response greater than 0.5 indicated a road segment that was predicted to fail.

Table 3 shows the average model performance over these five randomly selected data sets, where a 0 indicates a road segment that did not, or is predicted to not, fail and 1 indicates a road segment that did, or was predicted to, fail.

Table 3: Model Test Results

	Predicted		Percent
Observed	0	1	Correct
0	20	10	66.7%
1	7.2	22.8	76.0%
	Overall Percent Correct		71.3%

The model results were relatively balanced with Type II errors (falsely predicting a road segment will produce a landslide when it does not) approximately equaling Type I errors (predicting a road segment will not produce a landslide when a landslide does occur).

DISCUSSION

Parameters

Slope

This slope variable is similar to the slope value that could be gleaned from a topographic map or a DEM. In this case, the value of slope was collected in the field during the road inventory and the average side slope for the road segment.

It was expected that slope would be a significant variable when comparing a non-stratified sample of road segments that did and did not fail. The majority of landslides in this road network occurred on slopes greater than 50% and averaged 73% (standard deviation 23.9), while road segments that did not experience a landslide were on slopes that averaged 59% (standard deviation 13.7). These two populations are shown graphically in Figure 1. This relationship is expressed with a positive value of β_1.

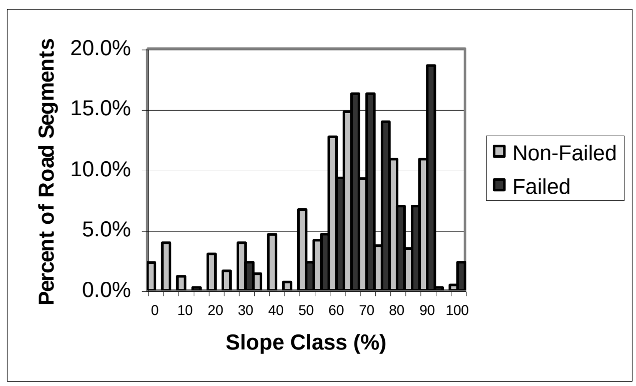

Figure 1: Slope of Failed and Non-Failed Road Segments

Cut Slope Height

While cut slope height is partially correlated to slope, it is also strongly influenced by road construction method. Figure 2 graphically displays the relationship between slope and cut slope height. Some of the older main haul roads in the Mapleton and Vida study areas have high cut slopes despite relatively gentle, stable terrain. This may account for the relationships expressed in the model between slope and cut slope height: the product of slope and cut slope is positively correlated with landsliding and is modified by cut slope raised to the third power (negative coefficient).

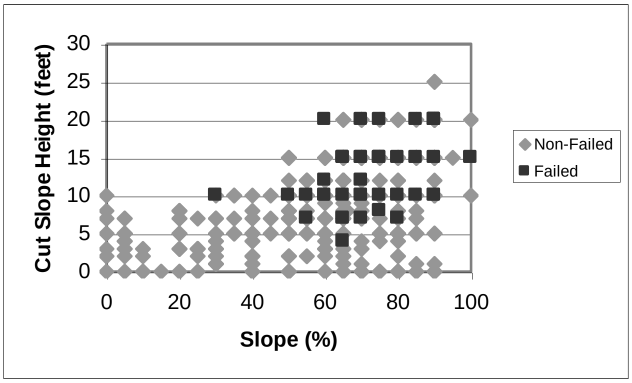

Figure 2: Cut Slope Height as Compared to Slope

Prism Width

Prism width is the combined width of the roadway, ditch, cut slope, and fill slope. The total width of a road segment prism is partly a function of the slope of the hillside the road is traversing and partly a function of the road construction method. Additionally, minus the roadway, prism width is a description of the area oversteepened by road construction and is therefore highly correlated with cut slope height (Figure 3). If slope and road construction method are held constant, a wider road prism means that more land is subjected to oversteepening due to cut and fill slopes. Despite this apparent positive correlation with landslide occurrence, prism width serves alongside cut slope height as another adjustment to the term (slope * cut slope height) in this model.

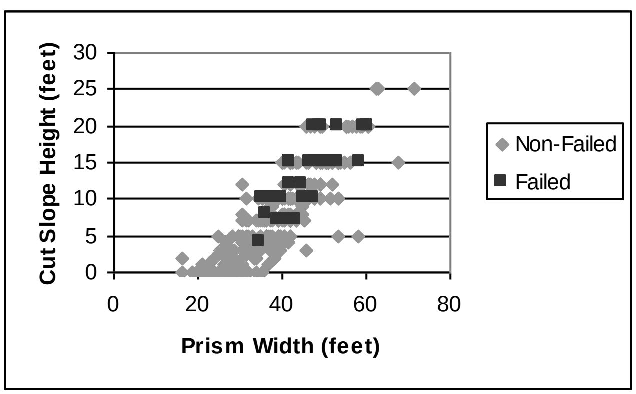

Figure 3: Relationship Between Cut Slope Height and Total Prism Width

Road Surface

Taken alone, road surfacing does not appear to have any direct link to road stability. However, non-surfaced roads in the Mapleton and Vida areas are most likely temporary access roads used only for summer operations. This points towards a lower standard of road construction and lower maintenance levels. Road drainage is more likely to be inadequate and fills may not have been properly compacted. Taken in this light it is reasonable to assume that a road built to a lower standard and maintained less would be more prone to landsliding.

Other Parameters

It is recognized that other parameters such as soil type, up-slope contributing area (drainage area), and slope shape (convex, concave, planar) may also be important predictors in road-related landslides. However, this data was not readily available at the time of this analysis.

Prediction Difficulties

As shown in Figures 1, 2, and 3, many variables collected during a road inventory are highly correlated. Despite this high correlation in a statistical sense, the significance of the individual variables may be quite different when it comes to the mechanisms that cause road-related landslides. This provides some interesting and difficult challenges for analysis. For example, cut slope height is correlated with slope and so may be statistically significant when looking at fill slope failures. However, mechanistically the height of the fill slope has little to do with a failure in the fill slope.

Like the road surfacing variable that was significant in this model, variables may serve as surrogates for mechanisms or processes that may not be readily apparent. Understanding these relationships can help to define the true drivers of road-related landslides. These relationships can then lead to more appropriate road inventory design by collecting only those data that increase a manager's ability to predict where road-related problems are likely to occur.

Slope is obviously a factor in determining where a landslide may occur, but a more interesting question to ask would be the difference between roads on steep slopes that fail and roads on steep slopes that do not fail. Teasing out the answer to this question would greatly improve our ability to manage road networks in steep, mountainous terrain.

CONCLUSION

A preliminary model has been developed that gives reasonable estimates of road-related landslides in western Oregon. The model combines the hillslope-level variable of slope with the road-specific variable of cut slope height, prism width, and road surface material. The model appears to give reasonable estimates of road-related landslides in western Oregon. A better understanding of road-related landslides, their mechanisms and distribution across the landscape, may be gained by stratifying the dataset and by adding additional data that could be gained either through use of a GIS or through additional road inventories.

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Dry Forest Mechanized Fuels Treatment Trials Project

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ABSTRACT - Many studies exist about costs, production, and impacts for sawlog and commercial wood chip market harvest systems, but very little information of this type exists for systems intended to treat primarily non-commercial forest biomass, especially in the dry forests of the Intermountain West. This project was funded by the USDA Forest Service, using National Fire Plan funding, to organize and coordinate realistic fuels treatment trials in four locations in three states, and synthesize and disseminate results to natural resource agency personnel involved with fuels treatment planning decisions, potential local contractors, and other interested groups and organizations. Expected short-term outcomes include: 1) Improved ability of government agencies to plan and budget for future fuels treatment projects; and 2) More informed local contractor business decisions about what equipment to buy or lease. Projected long-term project outcomes include reduced site impacts, increase in acres treated to reduce hazardous fuels, and local job retention and creation. Realistic mechanized fuels treatment trials are planned for winter and late spring of 2002 in two locations in Oregon (Central Oregon February 12-16, 2002 and Blue Mountains June 4-7, 2002), one location in Washington (Okanogan-Wenatchee National Forests February 26- March 1, 2002), and one location in Idaho (Boise National Forest May 28-31, 2002). All locations represent different dry forest management challenges.

INTRODUCTION

The Dry Forest Mechanized Fuels Treatment Trials Project (DFMT) was conceived to:

- Improve the ability to government agencies to treat non-merchantable fuels;
- Provide potential contractors with information on available equipment, costs, and productivity;
- Quantify environmental impacts of various fuel reduction systems; and
- Open up a dialog between agency personnel, potential contractors, and the interested public.

PROJECT DESIGN

The DFMT project is designed as a series of four realistic field trials, one each at the following locations in the inland northwest:

- Sisters, Oregon, Deschutes National Forest, February 12-16, 2002,
- Leavenworth, Washington, Okanogan-Wenatchee National Forests, February 26-March 1, 2002,
- Idaho City, Idaho, Boise National Forest, May 28-31, 2002, and
- John Day, Oregon, Malhuer National Forest, June 4-7, 2002.

Each trial consists of a day to move in equipment, a day to move out equipment, and three working days. Of these three working days, one day is set aside for time and motion study, one for local contractors and other interested citizens, and one for media and elected officials.

The implementation of the DFMT Project is guided by a steering committee comprised of US Forest Service researchers and specialists, representatives from academia, and local site liaisons (Forest Service personnel) and contractor representatives representing each of the four trial locations.

The main focus of the project is on the treatment of fuels that are not non-merchantable. The lack of merchantability is a function of either the specific characteristics of the material being treated and/or insufficient markets. Our contention is that the fuel accumulation problems in the inland northwest are grave enough that a lack of markets is not enough of an excuse to do nothing.

Target Audiences

Several key target audiences have been selected for this project:

- Forest contractors,
- Agency personnel,
- Fiber purchasers and biomass consumers,
- Private forest landowners,
- Elected officials, and

- Interested public.

We have been working through state logging contractors associations (Associated Oregon Loggers, Washington Contract Loggers Association, and the Idaho Contract Loggers Association) to attract potential forest contractors to the demonstrations. These state associations have assisted by providing credit towards professional certification for those contractors that attend.

Forest Service and other agency personnel, both state and federal, have been encouraged to attend trials through many invitations, both agency and private. Of particular interest are personnel from regulatory agencies such as the United States Fish and Wildlife Service and the National Marine Fisheries Service.

Fiber and biomass purchasers have been involved in the planning of each of the four trials as local industry representatives. This has been done primarily to aid in the dialogue concerning the development of local markets for treated material.

The over-accumulation of forest fuels is not a problem encountered solely by public land managers. For this reason, private landowners have also been encouraged to attend the treatment trial demonstrations. Assistance from landowner groups such as the Oregon Small Woodlands Association has helped to inform landowners about the trials as well as to encourage their participation.

Elected officials often have great say in what projects and programs get funded. For this reason, an attempt has been made to encourage the attendance and participation of elected and appointed officials at the local, states, and federal levels to attend the field trials to observe for themselves some of the options for treating overstocked stands with potentially dangerous fuel levels.

Interested public, specifically local environmental groups, have been encouraged to actively participate in the field trials and the discussions that surround the field trials.

A major tool that has been used to inform the target audiences of the goals and specifics of the DFMT project has been the project web page. This page is located at www.theyankeegroup.com/mechfuels.

Systems Demonstrated

A variety of fuel reduction systems are demonstrated at each of the four field trials. These systems range from low initial costs, often labor intensive and low production systems to high initial costs, mechanized, high production systems. Examples of systems demonstrated include: ATV (all-terrain vehicle) with a skidding arch; ASV (all-season vehicle) with various cutting and skidding attachments; numerous mastication systems mounted on excavators, crawler tractors, and other carriers; chippers; CTL (cut-to-length) systems; and conventional systems such as rubber-tired skidders and small yarders. Some of these systems, such as mastication, are designed solely for treating non-merchantable material while others are designed to remove some form of a product from the stand.

Monitoring

While the focus of the DFMT project is to organize and carry out realistic fuels treatment some quantitative data will be taken. This data consists of treatment costs, system production, impacts to soils, and reduction in crown fire potential.

Treatment costs and production estimates will be gathered in order to provide potential contractors and agency personnel with realistic estimates of treatment costs and potential production rates so as to aid in decision making. Costs and production rates will be estimated using one day of time and motion study per trial combined with contractor estimates to produce a range of expected costs and production rates. The expected outcomes are estimates of \$/acre, \$/ton, and acres/day.

Impacts to soil resources are of major concern to private landowners and government land managers. A protocol originally developed by Weyerhaeuser Co. and modified by Steve Howes, U.S. Forest Service, Pacific NW Soils Program Manager, will be used pre- and post-treatment at each of the four sites to estimate ground disturbance resulting from fuel reduction activities. Local soil scientist monitoring and assistance has been solicited at each site.

Reduction in the risk of catastrophic wildfire is of major importance to land managers, landowners, and rural residents, and a key reason for the funding used for this project. Susceptibility to crown fire will be assessed pre- and post-treatment at all four trial sites. Stand inventory data will be entered into the FMAPlus program to obtain estimates of susceptibility to crown fire. The same protocol will be used at all four sites. The results will be presented as the change in susceptibility to crown fire resulting from fuels treatment.

Expected Outcome

Results from the DFMT project have been and will continue to be disseminated through meetings and conferences, the project web page, peer-reviewed journal articles, trade publications, and a final report. All of these outlets are open to the public. Results of the quantitative data collection will be targeted to agency personnel and potential contractors to provide them with easily understandable information concerning alternative systems for fuels reduction, including expected costs, production rates, and potential for environmental disturbance.

CONCLUSION

The Dry Forest Mechanized Fuels Treatment Trials Project consists of a series of four mechanical fuels reduction field trials in three states designed to demonstrate a variety of fuel reduction systems currently available. While the main focus of the project is to show these systems in use, some quantitative data will be collected in order to estimate treatment costs, system production, soil impacts, and the reduction in crown fire potential resulting from fuels treatment activities. A major outcome of these trials is the beginnings of dialogue between agency personnel, local contractors, and local citizens concerning the need to treat fuels on public land.

This project funded by a National Fire Plan grant from the USDA Forest Service, administered by the Central Oregon Intergovernmental Council, Redmond, OR.

PROFILES OF LOGGERS AND LOGGING COMPANIES IN MAINE AND THE SOUTHERN STATES

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ABSTRACT - Despite much literature on logging folklore and history, documenting a statistically defensible description of modern-day loggers and their businesses remains a somewhat elusive task. Surveys were conducted of loggers in northern New England and in the mid-southern and southeastern states to gain a realistic "picture" of logging companies and of the people who work in them. Questionnaires were mailed requesting information on the size of the logging companies, their production levels, log marketing & procurement methods, background of individuals, perceived problems & public perceptions, etc. Results and comparisons are given in this presentation.

INTRODUCTION

Given the recent changes and challenges in the forest products industry, it became desirable to develop systematically gathered, credible, and unbiased information about logging businesses in the US. This information could then used by the logging community and trade associations to help plan policies, legislation, programs and worker training. Periodic reassessments of the logging industry could help in understanding trends in the industry over time. However, baseline information was needed to initiate the process.

In addition, a broad profile of the industry can assist various research projects in evaluating whether a smaller group of logging companies that participate in a study are representative of the industry as a whole. Adjustments can be made to the results of such studies based on key business structural factors (such as contractual relationships) and size distribution of companies. Importantly, information may also be used to identify areas for further research.

Surveys of loggers in Maine and in eight southern states were conducted. Results were used initially to provide a mechanism for validating the results of the Logging Capacity Study sponsored by the Wood Supply Research Institute (Chumbler et al.; Mayo et al. 2002; and Ulmer et al. 2002). This paper will focus on survey results that describe attributes of logging businesses related to production capacity, and offer a rationale for a multiple methods research approach.

THE MAINE LOGGER SURVEY

A survey of loggers who work in the state of Maine was conducted in 2001. A comprehensive list of loggers was developed from three sources: (1) a list of all loggers who were mentioned on logging operation notification forms in 2000; (2) a list of loggers who were Maine residents supplied by the Certified Logging Professionals (CLP) Program; and a list of loggers from neighboring Canadian provinces who worked in Maine, supplied by the CLP Program. Computerized CLP logger lists were provided to the research team in 2001. Both English and French versions of the survey were developed. All loggers on these lists were mailed the 7-page survey (Taggert 2001; Taggert and Egan, in preparation). Multiple mailings (two survey mailings and one reminder postcard) were executed to increase the response rate and mitigate bias due to nonresponse. Follow-up phone calls and several on-site interviews were used to both clarify and add depth to some mail survey responses, as well as to increase response rates. The following results focus on responses to questions relate to unused logging capacity from those loggers who are residents of the State of Maine.

Survey results: Background information. Approximately 700 loggers who work in Maine responded to the survey. Of these, 572 were residents of the State of Maine, and114 were residents of the Province of Quebec. The mail survey response rate for loggers who were residents of the State of Maine was 27%. Phone surveys of 100 nonrespondents increased the response rate to 32 percent The average age of these loggers was 44.8 years (standard deviation = 10.8 years), and the average education was 12.2 years (sd = 2.0 years). On average, respondents had logged for 22.6 years (sd = 10.8 years).

In the year 2000, Maine loggers worked an average of 48.2 hours (sd = 15.6 hours), and 38.5 weeks per year (sd = 10.7 weeks). Their average annual gross income was $217,049, and their annual personal profit from logging was $20,053, although reports of annual personal profits were highly variable (cv = 171%).

When asked whether they expected to be in the logging business in five years, just over half (50.9%) responded "yes," 24% responded "no," and 25% were not sure. When asked to describe their expectations for profitability in 2001, 15% expected better profits, 38% anticipated lower profits, and 47% expected profits to be about the same as they were in 2000.

Unused Logging Capacity Survey Results. Over three-quarters (77%) of logging business owners indicated that they experienced unused capacity. Less than one-quarter (23%) of logging business owners indicated that they did not experience unused capacity in their logging business. Eighty-four percent of loggers from southern Maine and 73% from northern Maine reported idle logging capacity.

Further analyses indicated a significant association between loggers who reported unused capacity and (a) profitability in 2000 (G^2 p-value = 0.05) – 43% of those reporting unused capacity also indicated very poor to poor profitability in 2000, while 46% of these reported average and 11% reported above average profitability; and (b) the behavior of profit margins since they began logging (G^2 p-value = 0.02) – 69% of those reporting unused capacity also indicated decreased profit margins, while 12% reported an increase and 18% said profits remained about the same.

Causes of unused capacity. The most often cited cause of unused logging capacity by Maine logging business owners was weather (n = 168 respondents), followed by road conditions (n = 113), equipment breakdowns (n = 112), and mill imposed quotas (n = 111). Other commonly reported causes included regulations (n = 56), moving equipment to other locations (n = 51), inability to find stumpage (n = 47), and mill closure(s) (n = 46).

When causes of unused logging capacity were evaluated based on both the number of respondents citing each cause and the reported percentage of unused logging capacity attributed to each cause, the following ranking (from highest to lowest) for the top six causes was: weather, mill imposed quotas, road conditions, equipment breakdown, inability to find stumpage, and inability to compete for stumpage. Causes that did not rate highly included (in order of decreasing ranking): regulations, mill closure(s), lack of labor, moving equipment, unproductive labor, poor planning on someone else's part, poor planning on the respondent's part, inefficient unloading or handling of delivered wood (e.g., excessive truck turn around delays), and lack of trucking.

Costs of unused capacity. For those Maine logging business owners who experienced unused logging capacity, the average reported cost of this phenomenon was $40,257 per year (logging contractors = $81,727; independent loggers = $23,669), although this figure was highly variable from one respondent to another.

Of the business-related variables investigated, the amount of capital that loggers had invested in their businesses and the proportion of wood harvested that was cut on stumpage they had bought (arcsine transformed) were positively associated with the costs of unused capacity (r^2 = 0.55). Variables not retained in the model were proportion of trucking that was contracted (arcsine transformed), hours worked per week, and weeks worked by year. Loggers who reported unused capacity had an average capital investment in their businesses of $382,288; those that did not report unused capacity had an average capital investment of $181,170. In addition, loggers who reported unused capacity harvested 33% of their wood on stumpage they had purchased, versus 19% for loggers who did not report idle logging capacity.

When asked to rate a battery of items that they considered as barriers to maintaining or expanding their logging businesses, 65% of logging contractors and 73% of independent loggers rated as "unimportant" the statement "I already have too much logging capacity;" 32% of contractors and 18% of independent loggers rated this as "important;" and 2% of contractors and 9% of independent loggers rated it as "very important." However, when asked to rate the statement "there's too much capacity in my area" as a barrier to maintaining or expanding their logging business, 35% of the contractors and 45% of the independent loggers indicated that this was "unimportant;" 38% of contractors and 23% of independent loggers indicated it was "important;" and 27% of contractors and 31% of independent loggers rated it as "very important."

THE SOUTHERN LOGGER SURVEY

Persons questioned. Mailing lists were obtained of 7404 logging companies in Virginia, North Carolina, South Carolina, Georgia, Florida, Alabama, Louisiana and Texas. Multiple individuals working for the same company were purged down to one individual per company – the owner or boss, if it could be discerned. Questionnaires were sent to 7,115 individuals.

Questionnaire. Questions were asked on the status of preferred suppliers, wood dealer relationships, contract trucking, sources of timber, species hauled, and size of operation. The final question was a subjective question, asking loggers to check off the top three reasons that prevented their crews from working at full production capacity. It should be noted that the survey is based on the most productive crew in each company, for those companies with multiple crews.

Questionnaires were mailed in late December 2001, preceded by announcement post cards and followed by reminder post cards. On February 8, 2002, questionnaires were re-mailed to those companies that did not respond. Of the 2555 respondents (36% response rate), 2217 (87%) were actually in the logging business.

Results of the Southern Logger Survey. The preferred supplier concept is relatively new in terms of common popularity. Fifty-three percent of the survey respondents indicated that they are a preferred supplier to a mill. This number indicates that the preferred supplier system has already become quite commonplace.

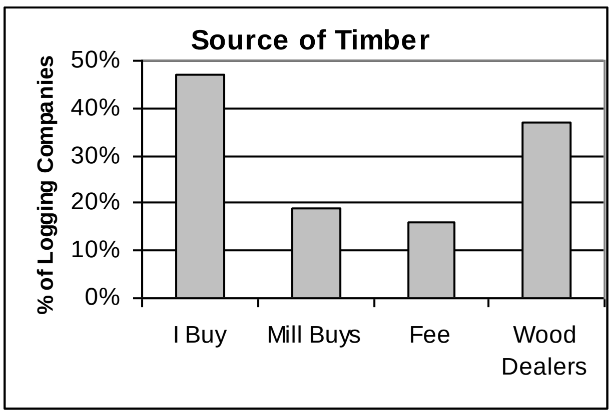

Figure 1. Source of timber for logging companies.

In contrast to the newness of the preferred supplier relationship, the dealership relationship is very traditional. Fifty-one percent (51%) of the respondents reported that they delivered mostly through a wood dealer/supplier. Thirty-one percent reported that they have a wood dealer supply some of their timber (Figure 1). As to further stumpage sources, 47% of respondents purchase a substantial amount of their own timber. By contrast, 33% reported having timber supplied by a mill (either purchased stumpage or fee-simple timber).

Just over one-half (54%) of the companies utilize only company-owned trucks. The other half use exclusively contract trucks (23%) or a mixture (22%).

A high number of log sorts is generally known to slow production somewhat, but it is also an indication of a logger's flexibility to sell to different markets, thereby positively influencing production. Most loggers reported making five or fewer sorts, with many of them reporting three or fewer sorts (Figure 2). Three percent of the respondent companies have at least one chipping crew.

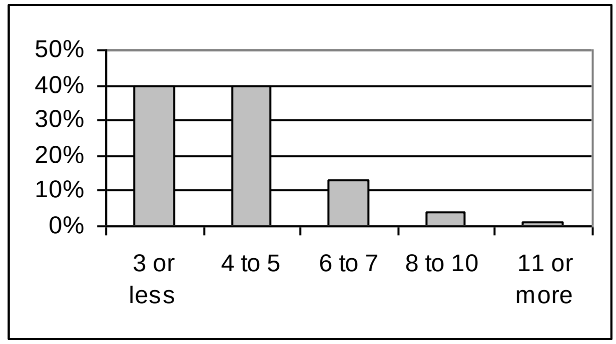

Figure 2. Number of log sorts.

As to type of harvest (clearcut, plantation thinning, and thinning), 76% of the logging companies work clearcuts to a large extent, 52% work thinnings (including diameter-limit, select cuts and house lot cuts), and 27% work plantation thinnings.

Most companies (55%) haul a substantial mixture of pine and hardwood species. Thirty six percent of the respondents haul pine (defined as more than 70% pine), while only 8% haul hardwood (also > 70%).

The logging companies averaged 1.5 crews each. Only 42 companies (2%) reported running six or more crews. The majority reported working more than 226 days per year. Forty respondents (2%) wrote in the comments section that they log part-time; all except one produce 20 or fewer loads per week.

In the design of the survey questionnaire, we failed to anticipate the large number of logging companies that produce low volumes. The median crew produces 29 loads per week, with 35% producing 20 or fewer loads per week (Figure 3). It is not known how many of them work part-time, but that number would be somewhere between 2% and 20% of the logging companies.

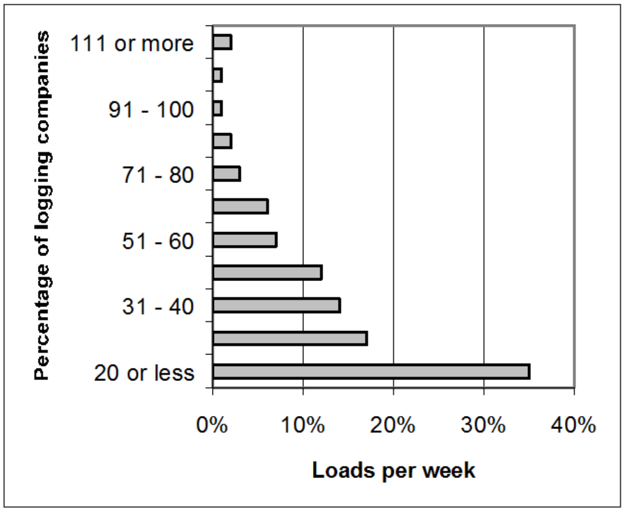

Figure 3. Size of logging companies by production.

As an item of interest, we asked the loggers in the survey to check off the top three reasons that prevent them from working at full capacity (Figure 4). Weather and Quotas were most often cited, followed by Other market factors, Mechanical problems, and Stand & tract issues.

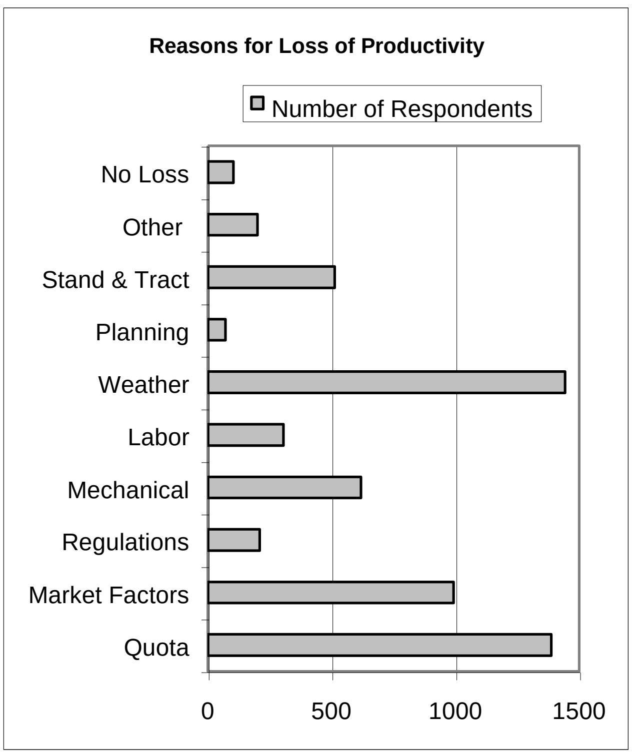

Figure 4. Survey respondents were asked to list the top three reasons that prevent their crews from working at full capacity. The category "No Loss" represents those who reported that their crew always works at full capacity.

Possibly the two most significant findings of the southern logging survey pertain to the preferred supplier status and to the size distribution of companies. The preferred supplier concept, although relatively new to the industry, has gained large popularity, as evidenced by over half of the logging companies reporting a preferred supplier relationship with at least one mill. We expect this trend to continue in the foreseeable future. One of the most surprising findings of the survey was the preponderance of small logging companies in the industry – even smaller than we expected. Thirty-five percent of the companies' most productive crews produce 20 loads or fewer per week. This was by far the largest category.

CONCLUSIONS

The mail surveys of loggers in Maine and the southern US initially provided additional insight into the results of the Logging Capacity Study sponsored by the Wood Supply Research Institute, and provided a mechanism for more broadly describing the phenomenon. This multiple methods approach – combining in-depth weekly reports from a smaller sample of logging businesses with survey and interview methodologies – appeared to both add depth to and broaden the generalizability of the Logging Capacity Study. In addition, it provided baseline information, systematically gathered, that could be used to initiate a study of trends in the logging business over time.

Survey results also offered the opportunity to discover and develop researchable questions related to the logging community. For example, the Maine logger survey found significant differences between Maine resident and cross-border Quebec resident loggers who work in Maine that may be useful in understanding Canadian woods labor – an often contentious issue that is revisited periodically in that state. The southern US logger survey found an unexpected number of logging companies that produced 20 or fewer loads per week. Periodic follow-up surveys will be able to help discern whether there is a trend in logging business size (and other logging-related phenomena) over time.

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Life Cycle Assessment and Environmental Product Declaration of Forestry related Products and Processes - a Way to meet Environmental Objectives.

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ABSTRACT -The demand for quantified and verified information about the environmental performance of products and services constantly increases. A number of environmental tools that can help companies to understand and measure the environmental impacts associated with their products, processes, and activities has emerged e.g. Design for the Environment (DfE), Life Cycle Assessment (LCA) and many more. LCA is a systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the function of a product or service system throughout its life cycle. The aim of the study was to describe the environmental performance of a forwarder crane in a life cycle perspective taking into account the following stages of the crane's life time; (1) raw material acquisition and intermediate processing (2) fabrication of individual components and assembly of the crane, (3) associated transports and (4) use. It was found that a forwarder crane will consume 1050 MWh of energy during its lifetime while at the same time 360 tonnes of CO_2 equivalents (CO_2, CH_4, etc) will be released into to atmosphere. 97% of that amount of energy and 98% of the CO_2 equivalents were due to the use phase. The results were used to prepare an Environmental Product Declaration (EPD) for the forwarder crane. With the help of EPD:s, products that perform the same function can be compared to each other with respect to energy and resource consumption and associated emissions to air, water and soil, tied to system performance and final product produced.

INTRODUCTION

Industrial activity is a major contributor to environmental deterioration. Due to a prevailing pressure from markets and governments, companies and organisations pursue to improve their environmental performance. A number of environmental tools that can help companies to understand and measure the environmental impacts associated with their products, processes, and activities has emerged e.g. Design for the Environment (DfE), Life Cycle Assessment (LCA) and many more. These tools are drawn up differently depending on whether they focus on product and service systems, plants and installations or specific sites. LCA is one of many tools for studies of the environmental dimension in sustainability; it is an analytical and mainly quantitative tool that has a perspective of product rather than site. It is a systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the function of a product or service system throughout its life cycle - with a "cradle to grave" approach, from raw materials acquisition through production, use and disposal. This is done by compiling an inventory of relevant inputs and outputs of a system; evaluating the potential environmental impacts associated with those inputs and outputs; and finally interpreting the results of the inventory and impact phases (ISO 1999). LCA applications include identifying process-related improvement options, eco-labelling of products, and comparison of alternative product systems.

Cranab AB commissioned the Swedish University of Agricultural Sciences (SLU), to carry out an LCA for one of its forwarder cranes. The aim of the commissioners was to acquire a certified environmental product declaration (EPD). The company was the first manufacturer concentrating on forestry cranes to be approved in accordance with the international ISO 14001 environmental standard and is also EMAS registered. The EPD system is an attempt to apply ISO TR 14025 (a normative technical report for provisional use in the field of Type III environmental declarations) in practice. The system is based on LCA, according to ISO 14040 – 14043 standards. The company aimed to use the results from the LCA in product development; that is identify opportunities to improve the environmental performance of the product at various points in its life cycle.

The aim of the study was to describe the environmental performance of a forwarder crane based on a life cycle assessment by taking into account the following stages of the life cycle of the crane; (1) raw material acquisition and intermediate processing (referred to in the tables as raw material) (2) fabrication of individual components and assembly of the crane (refereed to in the tables as fabrication), (3) associated transports (raw material to component manufacturers, components to assembly factory, complete crane to final customer) and (4) use.

MATERIAL AND METHODS

The CRF 8 forwarder crane was examined. The technical life expectancy of the crane was set to 1 200 000 crane cycles and the production capacity of a forwarder with the CRF 8 throughout its lifetime was set to 680 000 m^3

overbark (vob). The reference flow (functional unit) of the study is 1000 m^3 vob at the roadside. All energy and materials consumed as well as emissions to the environment were normalized to the functional unit. The functional unit is crucial as it defines a product's performance and enables comparisons between EPD:s.

The main components of the forwarder crane are the slewing motor, the pillar, the main boom, the outer boom, the grapple, the hydraulic cylinders, the rotator, and the hydraulic hoses (Figure 1). These are either manufactured at Cranab or at suppliers and transported to Cranab (mainly by truck). The material composition of the crane was decided by examining each component. The contribution of the materials to the total mass of the crane was the following (in kg); Steel/iron: 1960, bronze: 1.2, brass: 7, nitrile rubber: 2, Polyethylene (High Density): 3, Ethylene Propylene Diene: 21, polypropylene 5.

Figure 1. The CRF 8 forwarder crane

Environmental data (amount of input materials, energy consumption, solid waste generation and air/water pollutant release) were collected for all life cycle stages of the crane. The system boundaries and data collection sources/methods are shown in Table 1.

Table 1 The system boundary and data collection methods and sources for the forwarder crane LCA

Life cycle stages		*Data collection method/source*
Raw material		Databases consulted: International Iron and Steel Institute, Association of Plastics Manufacturers in Europe, PRe4, Buwal 250
Fabrication	Suppliers	Data provided by suppliers by means of a questionnaire. Emission factors for energy sources as in Athanassiadis et al. (2002)
	In-house	Data was directly measured and/or provided by Cranab. Emission factors as above
Transport		Data provided by suppliers and Cranab. Database consulted: Network for Transport and the Environment
Use		Brunberg et al. 2000, Athanassiadis 2000a & 2000b

The crane contains at least 15% of recycled steel. For that reason, environmental benefit from recycling of the crane was left out of the boundaries of the study. Several, but not all, of the manufacturing processes at the suppliers were taken into account. Use phase modelling included fuel consumption and hydraulic oil consumption (3 l/ 1000 m^3 vob) by the forwarder, fuel consumption for the transport of the forwarder between logging sites and parts replacement requirements (mainly hydraulic hoses) of the crane (25 kg steel and 20 kg Ethylene Propylene Diene/1000 m^3 vob). Forwarder fuel consumption strongly depends on vehicle size, engine power, travel distance, load size, log and bunch size, grapple volume, terrain conditions and operator skill. In the case of the 14 ton forwarder with the CRF 8 fuel consumption was estimated to 9.5 l per hour. 70% of that was judged to be due to the crane.

The emission data were classified into five environmental impact categories such as global warming, eutrophication etc. (Figure 2).

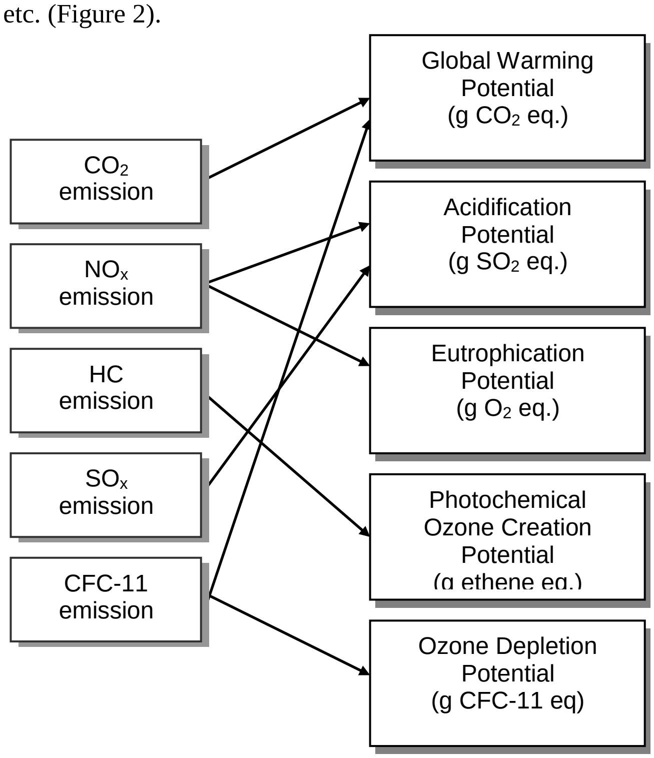

Figure 2. Flow process for calculation of the environmental impact

The impact was quantified with the aid of a category indicator. For the global warming environmental impact the category indicator is the global warming potential (GWP), expressed as CO_2 eq., of each greenhouse gas (e.g. CH_4 equals to 21 CO_2 eq., N_2O equals to 310 CO_2 eq. etc.). The environmental impacts and associated category indicators that were used are those recommended by the Swedish Environmental Management Council (2000). The environmental impacts are shortly described in Table 2.

Table 2. Description of the environmental impacts handled with in the study

Greenhouse effect	The so called greenhouse gases have the capacity to absorb and re-emit heat energy radiated from the surface of the earth thus causing changes in the Earth's climate and weather patterns. Climate change would have profound effects on the Earth's ecosystems, landforms and human society. The potential of gases to absorb and re-radiate heat energy, and thereby intensify the greenhouse effect is expressed in CO_2 equivalents.
Acidification	Acidification is defined as a decline in nature's ability to neutralise acid precipitation, which in turn lowers the pH of lakes and soil. In the terrestrial ecosystem the effects are seen in softwood forests (e.g. spruce) as inefficient growth and as a final consequence dieback of the forest. In the aquatic ecosystem the effects are seen as acid lakes without any wildlife. The acidification potential of substances is expressed in SO_2 equivalents
Eutrophication	Oxygen is consumed by the biological degradation of organic substance that is emitted to the sea and lakes. The decomposition of organic material is an oxygen consuming process leading to decreasing oxygen content of the water. This leads to a deterioration of the water quality and a reduction in the value of the utilisation of the aquatic ecosystem. The acidification potential of substances is expressed in O_2 equivalents.
Photochemical ozone formation	Photochemical ozone formation is caused by degradation of organic compounds in the presence of light and nitrogen oxides. Exposure of plants to ozone may result in plant dieback. Exposure of humans to ozone may result in eye irritation, respiratory whole plant. problems, and chronic damage of the respiratory system. The contribution of organic compounds to ozone formation is expressed in ethene equivalents.
Ozone depletion	Ozone in the upper atmosphere forms a shield that protects the earth from ultraviolet (UV) radiation. A diminished ozone layer allows more radiation to reach the Earth's surface. Increased UV radiation can have harmful effects on human health, plants, and marine ecosystems. The potential of gases to deplete the ozone layer is expressed in CFC-11 equivalents.

RESULTS

About 97% of the total amount of energy needed to manufacture and operate a forwarder crane is consumed at the use phase. During its lifetime the crane will need 1050 MWh in form of diesel fuel (100 tons of diesel oil). At the same time the crane will handle about 680 000 m^3 of wood. In energy terms this amount of wood equals to more than 2 750 000 MWh.

Steel producing was the second more significant stage in the life cycle of the crane. Steel is a central material in the crane comprising 98% of its mass. The process of making steel uses significant amounts of energy (6 kWh/ kg steel produced) and significant amounts of carbon dioxide are released (558 g/kg steel).

Carbon dioxide (CO_2), nitrogen oxides (NOx), sulphur oxides (SOx), hydrocarbons (HC) and particle emissions are some of the main emissions that cause a great impact to the environment and are mostly determined by the amount of energy consumption. The amount of these emissions from the different life cycle stages of the crane are shown in Table 3.

Table 3. Amount(g/1000 m3 vob) of selected emissions for the life cycle stages of the forwarder crane.

Life cycle stages	*CO_2*	*NOx*	*SOx*	*HC*	*Particles*
Raw material	9 500	11	11	0.2	7.5
Fabrication	1150	1.5	2	10	1
Transport	138	1.2	0.1	0.2	0.2
Use	530 000	4 600	200	550	320

The magnitude of environmental impacts in each of the crane's life cycle stages is shown in Table 4. Based on the impact assessment results, the major contributors to environmental problems at each stage were identified.

Table 4 Energy use and environmental impact per 1000 m^3 vob for the life cycle stages of the forwarder crane.

	Energy use and environmental impacts				
Life cycle stages	*kWh*	*g CO_2 eq.*	*g SO_2 eq.*	*g ethene eq.*	*g O_2 eq.*
Raw material	29	9 610	20	0.1	83
	2 %	2 %	0.5 %	0.04 %	0.3 %
Fabrication	17	1200	3	4.5	10
	1 %	0.2 %	0.09 %	2 %	0.03 %
Transport	0.15	140	1	0.1	8
	0.01 %	0.03 %	0.03 %	0.04 %	0.03 %
Use	1517	530 000	3 450	215	28 000
	97 %	97.8 %	99.3 %	97.9 %	99.6 %
TOTAL	1565	540 000	3 474	220	28 100
	100%	100%	100%	100%	100%

Most environmental impacts occur at the use stage owing to the emissions from fuel combustion. The material acquisition and intermediate processing stage follows the use phase in terms of amount of energy consumed and contribution to the global warming impact category. None of the in-house and at suppliers manufacturing stage processes involved a lot of emissions except the painting process where some solvents were emitted affecting the photochemical ozone creation potential of the crane. It is clear that transports cause only a minor part of the emissions (Table 4).

CONCLUSIONS

Using LCA methodology priorities for environmental improvements can be set. In the case of the forwarder crane it is apparent that fuel consumption and emissions to air during the operation phase should be targeted for reduction. This can be achieved by shifting to modern engines that consume less fuel or emit fewer pollutants. By using a low sulphur diesel oil, the SOx emissions and thus the acidification potential of the system can be reduced substantially. At the manufacturing stage solvent emissions could be reduced by substituting solvent borne by water borne paints.

Through an accredited certification body an external review of the study was conducted. It was confirmed that the data and the declaration is in conformance with the requirements for a certified Environmental Product Declaration. The final document, the first to be issued world-wide for a forest machine component, was approved on November 2001 and the EPD certification was issued shortly after the approval.

The use of LCA has expanded among companies and organisations around the world and is more commonly regarded a strategic tool for a rational and preventive environmental work. In general LCA could be used for many purposes e.g.:

• in product development work to identify opportunities to improve the environmental performance of products and services at various points in their life cycle

• in environmental management work as a base for a methodological approach in identifying significant environmental aspects and thereby assisting in setting targets and objectives within the framework of an environmental management system

• in communication and marketing giving a holistic basis for describing the environmental performance of products and services.

ACKNOWLEGMENTS

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Economic and Operational Feasibility of Short Rotation Hardwood Inventory

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Abstract. Procuring wood during the winter months for a pulpmill in the Southeast has some difficulties, especially in hardwood. Soft ground reduces the operational feasibility of many sites, forcing companies to store hardwood in woodyards for retrieval during wet weather. Intensively managed, short rotation hardwood grown on dry sites could economically supply a pulpmill during a wood shortage and thereby eliminate stop-gap measures taken by procurement organizations.
This paper will discuss the pro's and con's associated with short rotation hardwood plantations, along with its potential. A comprehensive study plan is presented that includes using wood cost from three southeastern pulpmills over a three year period. The study will determined whether short rotation hardwood could be economically substituted for purchased wood.

INTRODUCTION

Pulpwood consumption across the South has increased steadily over the past decade as production has relocated from other parts of the country and market demand increased (APA, 2000). The South now accounts for over 70% of the pulpwood consumption of the United States. During this same time, hardwood usage in the pulpmills has also increased as a percentage of raw material furnish, resulting in a 16% increase in hardwood consumption. There are many factors behind this increase. In many localities, hardwood pulpwood may be cheaper than pine pulpwood (TimberMart South, 1999). Depending on the product output from the pulpmill, hardwood furnish may be more desirable for some plants because of paper qualities. Some companies have also developed a niche market for themselves by producing a hardwood pulp that is sold around the world where hardwood furnish may not be readily available.

Concerns for Hardwood Supply in the Southeast

In the South the hardwood resource is generally available at competitive prices, but during specific winter months it may be very difficult to procure, often causing seasonal increases of hardwood prices. This is commonly due to wet ground conditions, which may cause problems with in-woods harvesting and truck transport. While the winter months may not have more rainfall than do the summer months, the reduced evapotranspiration causes soils to remain wetter for longer periods of time. These wetter conditions constrain timber removal since most companies are reluctant to continue harvesting operations when a threat exists to water quality. Also in the winter, rainfall tends to fall slower over a longer period of time, allowing it to soak into the soil (Frederick, 1979). This leads to difficult woods access as roads become saturated and impassable. As a result of the difficult winter season logging conditions, a seasonal increase in hardwood prices often results. This is particularly true since harvesting cost is often the largest component of delivered wood cost.

Additional concerns for hardwood supply arise from local availability. Many paper companies have planted upland sites on company-owned (fee) lands with pine, converting thousands of acres from upland hardwoods to southern pine in search of higher investment returns. This practice has reduced hardwood supply on fee lands over time. Industry owned hardwood can still be found growing on thousands of acres of bottomland sites in many regions of the Southeast, but access and availability may be a problem for many stands due to terrain, soil conditions, a high water table and other environmental concerns.

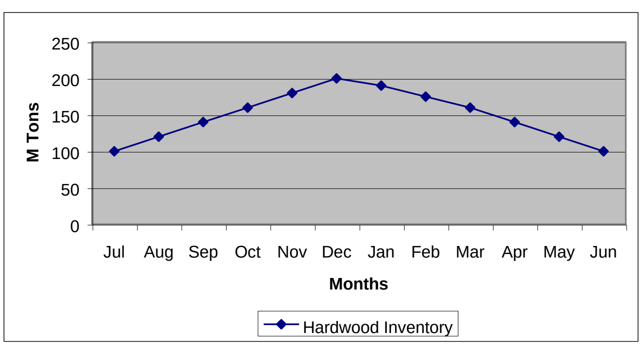
Most of the remaining hardwood stands are owned by private non-industrial landowners. These owners may not be interested in timber production but focus on hunting and aesthetics. Also, timber availability from these sites may be constrained by steep slopes, swamps, limited road access and marginal volume per acre.

While most reports on region wide timber resources conclude that large quantities of hardwood volumes are present, the availability of the resource for future harvest remains uncertain. Recent political issues have further complicated availability. When companies have located chipmills in areas with abundant hardwood resources, environmental organizations often fuel public concerns about overcutting. Foresters view clearcutting of high-graded stands in the mountain regions as being beneficial for regeneration of more desirable species. However, the public is often skeptical about the increase in clearcutting in a region where "selective" harvesting has historically been used. As a result of these environmental and political concerns, locating chipmills in areas with extensive hardwood resources may not be an available solution to the hardwood pulpwood demand in some areas.

The traditional solution to wet weather access problems and other raw material availability fluctuations is to increase pulpmill wood inventories during drier periods. To insure an adequate volume of hardwood furnish during the winter months in the South (and throughout the year), pulpmills typically "inventory" hardwood pulpwood on company or supplier woodyards. Wood is bought and stacked for later retrieval when necessary. Most of this material is inventoried for short periods of time (1-6 months), while some wood is inventoried under water sprinklers for longer periods (6-24 months).

Inventory increases typically begin in the Fall and peak around the first of the year (beginning of winter) (International Woodfiber, 2000), and are utilized during the few months of the year when wood purchases are often reduced by difficult logging conditions (Figure 1). The inventory is then further reduced in the spring to a more operational volume based on daily wood consumption. Pulpwood held in inventory has additional costs associated with it due to the extra unloading and loading, some deterioration while in storage, and the cost of the woodyard where the pulpwood is stored. These additional costs associated with this wood storage are considered "insurance" against the pulpmill running out of wood. During a mild winter, this wood may not be needed but must be consumed because it will deteriorate. The stored wood is then supplied to the mill at an above average cost. Purchasing and storing excess wood inventory is a costly operation for pulp and paper companies, but is the traditional way to ensure a constant supply of wood for the pulpmill during the winter period.

Figure 1. Hardwood inventory levels for a typical



Southern pulpmill peak around the first of the year.

Green Storage

In the Pacific Northwest, wood procurement has become a year round problem primarily due to a massive reduction in the volume of timber harvested from National Forests. In response, some companies have established intensively-managed, short rotation, hardwood plantations to supply their mills with fiber (Kaiser et al, 1994) (Figure 2). These plantations are intensively cultivated, irrigated, and fertilized. With this level of intensive management, it is possible to grow 40 tons of dry hardwood fiber per acre on a planned rotation of 7 years (Withrow-Robinson, 1994). In this region, the high costs involved with intensive plantation management are necessary to assure a raw material supply for pulpmills in the region. In the South, the cheaper cost of hardwood during much of the year makes short rotation hardwood plantations more difficult to justify economically. In an analysis completed for the Southeast in 1998, Bar (1998) estimated current prices for fiber and projected costs for fertigated (fertilizer applied during the irrigation process) hardwood plantations. Those findings predicted that it would be several years before hardwood stumpage prices in the South increase to the level necessary to justify intensive culture plantations as a daily source of fiber.

Research Objectives

The objective of this on-going research project is to determine if strategically located, short rotation, intensively-managed hardwood plantations are economically and operationally feasible in the South as a cost effective alternative to the annual storage of large volumes of hardwood pulpwood inventory. For example, if the procurement organization for a pulpmill has determined that it requires 150,000 tons of hardwood fiber available to carry the mill through the winter months, what savings could occur if alternatively, 120,000 tons were inventoried in conventional storage methods, and 30,000 tons were inventoried on "green hardwood" plantations? During a mild winter, the plantation wood may not be utilized, allowing the trees to grow for another year. Thus, only 110,000 tons would need to be inventoried next year before winter arrives, as the plantations would now make up the other 40,000. The study will examine the biological, operational and economic feasibility of developing and maintaining a "green inventory" short rotation, hardwood plantation as a winter inventory buffer for a southern pulpmill. A model will be developed that can be used by pulp and paper industry firms to determine whether or not a "green inventory" strategy is appropriate for their location.

METHODS AND PROCEDURES

Three pulpmill case studies will be analyzed. This "green inventory" plantation, perhaps 400 to 800 acres for an average size pulpmill (roughly 3 million tons of consumption per year, with at least 50% hardwood), would be strategically located near the mill, on a well-drained site to allow for winter harvesting. A sandy site would be most practical from an operational standpoint, and fertilization and irrigation would likely be required to enhance the site productivity. The costs and yields for a hypothetical hardwood plantation will be determined, with the model output being an estimated price per ton for the short rotation fiber delivered to the pulpmill.

Developing Hardwood Plantation Growth and Yield Estimates for the Model

Growth and yields for poplar species have been studied for many years. Ek and Dawson (1976) looked at *Populus Tristis* grown under intensive culture in Wisconsin. Their findings indicated height growth of 6 – 8 feet and diameter growth of 1 inch per year. A study conducted in the Southeast (Cox and Leach, 2000) yielded height growth of 10 feet and diameter growth of 1.1 inches each year for four-year-old plots of cottonwood. This amounted to just under 1200 cubic feet per acre of volume. Sycamore and sweetgum trials at the same site were not as productive. A recent personal visit to a forest industry site in South Carolina growing eastern cottonwood also supported these findings. Cottonwoods in various age classes were averaging similar growth rates of 10 feet of height and 1 inch of diameter per year.

The U. S. Department of Energy has been investigating hybrid poplar for biomass production for many years. In a recent report (De La Torre Ugarte et.al., 2000) on bioenergy crop production, hybrid poplar yield in the Southeast averaged 4.5 dry tons/acre/year.

While several studies on West Coast short rotation plantation yields provide information on volumes available from these plantations, growth and yields for this study will come from estimates of existing industry trial cottonwood plantation trials in Florida, Missouri and South Carolina. Summary diameter and height estimates will be used determine volume (tons) per acre over various ages.

Determining Hardwood Plantation Silvicultural Costs

To evaluate all the costs for a short rotation plantation in the southern coastal plain region, costs will be estimated for the land purchase, site preparation and planting, and annual management practices such as fertigation and weed control. These estimates will be summarized in a spreadsheet by category on a year-by-year basis so a sensitivity analysis can be done to determine what effect cost fluctuations will have on the final product cost.

Land costs – The value of bare land for plantation establishment can vary greatly across a region. For this study, land costs will be determined from fair market value comparisons of sites in the vicinity of the pulpmills. Local real estate businesses who specialize in farm transactions will be surveyed. In addition, local consulting foresters will also be asked to verify the values. As mentioned earlier, dry sandy sites with good road access will be required.

Initial irrigation costs – there are several companies in the Southeast region who provide design and installation of irrigation systems for farm use. At least three companies will be asked to supply the estimated cost for a complete drip irrigation system and their expectations of annual costs. The costs from the three suppliers will be averaged for input to the model. Following standard accounting procedures, the costs for the installation of the drip irrigation system along with the land costs will be capitalized and spread over 15 years (the equivalent of two rotations).

Site preparation costs – *Forest Landowner* magazine publishes a survey every other year summarizing various site preparation costs for the southern region. The most recent survey was published in March of 2001 (Dubois et. al., 2001). These estimates will be verified with local land and timber personnel for each pulpmill site to ensure they are representative of the area.

Planting costs – Private and state nurseries in the southern region who offer cottonwood cuttings for plantation establishment will be surveyed to determine the cost of cuttings. Hand planting will be the method for establishment because the cuttings must be placed correctly at the drip tube openings. Cost of hand planting will be obtained from industry sources.

Annual maintenance costs – the cost of weed control and operating the irrigation system to supply water, fertilizer and insecticides will be estimated for each year. Weed control costs will decrease each year as the tree crowns develop and begin to shade out the forest floor thus preventing most weed germination. Costs for a backpack spray application completed by contractors will be estimated for years one and two. Fertilizer needs will increase each year as the trees require more nutrients for maximum growth. Insecticides are required on an "as needed" basis, so an application each year will likely be included. Both fertilizer and insecticide can be applied through the irrigation system, so sample chemical companies will be asked for material cost estimates.

Supervision – While most costs will be calculated on a contract basis, it will likely take one or two full time employees to maintain the plantations, and this labor cost will be included in the model. Interviews with companies conducting these operations verify that two people are typically required because of the necessary constant monitoring of the irrigation system, as well as the periodic sampling for insect presence.

Developing the Economic Feasibility Model

The economic feasibility of short rotation hardwood "green inventory" plantations for certain Southeastern pulpmills will be analyzed in two ways:

- as a direct cost comparison to other wood deliveries
- in wood cost savings by keeping "green" inventory instead of roundwood inventory on woodyards.

For a direct comparison with other wood deliveries, a model will be developed to summarize all the costs for a short rotation hardwood plantation, and combined with yield, a price per ton for wood delivered to the pulpmill from this source will be calculated for each year. Harvesting costs for two potential systems, (1) a roundwood system and (2) an in-woods chipping system, will be included to determine a delivered price of the fiber to the pulpmill. Historical wood cost data from three cooperating pulpmills will be collected for a three-year period. This data will include the most expensive source for hardwood pulpwood and chips purchased by the mill each month. These maximum cost wood sources will then be compared to the estimated hardwood plantation delivered price. This comparison should indicate whether short rotation plantations are economically feasible for the sample pulpmills on a direct wood cost basis.

A second analysis will examine the effect of carrying green hardwood plantations as an alternative to roundwood inventory on woodyards as a strategy to supply the pulpmill over the course of the year. For those years when the delivered cost of fiber from the green inventory plantations are higher than the firm's highest actual wood costs, an assumption will be made that the hardwood plantations are not harvested. The remaining volume will then be used to "replace" wood that would likely have been purchased and inventoried on company wetyards. Theoretically, savings should accrue since the company will buy less wood to be stored on woodyards (a more expensive option) and replace it with wood purchased directly from the woods to the pulpmill. If less wood is purchased during the inventory building phase on a given year, savings should occur in total wood cost. The additional volume in "green inventory" hardwood plantations would only be harvested when the procurement manager for each pulpmill determines inventory levels at the pulpmill have reached a critical stage. If a dry winter occurs, and the pulpmill wood inventories do not drop below acceptable levels, the hardwood plantation will be left standing to grow another year. Then, the following winter, a reduced volume of wood will need to be purchased for storage on company woodyards. Assuming this occurs over a period of several years, a substantial reduction in total, overall wood cost may be achieved.

CONCLUSION

This paper has discussed the pro's and con's of green plantation storage versus traditional woodyard storage of hardwood in the South. A detailed study plan has been presented and will be carried out at Virginia Tech.

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A Case Study on Cable Yarding for a Stream Habitat Treatment and the Utility of a 'Roadside' Log Sale

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ABSTRACT - During September and October of 2001, a USDA Forest Service stewardship contracting pilot project took place at Burns Creek in the Clinch Valley Ranger District of Virginia. Stream habitat improvement was achieved through the placement of limestone in the headwaters. A two ton capacity bucket attached to the mainline of the yarder placed 6.21 tons of lime per productive machine hour into the creek at a cost of $53/ton. Instead of a typical stumpage sale, timber was merchandized by the Forest Service and stored on the landing for a roadside log sale. Benefits and opportunities for a roadside log sale were identified. Upon the completion of the log sale, the consensus from the consumers was that the true value of the timber was realized.

INTRODUCTION

Changing political and public concerns require new methods of managing forestlands. The Forest Service, which manages its' land for multiple objectives, is investigating ways to harvest or manage public timber stands in order to meet multi-criteria demands.

Suggestions have been made for changing Forest Service policy to address timber program issues (Liggett et al. 1995). One recommendation involves revising the Forest Service's production processes towards European systems to sell cut logs instead of standing timber, or, conversely to allow private contractors to perform more timber sale and harvest activities. Unlike private enterprise, the Forest Service has limited authority to set their own budgets or to reorganize operations (Liggett et al. 1995).

The Burns Creek pilot project incorporated multiple land stewardship goals within an integrated contract. Contract logging, road construction and stream habitat improvement were combined into one contract (USDA Forest Service, 2001). Public Law 105-277, Section 347 allowed for the authorization of the goods for services trade-off (the logging/restoration contractor exchanged a part of his services) in Burns Creek that could not have been treated otherwise.

The evaluation of the contract logging stewardship pilot project was done through a comprehensive productivity study that was carried out on the manual falling, skidding and yarder extraction operations. The productivity functions and costs are presented in Haynes and Visser (2002).

The two main objectives of this case study were:

- To determine an average productivity and cost of the lime placement operation.
- To identify the benefits and opportunities for roadside log sales.

Harvesting and Extraction Operation

Johnny Hillman Logging Company began harvesting three units located in the Burns Creek headwaters at the beginning of September 2001. The use of a cable-yarder to extract timber and deposit lime was prescribed to avoid access road construction. The main economic benefits for using this system is that it enabled harvesting without the initial estimated $17,000 investment in road construction (Haynes and Visser, 2002) and subsequent road maintenance expenses. The environmental impact for this operation was minimized because roads (major sources of erosion) were not introduced into this steep terrain area.

Standing trees on 32 acres were felled and skidded to one of three swing landings (Figure 1). The topped and partially delimbed stems were yarded with a Thunderbird TMY45 across the valley through a yarding corridor to a full service landing. All three yarding corridors were downhill and required a haulback line to be rigged. The lime placement operation was used on the unit 3 setting.

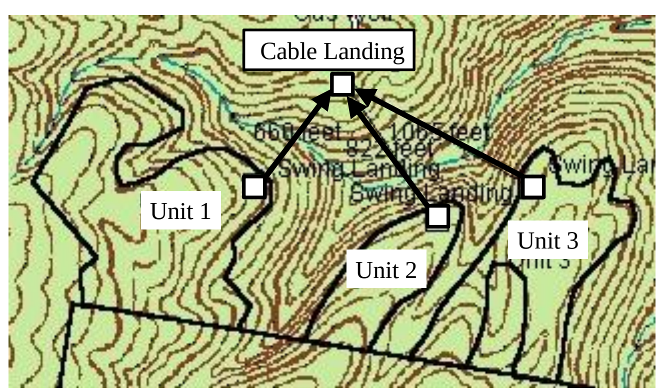

Figure 1: A topographic representation of the three harvesting units. The location of the swing landings are shown above.

The stems were merchandized at the full service cable landing by the contractor using a CAT 320B shovel excavator with a Hultdins 32 inch grapple saw. Two Forest Service personnel used a market driven saw log decision matrix (Haynes and Visser, 2001) to merchandize and mark the timber for bucking at this landing (Figure 2).

Figure 2: Forest Service personnel marking the merchandized logs at the main cable landing.

Daily tally sheets were kept with information on the species, log dimensions and product grade. At the end of each day the log ends were painted with a wax log seal to prevent decay. Five saw log grades were used to separate the log piles. These were (based on the log-making decision matrix the Forest Service had designed using consuming mill input),

1. pure Red Oak logs;
2. pure White Oak and Chestnut Oak logs;
3. Red Oak, White Oak, Chestnut Oak Yellow Poplar, Cucumber and other hardwood logs;
4. Yellow Poplar and Cucumber peeler logs;
5. Red Oak, White Oak and other hardwood tie logs.

Due to the nature of the operation and the sale mechanism that was employed, the landing had to be made substantially larger to facilitate the storage of the respective log piles.

The landing also had to accommodate the pulpwood trucks that were loaded twice a day on average throughout the duration of the operation. Trading goods for services was authorized for this project through the stewardship pilot process. The small roundwood (pulpwood) was removed and sold by the contract logger, Johnny Hillman Logging This removal of pulpwood inventory from the landing allowed for less overall storage space. The cost of the landing was estimated at $1,400 (Haynes and Visser, 2002).

PART I: Stream Habitat Treatment

As a part of the Forest Service's multiple-use objective, the Forest Service was concerned with the proper maintenance of fish habitat within and downstream of this harvest operation. This area of southwestern Virginia has naturally acidic water systems. To improve the water quality for fish habitat, the Forest Service prescribed the addition of lime to the headwaters of the Burns Creek watershed.

A two-ton capacity concrete bucket was attached to the carriage. The lime was placed in front of the yarder tower with a dump truck. A backhoe was then used to load the bucket (Figure 3). The opportunity to use the selected harvesting system (cable-yarder) to transport the lime was initiated, because the Forest Service was also planning a silvicultural prescription for the same tract of land. The reason for this was two-fold: no extra costs for the helicopter placement of the lime and no change in the set up of the yarder, except for the addition of a bucket to the end of the mainline.

Figure 3: Tractor-mounted backhoe loading the bucket with lime.

Stream Habitat Treatment Study Methodology

A basic elemental time study of the lime placement yarding operation was carried out using Husky FG/GS handheld computers running Siwork3 software (Table 1).

Total cycle time and total turn volume was combined to calculate delay-free productivity. The volume per cycle was determined by the amount of lime initially placed in front of the yarder tower. All cycles had full bucket loads, so it was assumed each load had the same weight.

Table 1: Description of the individual physical parameters and time elements used in the lime operation.

Type	Name	Desription	Unit
Dependant-Variables	cycle	- total cycle time for one turn. Productive Machine Hours	min.
	loadwt	- total payload for a single yarder cycle	tons
	$Prod_{lime}$	- (loadvol/cycle)*60	tons/PMH
Co-variables	Distance	- yarding distance	ft.
	Avgwt	- average weight of the loaded lime	tons
Times	load bucket	- the time taken to load the bucket with the backhoe	0.01 min.
	outhaul loaded	- the time taken to haul the bucket to Burns' Creek	0.01 min.
	unload bucket	- the time required to lower the bucket and place the lime in the creek	0.01 min.
	inhaul empty	- the time taken to haul the bucket from the placement zone	0.01 min.
	delay	- unproductive machine hours	0.01 min.

Stream Habitat Treatment Results

A total of 11 cycles were captured. The average productivity measured for the lime placement study was 6.21 tons per productive machine hour. The operational delay time accounted for 6 percent of the total time.

As the 21 tons of lime became depleted over time, the bucket loading time increased notably (Figure 4). The average loading time per cycle was 5 minutes 41 seconds compared to the final loading time of 11 minutes 13 seconds.

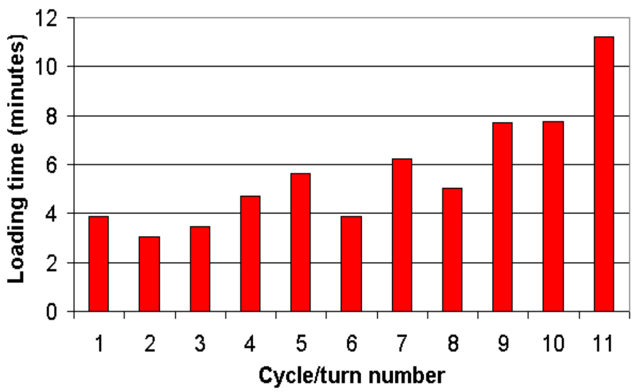

Figure 4: The amount of time equired to load the bucket per cycle with the tractor-mounted backhoe.

During this part of the study, the yarder had a mechanical availability of 94 percent. This results in a cost of $33.83 per ton of lime placed in the stream. This costing excludes all yarder set-up times and mechanical, operational and social delays. Typical availability is 60%, in which case the cost is approximately $53 per ton. The cost of the lime, tractor mounted backhoe and the bucket was not included in the costing exercise (Table 2).

Figure 5: Two chokermen line up the bucket before opening the faucet in order to place the lime.

Discussion on Stream Habitat Treatment

The logging/restoration contractor was only remunerated on the volume of timber harvested from the three units. The added responsibility of the lime placement operation was facilitated through the authority of exchange of goods for services (Public Law 105-277; H.R. 4328; Section 347), where the contractor exchanged the lime placement services for the pulpwood logged on the project (USDA Forest Service, 2001).

Through this legal mechanism, the Forest Service was able to lime Burns creek and treat the timber stands in one operation. The use of a integrated contract allowed for a more efficient and timely stewardship treatment to the project area.

Table 2: Productivity and cost for the lime placement yarding operation.

	Cost/hr ($)				Ave. vol. (tons)	Ave. dist. (ft.)	Ave. time (min)	Productivity (tons/hr.)	Cost ($/ton)
	Fixed	Running	labor	Total					
Lime yarding[1]	68.62	47.9	80.98	197.49	1.91	630	18.78	3.73	52.99
Lime yarding[2]	68.62	47.9	80.98	197.49	1.91	630	18.78	5.84	33.83

* Purchase price for the yarder was $590 000 and an expected life of 10 years was assumed, labor costs included 1 yarder engineer and 2 chokermen.
[1]Assumes 60% availability and utilization.
[2]Assumes 94% availability and utilization as realized in the actual study.

PART II: Comparison of Traditional Sale Methods

For the Burns Creek timber sale, the Forest Service decided to sell the high grade bucked logs at the full service yarder landing to targeted markets, as opposed to selling stumpage.

A 'stumpage sale', common in the southeastern United States forestry industry, involves trees that are sold standing. The forest owner finds an end-user for the logs and then contracts the trees to be cut and transported. In most instances the end-user bids on a tract of standing timber and then sub-contracts the harvesting of the standing timber. The end-user has final say to how and where the standing timber is utilized. A 'hot deck' system at the landing is primarily used; the timber is extracted and merchandized just before it is hauled to a mill.

In a roadside 'log sale' the landowner takes over the responsibility of contracting the services of the harvesting crew. The landowner, represented by the Forest Service in this project, decides how the standing timber is merchandised, under the premise that they can maximize the value of the timber being harvested by making many products available to a varied market. A 'cold deck' system is used where the logs are stored until the harvesting is completed. They are then put on sale to the end-user, who bids on this value-added product. This system allows the landowner to fully maximize the value of the timber.

The 'log sale' approach as mentioned by Liggett et al (1995) is designed to achieve a 'working environment' where the contractor/logger provides a service that meets the Public Service regulatory needs. Simultaneously, they are ensuring fiscal efficiency is maximized throughout this facet of the operational management process.

For the log buyer and contractor, this system has the following benefits:

- not having to pay a lump sum up front,
- simple haul only,
- close supervision of harvesting is not needed.

Log Sale Study methodology

Telephone interviews were conducted with four Appalachian hardwood lumber companies during the first week of February 2002. Three of the companies were participants in the Burns' Creek log sale and were involved with the sealed-bid sale that took place on January 10, 2002 (Haynes and Visser, 2002). The fourth company had an interest in this sale mechanism and agreed participate in the interview. Comments of each interview were then summarized.

Log Sale Results

Advantages of the log sale as perceived by the consuming mills:

- This type of sale allows the consuming mill to purchase specific products and avoid other products.
- The guesswork involved in estimating volume and quality in a stumpage sale was minimized because the actual quantity and quality of the logs was visible.
- The purchasing mill was able to improve their cash-flow because the throughput-time component of the procurement operation was minimized from the usual three week to two month period to just three days.
- The purchasing mill incurred no logging liabilities; the logging responsibility is placed solely on the landowner and contractor.
- There were no supervision overhead costs incurred by the purchasing mill for the harvesting and merchandising operation.
- Consuming mills viewed the sales as an opportunity to improve inventory levels in a short amount of time. This is dependant on the current status of the timber purchasing and lumber markets at the time of the sale.

Disadvantages of the log sale, as perceived by the consuming mills:

- The consuming mills perceived less flexibility in the ability to customize the merchandizing process to their needs.
- Some high-grade logs were not merchandized to quality requirements and some errors were made in bucking the logs to maximize value. The consuming mills felt they had lost an opportunity in this primary raw material market.
- The consuming mills would have preferred longer saw logs so they could capture the high-end log markets.
- On this specific sale the logs sat for too long (October 2001 to January 2002). High temperatures during this period caused sap staining of the high-grade red oak and white oak logs.
- Logs at the bottom of the pile were difficult to quantify at the time of the sale, this also compounded by 14 inches of snow covering the log piles on the day of the sale.
- The time differential between the design and implementation of the merchandizing decision matrix needs to be shortened. By the time of the log sale, the market, for which the decision matrix was designed, had changed, causing the consuming mills to lose opportunity that the current market presented.

Discussion on the Log Sale

The log sale was well received by the industry as an alternative to the stumpage sale. The need for comprehensive planning and execution will be critical, especially if this type of sale is to be implemented by private landowners. From the perspective of the Forest Service this type of sale does provide an alternative means for them to market timber. For example, this specific Burns Creek Sale had been presented as a stumpage sale on two separate occasions that attracted no buyers. The log sale allows the Forest Service to treat areas that it could not with traditional methods.

Log sales are dependent on the site and quality of standing timber. The need for a large landing to display the log inventory over long periods of time is paramount to the successful execution of the sale. The sale of high quality logs can be maximized from this type of sale. There is also an opportunity to auction superior logs on an individual basis and should be pursued.

According to the consuming mills interviewed, the sale was a success and the true value of the timber was realized.

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The Effectiveness and Efficacy of the Alabama Professional Logging Manager Course

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ABSTRACT-The purpose of this project is to determine the impact of logger training on professional loggers. Data were collected using a mailed survey instrument constructed according to the Total Design Method (Dillman 2000). Five hundred survey instruments were mailed to Alabama's loggers who have completed the Professional Logging Manager (PLM) training with 34% (171) responding. Mailed surveys were used to allow the respondents to carefully and accurately contemplate their answers. First aid/CPR and logger safety received the highest marks in useful information taught as well as the amount of information that should be taught. The lowest scoring section in these categories was harvesting systems. Sixty-seven percent of loggers responding believed that field exercises increased their understanding of material presented and 71% indicated that field exercises increased their enjoyment of those sections. The Chi square test for independence was used to determine there were no significant relationships between the change in behavior of loggers after attending the PLM and specific personal characteristics. A general linear model was used to determine that no significant variable existed in determining a change in behavior given certain logger characteristics.

INTRODUCTION

The Alabama Professional Logging Manager (PLM) course was initiated to assist loggers in becoming safer operators, achieving higher productivity, becoming more profitable, and to aid them in understanding basic biological and environmental principles.

Initially the PLM program was voluntary for Alabama's loggers. However, many large corporations have mandated that their wood suppliers become PLM certified (Oates 2002). The survey results in this project support this statement with 80% of participants responding they were required to attend PLM by a company they delivered to or by their employer.

This purpose of this project is to determine the impact of logger training on professional loggers. The data gathered in this project can be used to market the Alabama Professional Logging Manager (PLM) course and similar courses to prospective participants by showing them the positive impacts of the course and to improve these courses by strengthening the areas where negative responses are found.

Requirements of the Alabama logger education program

The logger education program in Alabama requires the completion of a series of five course modules (30 hours) in order to become certified. These courses consist of logger safety training, first aid, harvesting systems, forest management and silviculture, and logging business management.

As described in the Alabama PLM directory (2000), the specific requirements in each module include:

Logger Safety Training - Presentation of general logging safety precepts that are applicable to all logging workers, and training on specific job task safety principles for workers according to their particular job in the woods.

First Aid for Loggers - Loggers learn basic lifesaving techniques, with special emphasis given to those injuries that occur in the woods. Completion of this program satisfies the Occupational Safety and Health Administration (OSHA) first aid requirement and provides the participant with basic first aid and CPR certification.

Harvesting Systems - A comprehensive overview of economical and environmentally sound harvesting techniques. Various types of timber harvesting systems are discussed as well as harvest planning and analysis.

Forest Management and Silviculture - An overview of modern forest management concepts and how these concepts affect the performance of the logger. Forest biology, silvicultural prescriptions, management plans, the environmental concerns of Best Management Practices

(BMPs), the Sustainable Forestry Initiative™ (SFI™), endangered species and biodiversity are presented.

Logging Business Management - Business skills such as understanding laws affecting logging contractors, basic accounting and bookkeeping, cost analysis, record keeping and decision-making are addressed.

METHODS

Given the various approaches to program evaluation there can be many data collection methods. These methods can be tailored for different types of data collection, quantitative or qualitative, or be tailored to various backgrounds of individuals, harvesting professionals or loggers. A common method of data collection is the survey. Goodwin (1995) defined a survey as a structured set of questions or statements given to a group of people in order to measure their attitudes, beliefs, values, or tendencies to act. Surveys may be mailed (surface or electronic), completed on-site, or administered through interviews, conducted either face-to-face, by telephone or electronically (Taylor-Powell and Steele 1996). Rennekamp, Warner, and Maurer (1997) listed a number of advantages and disadvantages of this type of research such as:

- Surveys can be efficient for the volume of information collected but can become expensive as postage costs increase,
- Without good follow-up management, survey response can be low and can take weeks to receive responses, and
- People are also more likely to provide frank and thoughtful answers to mail surveys when they have time to contemplate their answers.

Surface mail surveys were used to collect information in this project to take advantage of an allowance of time for the respondent to appropriately contemplate their answer. The survey and cover letters for this project were constructed using the format suggested in the Total Design Method (Dillman 2000). This method utilizes five key elements for achieving high response rates that includes:

1. A respondent friendly questionnaire,
2. Four contacts by first class mail with an additional special contact,
3. Return envelopes with first class stamps,
4. Personalization of correspondence, and finally
5. Token prepaid financial incentives.

Pretesting, an important element for accurate survey responses and a high response rate, was also utilized in this project. Pretesting can help eliminate ambiguous questions not understood by the respondent and help structure questions so there will be not predisposition by the respondent to not answer any questions. The survey instrument for this project was pretested by the current members of the Alabama Loggers Council and peers of the investigator who are knowledgeable of both the Alabama PLM course as well as survey methods.

Evaluation information sources

Evaluation information can come from a variety of sources. Three sources of this information are:

1. Existing information,
2. People, and
3. Pictorial records and observations (Taylor-Powell and Steele 1996).

The most common source of evaluation information is people. People can provide information about the need for a program, its implementation, and outcomes. Ways that people can provide this information are by actions, volunteering comments and testimony, by taking knowledge and skills tests, and by responding to questions (Taylor-Powell and Steele 1996). Alabama’s loggers who have completed the requirements for initial logger certification were the subjects used for data collection during this project. Utilizing the survey method of research allowed the investigators to gather the candid opinions of Alabama’s loggers toward the PLM program, whether or not the program changed the way loggers in Alabama conduct their day to day operations, and the personal characteristics such as age and capital investment of Alabama’s loggers. Soliciting these attitudes and opinions with the survey, and analyzing these responses will provide the basis of evaluating the effectiveness and efficacy of the Alabama PLM program.

Statistical analysis

The survey results were analyzed using descriptive statistics. These simple statistics will give the investigators the mean response for each question and the percentage and number of respondents who marked a particular score on each question.

The data were also analyzed using the Chi square test for independence. This statistical test is the most common procedure used for nominal data and will test for relationships between personal characteristics and a particular safety and BMP behavior. The Chi square test for independence utilizes contingency tables to inquire what cell frequencies would be expected if the two variables being tested were independent of each other in the population. Chi square may then be used to compare the calculated cell frequencies with those under the hypothesis of independence. If the discrepancy between those are small, Chi square will be small, suggesting the two variables are independent (Minium 1978). For analysis purposes, various response categories with a low number of observed counts were combined with adjacent categories to reduce

Respondent Behavior Change
Change in use of chainsaw chaps Category 0-no change; Categories 1 and 2-merged; Categories 3 and 4-merged; Category 5-deleted
Change in use of hardhats Category 0-no change; Categories 1 and 2-merged; Categories 3 and 4-merged; Category 5-deleted
Change in use of safety boots Category 0-no change; Categories 1 and 2-merged; Categories 3 and 4-merged; Category 5-deleted
Change in use of BMPs with respect to SMZs Category 0-no change; Categories 1 and 2-merged; Categories 3 and 4-merged; Category 5-deleted
Change in use of BMPs with respect to stream crossings Category 0-no change; Categories 1 and 2-merged; Categories 3 and 4-merged; Category 5-deleted
Change in use of BMPs with respect to road construction Category 0-no change; Categories 1 and 2-merged; Categories 3 and 4-merged; Category 5-deleted
Respondent Personal Characteristics
Respondent age Categories 1 and 2-merged; Categories 3 and 4-merged
Logging Experience Categories 1 and 2-merged; Categories 3 through 5-no change
Respondent Education Categories 1 and 2-merged; Category 3-no change; Categories 4 and 5-merged
Logging Production Categories 1 and 2-merged; Categories 3 and 4-merged; Category 5-no change

the number of 0 observed cells in the Chi square contingency tables (Table 1).

Table 1. Category responses merged for Chi square test for independence.

Note: Table 2 defines each category above as presented in the survey instrument.

Table 2. Response categories as presented in the survey instrument.

Respondent Behavior Change
Change in use of chainsaw chaps Category 0-No change; Categories 1 & 2-Small behavior change; Categories 3 & 4-Large behavior change; Category 5- Not applicable
Change in use of hardhats Category 0-No change; Categories 1 & 2-Small behavior change; Categories 3 & 4-Large behavior change; Category 5- Not applicable
Change in use of safety boots Category 0-No change; Categories 1 & 2-Small behavior change; Categories 3 & 4-Large behavior change; Category 5- Not applicable
Change in use of BMPs with respect to SMZs Category 0-No change; Categories 1 & 2-Small behavior change; Categories 3 & 4-Large behavior change; Category 5- Not applicable

Table 2. Continued

Change in use of BMPs with respect to stream crossings Category 0-No change; Categories 1 & 2-Small behavior change; Categories 3 & 4-Large behavior change; Category 5- Not applicable
Change in use of BMPs with respect to road construction Category 0-No change; Categories 1 & 2-Small behavior change; Categories 3 & 4-Large behavior change; Category 5- Not applicable
Respondent Personal Characteristics
Respondent age: 1. Less than 30 years 2. 30-50 years 3. 51-65 years 4. More than 65 years
Logging Experience: 1. Less than 5 years 2. 5-10 years 3. 11-15 years 4. 16-20 years 5. More than 20 years
Respondent Education: 1. No high school 2. Some high school 3. High school graduate/GED 4. Some college/2 year graduate 5. College graduate
Logging Production: 1. Less than 2 loads 2. 3-5 loads 3. 6-8 loads 4. 9-11 loads 5. More than 11 loads
The amount of useful information presented in each segment of and the amount of information that should be taught in each segment of the PLM course.
Response 0-No amount of information; Response 1, 2, and 3-Increasing amount of information; Response 4-Large amount of information

RESULTS

Survey response

Five hundred of the 2,300 loggers who have completed the PLM course were sampled. One hundred seventy one of the 500 loggers surveyed responded which resulted in a 34% response rate for the survey.

Descriptive statistics

Logger safety and first aid/CPR received high marks in the amount of useful information taught and the amount of training loggers believed should be offered. Logger safety ranked the highest of all sections in the amount of training Alabama loggers thought should be offered. Sixty-one percent of those surveyed indicated that a large amount of useful information was presented in first aid/CPR section and 49% marked logging safety as having a large amount of useful information presented. The lowest ranking section in the amount of useful information taught was harvesting systems with an average score of 2.70 out of a possible 4.0. Unlike previous logger education studies, business management ranked higher in the amount of training that should be offered than did the harvesting systems or forest management and silviculture sections. When asked to rate the amount of useful information taught in the entire PLM course, loggers indicated an average score of 3.13 out of a possible 4.00. The loggers marked an average score of 2.93 out of 4.00 in reference to the amount of training they thought should be offered in the entire PLM course.

Also sought by this study, were general opinions loggers felt towards the Alabama PLM course. Opinions were somewhat divided on the statement "PLM is too time consuming". Forty percent of the respondents disagreed or strongly disagreed that PLM was too time consuming while 27% of Alabama's loggers agreed or strongly agreed that PLM was too time consuming. Respondents were also divided on the question "is PLM too costly to attend". Costs associated with this question included all those costs incurred by the logger in order to attend training. These costs may include lost production associated with a loss of manpower on the job, wages paid to employees who attend training, and the monetary registration cost of the program. Forty-two percent felt that PLM was not too costly to some degree awhile 32% felt that PLM was in fact too costly to attend.

Field exercises were well received in the opinions of PLM certified loggers. Sixty-seven percent of loggers responding felt that field exercises increased their level of understanding of the material taught. Almost three-fourths (71%) of loggers surveyed indicated that field exercises increased their enjoyment of those sections.

Sixty-nine percent indicated that weekend courses should be offered and sixty-three percent responding felt that night PLM courses should be offered. This could be due to the logger's interest in keeping production at the highest levels possible. Fifty-four percent of loggers agreed that the PLM courses are held in convenient locations and that there are adequate numbers of course offerings.

Encouraging signs were found that the PLM course is having a positive effect on the way loggers conduct their day-to-day operations. Survey respondents were asked to indicate how much the PLM training changed the way they did their job. Included in this portion of the survey were aspects of training in both the safety and BMP sections of the PLM course. The data concluded that 29% of the respondents indicated a large change in the use of chainsaw chaps, 31% changed their use habits with respect to hard hats, and 26% reported a large change in the use of safety boots. These facts indicate that the logger safety portion of the PLM course is having the desired effect on Alabama's loggers.

Although encouraging for other reasons, 40% indicated no change in the use of chainsaw chaps, 43% reported no change in hardhat usage, and 44% marked no change in the use of safety boots.
Those loggers who have not changed their safety behavior and do not exhibit low safety incident numbers may resist changes due to reasons stated by Bordas et al (2001). The reasons include:

1. The difficulty managers face in conveying safety information presented in the PLM course to their employees,
2. The difficulty in implementing new safety techniques, and
3. The possibility that safety techniques could have a detrimental effect on production.

These same factors may also offer an explanation for a portion of those loggers who did not change their behaviors with respect to BMPs.

These data and the fact that 89% of those surveyed reported fewer than one workman's compensation claim last year, indicate that the loggers of Alabama are most likely already using the necessary safety equipment. Although these loggers may be using the necessary safety equipment, the PLM course can be seen as a positive reinforcement to continue use of the equipment.

Loggers indicated a higher amount of change in the way they operate their business with respect to BMPs. Fifty-eight percent of respondents indicated they significantly changed the way they operate their business with respect to BMPs concerning streamside management zones. Forty percent of those indicating a significant change indicated a large change, the highest amount of change possible. BMPs concerning stream crossings garnished similar marks with 57% indicating a significant change in their operations with respect to this. Significant change was found in 52% of the survey respondent's road construction methods.

Of the 171 respondents, 42 (25%) legally restructured their logging business as a result of the business management portion of the training and 31% began keeping detailed business records as a result of the training.

Loggers are of the opinion the certification program is good for them. Sixty-nine percent agreed to the statement "logger certification is good for loggers" and 58% of loggers agree that the forest products industry should require certification.

Chi square test for independence

Twenty-four relationships between respondent behavior change and their personal characteristics were tested using the Chi square test for independence (Table 3). The characteristics of age, education, experience, and production per day were thought by the investigators to have a possible effect on the amount of safety and behavior change. However, upon testing by the Chi square method no significant relationships were found.

Table 3. Variables used in Chi square test for independence.

Behavior change	Personal characteristics
Safety-	Age
Use of chainsaw chaps	Education
Use of hardhats	Experience
Use of safety boots	Production per day
Best Management Practices-	
With respect to streamside management zones	
With respect to stream crossings	
With respect to road construction	

CONCLUSIONS

Twenty-four hypotheses were tested using the Chi square test for independence. These hypotheses were formulated to test the relationships between selected personal characteristics and behavior change in key aspects of safety and BMPs after training in the PLM course. These hypotheses were all accepted, that is, there were no relationships found in behavior change and the respondents personal characteristics.

Although the Chi square test is suitable for this type of data it does have certain limitations. The Chi square test only seeks a relationship between one personal characteristic and one behavior change. Tests such as multivariate analysis search for relationships between a number of personal characteristics and behavior change.

There are many possible reasons why relationships were not found in this survey. Forty percent of Alabama's loggers indicated they did not change their safety behavior. This data, coupled with the fact there were few numbers of accidents reported in the survey, might indicate Alabama loggers are already operating safely.

Loggers have indicated that the PLM course is a worthwhile program. The support for this statement comes from a number of locations. The first of these is the high score for the entire PLM course in the question of how much information should be taught. This would indicate loggers do want training. Also indicating that the PLM is a worthwhile program is the high agreement among respondents that logger certification is good for them.

The fact that no relationships can be found between personal characteristics and behavior change indicates that the PLM course should continue in the current format.

Overall the PLM was found to be a beneficial program in the eyes of Alabama's loggers. However, the objective of finding specific groups of loggers to target and improve information transfer to has eluded this study. Further research could be conducted in order to determine those individuals who need more specific training and in what areas they need this training.

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Evaluation of a Shovel Logging System in the Gulf Coastal Plain

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ABSTRACT – During the Spring of 2001 the USDA Forest Service, Southern Research Station, implemented a study to evaluate productivity and costs of a shovel logging operation in the Gulf Coastal Plain. The site was a mixed pine/hardwood bottomland located in Escambia County, Florida. The system consisted of a Tigercat 845B tracked feller-buncher, a Tigercat S860 shovel, and a Tigercat 640 clambunk skidder. Feller-buncher productivity (stem wood and bark) averaged 167.2 green tons per PMH. Productivity of the S860 shovel was estimated to be 42.2 green tons per PMH. The 640 clambunk skidder encountered a maximum one-way skid distance of 2580 feet and averaged 44.8 green tons per PMH. The system rate was limited by the shovel at 34.2 green tons per SMH, resulting in a system cost of $7.66 per ton. Adding the cost of a slasher and chainsaws increased the system cost to $7.82per ton. Weekly production totaled 2046 green tons or 72 truck loads.

Introduction

In the US shovel logging is used most commonly in the Northwest and the Southeast. In the Northwest shovel logging is sometimes used as an alternative to cable logging. This system is limited to sites with less than 35 percent ground slope and moderate to gentle terrain conditions (McNeel and Andersson, 1993). Shovel logging is used in the Southeast in areas where access by traditional ground-based systems is restricted due to wet conditions. In these areas, typically hardwood bottoms, mats are constructed from felled trees for access by the transport equipment. The mats are then de-constructed at the end of the harvest as the shovel works its way out of the stand.

Bottomland hardwood forests provide important wood resources needed to meet hardwood lumber and fiber demands. McWilliams and Faulkner (1991) estimate that bottomland hardwood forests cover over 24 million acres of the southern coastal plain. The unique hydrology and soils of wetland forests make them highly productive in terms of wildlife, aquatic habitat, and plant communities (Rummer *et al*. 1997). Accessing and extracting wood from these sensitive areas in an environmentally acceptable and economically viable manner is a difficult challenge for loggers. Productive use must not compromise the ecological functions of these sites (Rummer *et al*. 1997).

Rummer *et al.* (1997) compared system rate, system cost, and unit cost of a variety of system configurations operating in a bottomland hardwood stand. Regression equations to predict productivity for a feller-buncher, grapple skidder, clambunk skidder, forwarder, and shovel loader were developed from observing these machines operating in bottomland conditions. They found that the feller-buncher, grapple skidder configuration had the lowest observed cost per ton at $5.78, followed by the feller-buncher, shovel, grapple skidder at $5.82 per ton. The most expensive configurations were the feller-buncher, grapple skidder, clambunk and the feller-buncher, grapple skidder, forwarder at $6.85 and $7.28 per ton, respectively. However, these costs are based on different extraction distances and therefore are not directly comparible.

McNeel and Andersson (1993) evaluated production and costs of two shovel logging operations in British Columbia where each operation used a different pattern to forward stems. One operation used an up-and-back pattern while the other used a serpentine pattern. They determined that the system using the up-and-back pattern had the highest productivity and averaged $0.04 per ft^3 for an average forwarding distance of 328 feet.

Objectives

This research evaluated a shovel logging system consisting of a feller-buncher, shovel, and clambunk skidder operating in a mixed pine/hardwood bottom in the Gulf Coastal Plain of northwest Florida. The research had the following objectives:

1) Evaluate productivity and cost of a tracked feller-buncher, shovel, clambunk skidder, and loader and

2) Determine productivity and cost of a shovel logging system.

Study Overview and Site

The study site was located in Escambia County, Florida on land owned by Swift Lumber Company in Atmore, Alabama. The stand was a mixture of pine and hardwood with 275 trees per acre on predominately flat terrain.

Volume per acre averaged 268 tons, and stems had a quadratic mean diameter of 12.8 in. Major hardwood species included yellow-poplar, ash, and bay. Products included pine saw-timber, pine pulpwood, plywood logs, hardwood saw-timber, and hardwood pulpwood.

Felling was performed with a Tigercat 845B tracked feller-buncher powered by a Cummins 6CTA 8.3 liter 230 hp engine and equipped with a Tigercat 5700 head that utilized a 22-in circular saw. Track width of the feller-buncher was 24 in. To improve operability, a mat was constructed by the feller-buncher from felled trees. The feller-buncher then made two passes along the mat. On one pass trees were felled with butts facing toward the landing. On the return pass trees were felled with butts facing away from the landing. The purpose of this was to aid the shovel in grappling the wood to create piles for the clambunk skidder. Equipment specifications for each machine are summarized in Table 1.

Table 1. Specifications for machines studied.

Component	Feller-Buncher	Clambunk Skidder	Shovel
Manufacturer	Tigercat	Tigercat	Tigercat
Model	845B	640	S860
Width (ft)	10.0	9.9	11.9
Height (ft)	11.7	10.3	11.2
Weight (lb)	46,860		72,160
Power (hp)	205	241	260
Boom reach (ft)	25.5		34.4

Trees were shoveled to the mat with a Tigercat S860 shovel powered by a Cummins 6CT 8.3 liter 260 hp engine and equipped with 24-in wide tracks. As the shovel grappled trees for bunching it also delimbed and topped most trees by twisting off limbs with its grapple. The shovel also loaded the clambunk skidder with its payload for transporting to the landing.

A Tigercat 640 clambunk skidder was used to transport trees from woods to landing. This machine was powered by a Cummins 6CT 8.3 liter 240 hp engine, was mounted on dual tires all around, and utilized a 32-ft^2 inverted grapple. On the front the 640 skidder was equipped with 30.5L-32 tires on the inside and 24.5-32 tires on the outside. On the rear the 640 utilized 28L-26 tires on the inside and 23.1-26 tires on the outside. The skidder traveled on the mat constructed by the feller-buncher. The landing was located on a small knoll, so just before arriving at the landing the skidder encountered two fairly steep sections; one section was 154 ft. in length with a 17% slope and the other section was 100 ft. in length with a 12% slope.

At the landing trees were sorted into products and loaded onto trucks by two Barko 160B knuckleboom loaders. One loader loaded pulpwood while the other loaded sawlogs and plywood logs. A CTR 42IP slasher was used for bucking logs. Debris was cleared from the landing with a John Deere 648E grapple skidder. Two Stihl 044 chainsaws were used to delimb, top, and trim loads. Support for the equipment was provided by a Ford F350 service truck.

Methods

Feller-Buncher

Detailed time-and-motion data were collected on the feller-buncher while operating in two 0.1-acre rectangular plots (45.0 ft x 98.6 ft), that were installed diagonally to each other on azimuths of 220° and 310°. Within each plot diameter at breast height (DBH) of each tree was measured to the nearest 0.1-in. using a D-tape. Total heights were measured to the nearest 0.5-ft using a hypsometer. Species of each tree was noted and a number was painted on each tree for identification during the study. The feller-buncher was then recorded on videotape cutting an entire strip of trees that contained the study plots. Elements evaluated included move, swing-to-tree, and fell. All delays that occurred during the study were also noted. Once the feller-buncher completed the strip, measurements of length and width of the cut strip were taken using a hypsometer to estimate gross productivity of the feller-buncher.

Shovel

The shovel was recorded on videotape as it worked the strip cut by the feller-buncher. Detailed time-and-motion data were collected on the shovel from video and included the following elements: move, shovel (reach to tree, grapple, and place in pile), load, place limbs/tops in trail, wait on skidder, adjust load on skidder, and pile maintenance. Waiting on the skidder was considered an element since the shovel and skidder interacted with each other regularly during loading.

Clambunk Skidder

Detailed time-and-motion data were collected on the clambunk skidder using stopwatches. Elements evaluated included travel empty, position, load, travel loaded, and unload. All delays encountered during the study were also recorded. Travel distances were measured to the nearest foot using a distance measuring wheel. A stem count by species and a sample of DBHs were obtained from each skidder turn for estimating load volume. Weights of stem wood and bark to a 4-in. top for pine and hardwood were estimated using appropriate weight equations (Clark and Saucier, 1990).

Loader

Time study data for loading trucks were collected using a stopwatch. Load time and delays were recorded along with the number of stems in a load. Load tickets were used to match load size to load time. A CTR slasher was used with the log loader for cutting sawlogs and plywood logs to length.

Results

Feller-Buncher

A total of 50 observations were collected on the 845B feller-buncher (Table 2). Of these, 92% where hardwood and 8% were pine. Mean DBH of cut hardwoods was 11.1 in. with a mean height of 69.2 ft. Cut pines averaged 19.3 in. DBH with a mean height of 97.8 ft.

Table 2. Time study summary for the 845B feller-buncher.

Variable	N	Mean	SD	Min	Max
Move (min)	8	0.25	0.17	0.07	0.63
Swing (min)	50	0.15	0.07	0.03	0.35
Fell (min)	50	0.12	0.04	0.04	0.22
Brush (min)	7	0.20	0.10	0.08	0.38
Total time (min)	50	0.34	0.15	0.11	0.95
Prod. (tons/pmh)	50	167.2	159.6	6.2	738.3
DBH (in)	50	11.9	4.6	5.0	24.8
Height (ft)	50	71.5	1.9	26.5	115.2
Stem wt. (tons)	50	0.90	0.90	0.08	4.4

Inventory plots revealed that there were 268 tons per acre within the study area. The feller-buncher spent a total of 1.84 productive machine hours (PMH) cutting a total area of 1.28 acres. This gross summary estimated productivity of the feller-buncher to be 186 tons per PMH. Productivity from the detailed time study of 50 trees was estimated to be 167 tons per PMH.

On a per cycle basis, move time accounted for 12% of the total time. Swing-to-tree time accounted for the largest portion of time at 44%, followed by felling with 35.4%. Cutting brush out of the way accounted for 8.5% of the total time.

During a total of 3.5 days the feller-buncher incurred 2.17 hrs. of mechanical delays and 5.42 hrs. of non-mechanical delays. Mechanical delays included replacing a hydraulic hose and repairing track rollers. Using 8 scheduled machine hours (SMH) per day resulted in a utilization rate of 73%.

Clambunk Skidder

Productivity of the skidder averaged 44.3 tons per PMH at a mean one-way distance of 2262 ft. Mean cycle time was 28.9 min. The skidder averaged 26 stems per turn with a mean load size of 21.1 tons. A time study data summary is displayed in Table 3.

Table 3. Time study summary for the 640 clambunk skidder.

Variable	N	Mean	SD	Min	Max
Trv. empty (min)	27	8.08	1.38	6.02	11.87
Position (min)	27	1.81	0.46	1.03	2.74
Load (min)	27	7.46	1.45	5.45	10.55
Trim (min)	18	0.51	0.29	0.10	1.15
Trv. loaded (min)	27	10.84	1.23	8.72	13.76
Unload (min)	27	0.41	0.14	0.16	0.83
Total time (min)	27	28.9	3.17	23.8	34.6
One-way dist. (ft)	27	2262	176	1865	2580
# Stems	27	26.0	5.5	16	41
Load wt. (tons)	27	21.1	3.9	14.7	29.1
Prod. (tons/pmh)	27	44.3	10.52	26.5	72.6

Position time for the clambunk occurred when the machine arrived in the woods to be loaded and encompassed turning around and backing up. On average, the distance traveled by the skidder while backing up was 178 ft.

The 640 skidder was down 0.40 hrs. due to non-mechanical delays and 0.69 hrs. due to a other delay. However, the skidder did not have a mechanical failure but the operator assisted with replacing a hydraulic hose on one of the loaders. The skidder was observed for two days and performed 13 hrs. of productive work. Assuming 8 SMH per day resulted in a utilization rate of 81%.

Shovel

The shovel grappled felled trees and placed them in piles beside the mat for loading onto the skidder. Limbs and tops were broken off with the grapple and placed on the ground to improve trafficability of the shovel and skidder. Productivity of the shovel was measured by recording time required by the machine to shovel trees in a known area and relate this to the inventory data. This gross estimate resulted in a productivity of 42.2 tons per PMH for the shovel.

A detailed time study analysis was performed from video to determine the percent time spent by the shovel performing its different functions. (Table 4).

Table 4. Percent of productive time by element for shovel.

Variable	Percent
Machine travel	9.0
Move logs	49.7
Place tops	10.6
Load logs	24.6
Wait on skidder	5.4
Bunch maintenance	0.5
Adjust load on skidder	0.2
Total	100.0

The elemental time study analysis revealed that the shovel spent an average of 0.74 min. to swing, grapple, and pile 1.3 stems. Mean stem size was 1.0 ton. Table 5 summarizes the time study data for the S860 shovel.

Table 5. Time study summary for the S860 Shovel.

Variable	N	Mean	SD	Min	Max
Travel (min)	73	0.60	0.37	0.13	1.80
Move logs (min)	327	0.74	0.34	0.14	1.93
Place tops (min)	79	0.56	0.34	0.09	1.65
Load (min)	18	6.67	0.91	5.41	8.60
Wait on skid. (min)	24	0.84	0.55	0.21	2.22
Bunch maint. (min)	2	1.34	1.10	0.56	2.12
Adjust load (min)	2	0.46	0.29	0.26	0.67
Stems per grapple	312	1.3	0.62	1.0	4.0
Log wt. (tons)	312	1.0	0.67	0.28	4.20
Stems per load	18	21.8	4.35	15.0	29.0

It was common for the shovel to wait on the clambunk skidder to backup to load and pull-up after loading. This wait time averaged 0.84 min. Loading the clambunk skidder required an average of 6.67 min. for a mean load size of 21.8 stems.

Loading

Eleven observations of loading were collected during the study period. Of these loads, eight were hardwood pulpwood, two were ply-logs and one was hardwood saw-timber. Mean loader productivity was 98 tons per PMH. Load time averaged 20.22 min. with a mean piece count of 47.3.

Costs

Equipment owning and operating costs were estimated using standard machine rate analysis (Miyata, 1980), which reflects the average cost over the life of the machine. Table 6 summarizes the estimators used in the machine rate analysis. Salvage value and insurance rates are percent of purchase price. Repair and maintenance is percent of annual depreciation. Fuel consumption rates are gal/hp-hr.

Table 6. Estimators for machine rate analysis (Brinker and others, 1989).

Machine	Salvage Value (%)	Util (%)	Repair & Maint. (%)	Insurance Rate (%)	Fuel Rate (gal/hp-hr)
FB	15	73	75	3.5	0.0263
Skidder	25	81	90	5.0	0.0280
Shovel	15	81	75	3.5	0.0263
Loader	30	50	90	1.5	0.0217
Slasher	0	50	35	1.5	
Chainsaw	20	50	700		

Table 7 summarizes total owning, operating, and labor costs for the equipment. Costs for the loader are for two machines. Total cost of a CTR slasher was estimated to be $3.27/SMH. The cost of two chainsaws used at the deck was estimated to be $3.20/SMH.

Table 7. Cost summary for machines studied.

Variable	FB	Skid	Shovel	Loader
Purchase price ($x1000)	258	245	306	90
Salvage value ($)	38,708	61,408	46,015	27,215
Depreciation ($/yr)	43,870	36,845	52,150	12,700
Interest ($/yr)	15,329	15,475	18,222	5,878
Insurance ($/yr)	9,032	12,282	10,737	1,361
Total Owning ($/SMH)	**34.12**	**32.30**	**40.55**	**19.94**
Fuel & Lube ($/PMH)	8.78	9.74	9.93	4.52
R & M ($/PMH)	22.54	20.47	24.14	11.43
Tires ($/PMH)	-*	4.02	-*	-*
Total Oper. ($/SMH)	**22.86**	**27.73**	**27.60**	**15.95**
Labor ($/SMH)	13.79	13.79	13.79	19.29
Total Cost ($/SMH)	**70.77**	**73.82**	**81.94**	**55.18**

*Not applicable

For all machines an annual interest rate of 9% was assumed, with a fuel cost of $1.06/gal, a 5-year machine life and 2000 SMH/year. Lubrication costs were based on 36.8% of hourly fuel cost, except for the chainsaws where it was included in the repair and maintenance cost (Brinker *et al*., 1989).

Labor rates from Davis-Bacon for Escambia County, Florida were used. A rate of $10.61, plus 30% fringe benefits, was used for the feller-buncher, skidder, and shovel operators. For the deck hands a rate of $7.42, plus 30% fringe benefits, was used.

Using these estimators the system rate was limited by the shovel at 34.2 tons/SMH. This resulted in a system cost of $262/SMH and a cost per ton of $7.66. Table 8 shows the cost and productivity summary for the system without the slasher and chainsaws. Adding the cost of the slasher and chainsaws results in a system cost of $268/SMH and a system cost per ton of $7.82. These costs do not reflect overhead, profit, or tax effects.

Table 8. Shovel Logging system productivity and cost rate summary.

Machine	Productivity (tons/SMH)	System Rate (tons/SMH)	System Cost ($/SMH)	System Cost ($/ton)
FB	122.06	34.18	261.83	7.66
Skidder	35.88			
Shovel	34.18			
Loaders	97.98			

Conclusions

The system was well balanced for the range of skidding distances studied. Production among the skidder, shovel and loaders ranged from 34 to 98 tons/SMH. The shovel was the limiting function in the system at 34 tons per SMH. Felling, shoveling, skidding, and loading functions of a shovel logging operation were evaluated for productivity and cost. This was a high production operation with 12-15 loads hauled per day. During the week of the study the crew hauled 72 loads totaling 2046 tons. With over $1 million invested in equipment and hourly costs of $268 per SMH, an operation like this must be capable of functioning efficiently.

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PRODUCTION AND COST ANALYSIS OF A FELLER-BUNCHER IN CENTRAL APPALACHIAN HARDWOOD FOREST

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ABSTRACT - A time study was conducted to evaluate the productivity and cost of a feller-buncher operating in a Central Appalachian hardwood forest. The sites harvested during observation consisted of primarily red maple and black cherry. Trees felled in the study had an average diameter at breast height (DBH) of 16.1 in. and a total merchantable height of 16 ft. A Timbco 445C Hydro-buncher was used in conjunction with manual topping and delimbing with a Husqvarna 55 chainsaw. Hourly productivity ranged from 428.9 to 2267.7 ft^3 per productive machine hour (PMH) for the feller-buncher and 178 to 2186 ft^3/PMH for the top/delimber. Hourly costs were estimated to be \$99.68/PMH for the feller-buncher and \$28.23/PMH for the top/delimber. Estimated average costs of \$0.08/ft^3 for the feller-buncher and \$0.04/ft^3 for the top/delimber were derived, based on these production estimates.

INTRODUCTION

Manual felling with a chainsaw is most commonly used in the Appalachian hardwood region, but the need for increased production and safety has encouraged some companies to look at mechanized alternatives such as feller-bunchers. In the south, harvesting operations have moved quickly to complete mechanization with highly productive equipment in the past 25 years (McDonald et al., 2000). As a result of that trend, sawhead feller-bunchers have become standard equipment on many Southern harvesting operations (Greene and McNeel, 1991). Being relatively new to the hardwood region, little if any research has been conducted to examine the production and cost effectiveness of the feller-buncher when used on the terrain and with tree species common to this region.

It has been shown that harvest system mechanization leads to higher levels of productivity in the system.. A drawback is that as mechanization increases, costs also increase (Blinn et al., 1986). Site conditions are also a problem when using mechanized systems. Feller-bunchers can work on relatively steep slopes, but it is not known how cost effective they are in those conditions. Characteristics of the tree species in this region may also be a problem. Feller bunchers are commonly used for cutting coniferous species, since these species are typically characterized by straight boles and relatively small branches. In the Central Appalachian region mechanized systems would be required to deal with trees that might be leaning and with crown weights that are excessive. This makes for placement of trees after cutting and travel while carrying trees difficult, especially on steep slopes.

Time studies have been a popular way of investigating productivity of feller-bunchers and other machines on logging operations (Wang and Haarlaa, 2002). The objective of this study is to examine the production/cost effectiveness of using a feller-buncher in the Central Appalachian Hardwood Region. Results can help loggers and logging managers compare this machine to others and choose an appropriate one to improve the operations in the region.

METHODS

An elemental time study was conducted on logging operations in Northern West Virginia. The field study was conducted from February to April 2002 on two sites. Both sites contained most hardwood species common to the Appalachian region but were predominantly made up of 5 major species: red maple (*Acer rubrum*), black cherry (*Prunus serotina*), yellow poplar (*Liriodendron tulipifera*), black locust (*Robina pseudoacacia*), and white ash (*Fraxinus Americana*). All other species were grouped together as "Other hardwoods". Average DBH of the trees harvested was 16.1 inches and ranged from 7 and 31 inches. Slope on the sites ranges from 0 to 30% with an average of

15%. The machine used in the study was a Timbco 445C Hydro-buncher. This machine has a 260 hp engine, is capable of 4-way cab leveling, and has a boom reach of 167 inches. Top/delimbing was done using Husqvarna 55 chain saws, which have a 3.4 hp engine.

A handheld computer loaded with the Windows CE based Time Study Data Logger was used to measure and record elemental times (Wang et al., 2001). When the handheld computer could not be used, times were measured using a stopwatch and recorded on paper. A work cycle consisted of the following elemental functions:

Drive to tree: Starts when the feller-buncher finishes the previous cycle and begins moving to the next tree to be cut. Ends when movement has stopped and felling is ready to begin.

Cut tree: Begins when the head is positioned on the tree and ends when the tree is completely severed from the stump.

Drive to Dump: Begins when the feller-buncher moves from the stump with the tree and ends when movement is stopped and dump is started.

Dump tree: Begins when tree is tilted by head into dump position and ends when tree hits the ground

Bunch: Begins after tree is dumped and continues until move to next tree starts

Harvesting factors recorded for the feller buncher were distance to tree, distance to dump, tree species, DBH, and merchantable height. Only one tree was cut per cycle, so the number of trees per cycle was not a factor. Order and location of felled trees was noted so that species, DBH, and merchantable height of the trees could be recorded when felling was complete. DBH for each harvested tree was measured to the nearest inch but was later classed as follows for simplification of data analysis: (7 to 10 in.) ⇒ 10 in.; (11 to 15 in.) ⇒ 15 in.; (16 to 20 in.) ⇒ 20 in.; (21 to 25 in.) ⇒ 25 in.; (26 to 31 in.) ⇒ 30 in. Merchantable height of each felled tree was measured to the nearest ½ log or 8 feet. Due to the small number of occurrences of logs over 32 feet, all logs over 32 feet were classed as 32 feet to simplify analysis. After felling was complete on the group of trees being observed, the felled trees would be topped/delimbed. This operation required from one to three workers at a time, but usually consisted of two workers. Because of the difficulty in collecting topping and delimbing times for individual trees for each worker, total topping/delimbing time was measured for groups of trees and an average time per tree was calculated.

ANALYSIS

A total of 500 felling and topping/delimbing cycles were collected in order to provide a statistically viable dataset. An Analysis of Variance (ANOVA) model was performed on the dataset to determine if any differences existed between elemental times, cycle time, and hourly productivity. The model is expressed as:

$$T_{ijkl} = \mu + S_i + DBH_i + L_k + \varepsilon_{ijkl}$$
$$i = 1, 2.., 6$$
$$j = 1, 2,\ldots, 5$$
$$k = 1, 2, 3, 4$$
$$l = 1, 2,\ldots, n$$

where T_{ijkl} represents the l^{th} observation of the elemental times, cycle times, and hourly production for the i^{th} species, j^{th} DBH class, and k^{th} height class; μ is the mean of each response variable; S_i is the effect of the i^{th} species; DBH_j is the effect of the j^{th} DBH class; L_k is the effect of the k^{th} height class; ε_{ijkl} is an error component that represents uncontrolled variability; and n is the number of observations within each treatment. Regression techniques were used to produce prediction equations for elemental times, hourly productivity, and unit cost.

RESULTS

Means and significant levels of statistics for the feller-buncher and topping/delimbing during the time and motion study were computed (Table 1). Calculations were done by species, DBH (in), and merchantable length of log cut (ft).

ELEMENTAL TIMES

Total felling time – Adding all productive elements of felling including drive to tree, cut, drive to dump, dump, and bunch for each tree gives us a total felling time for each individual tree. Mean total felling time differed significantly among species (F=13.21; df = 5, 486; P = .0001), DBH (F=12.69; df = 4, 486; P = .0001), and height (F= 23.32; df = 4, 486; P = .0001) with ranges of .85 to 1.46 minutes, .79 to 1.85 minutes, and .89 to 1.78 minutes respectively (Table 1). A regression model was developed to estimate total felling time per tree (Table 2). Total felling time was best described by DBH and merchantable height of the tree being felled, distance to tree, and distance to dump.

Drive to tree – The density of the stand as well as the intensity of the harvest affect time moving to the tree to be cut because thinnings leave trees that must be maneuvered around. Drive to tree was the largest of the elemental times measured. There were significant differences in drive to tree time among species (F=5.09; df = 5, 486; P = .0001) with a range of .45 to .86 minutes and among height (F= 10.94; df = 4, 486; P = .0001) with a range of .49 to 1.07 minutes. Mean drive to tree time ranged from .44 to .70

minutes among DBH classes and showed no significant difference (F=1.31; df = 4, 486; P = .2664) (Table 1).

Table 1. - Means and significance levels of statistics for the felling and top/delimbing during time and motion studies.[a]

	Elemental Times (min)									Production Estimates (ft^3/PMH)	
	Total Felling Time	Drive to Tree	Cut	Drive to Dump	Dump	Bunch	Feller-Buncher Delay	Top/ Delimb	Top/Delimb Delay	Felling Productivity	Top/Delimb Productivity
Species											
Red Maple	1.06 A	0.51 AB	0.17 A	0.03 A	0.10 A	0.25 A	0.35 A	1.53 A	0.31 A	1204 A	723 A
Black Cherry	0.85 A	0.45 B	0.15 A	0.04 A	0.12 A	0.10 B	0.00 A	1.61 A	0.06 A	1386.1 AB	660.5 B
Yellow Poplar	1.46 B	0.86 C	0.21 B	0.09 B	0.10 A	0.20 AD	0.91 A	1.79 B	0.20 A	1478.7 B	989.7 C
Black Locust	0.90 A	0.51 AB	0.10 C	0.02 A	0.11 A	0.17 BD	0.85 A	1.55 A	0.10 A	939.8 C	400.3 D
White Ash	1.06 A	0.62 AB	0.10 C	0.08 B	0.09 A	0.16 BD	0.00 A	1.56 A	0.44 A	1162.1 AC	511.8 E
Other	1.39 B	0.70 BC	0.22 B	0.02 A	0.10 A	0.36 E	0.41 A	1.69 AB	0.18 A	1297.3 AB	920.8 F
DBH (in)											
10	0.79 G	0.44 G	0.07 G	0.02 G	0.08 G	0.17 G	0.50 G	1.50 G	0.00 G	428.9 G	178 G
15	0.99 GH	0.54 G	0.10 G	0.05 G	0.12 H	0.18 G	0.11 G	1.52 G	0.20 G	878.8 H	414 H
20	1.15 HI	0.61 G	0.17 H	0.04 G	0.10 GH	0.23 G	0.50 G	1.68 GH	0.22 G	1437.7 I	786 I
25	1.28 I	0.65 G	0.29 I	0.03 G	0.11 G	0.20 G	0.94 G	1.76 H	0.30 G	2333.6 J	1517 J
30	1.85 J	0.70 G	0.61 J	0.00 G	0.08 H	0.46 H	0.00 G	1.78 H	0.00 G	2267.7 J	2186 K
Length (ft)											
8	0.89 L	0.49 L	0.10 L	0.03 L	0.11 L	0.15 L	0.23 L	1.46 L	0.16 L	638.4 L	326 L
16	1.04 LM	0.55 L	0.14 L	0.04 L	0.10 LM	0.21 LM	0.45 L	1.59 M	0.24 L	1180.1 M	596 M
24	1.18 M	0.52 L	0.26 M	0.05 L	0.11 L	0.25 L	0.04 L	1.71 M	0.09 L	1910.1 N	1184 N
32	1.78 N	1.07 M	0.32 N	0.03 L	0.09 M	0.27 L	1.06 L	1.95 N	0.19 L	2238.6 O	1710 O

[a] Means with the same capital letter in a column are not significantly different at the 5 percent level with Duncan's Multiple-Range Test.

Cut – Time to cut each tree was significantly different among species (F=11.68; df = 5, 486; P = .0001) ranging from .10 to .22minutes, DBH (F=119.90; df = 4, 486; P = .0001) ranging from .07 to .61 minutes, and height (F= 64.58; df = 4, 486; P = .0001) ranging from .10 to .32 minutes (Table 1). A model developed using regression analysis allows estimation of cut time per tree (Table 2). It was found that cut time was affected by DBH and merchantable height of the tree.

Drive to dump – Drive to dump was not always performed in the felling cycle so it accounts for much less of total felling time than drive to tree. There were significant differences in drive to dump times for species (F= 3.84; df = 5, 486; P = .0020) with times ranging from .02 to .09 minutes. No significant differences were found among DBH classes (F=1.34; df = 4, 486; P = .2558) with times ranging from 0 to .05 minutes or among height (F= .23; df = 4, 486; P = .8770) with a range of .03 to .05 minutes. (Table 1).

Dump – Dump time was found to be significantly affected by DBH (F=5.05; df = 4, 486; P = .0005) ranging from .08 to .12 minutes. No significant difference was found for dump time among height (F=1.99; df = 4, 486; P = .1144) ranging from .09 to .11 minutes or species (F=1.50; df = 5, 486; P = .1868) ranging from .09 to .12 minutes (Table 1).

Bunch – Bunch time was found to significantly differ among species (F=16.42; df = 5, 486; P = .0001) ranging from .10 to .36 minutes, DBH (F=7.88; df = 4, 486; P = .0001) ranging from .17 to .46 minutes, and height (F= 4.78; df = 4, 486; P = .0027) ranging from .15 to .27 minutes (Table 1).

Feller-buncher delay – Feller buncher delay was only observed 20 times during the study. Delay was usually due to maintenance of the saw and included replacing the chain when dull and the bar when bent. Some delay due to hydraulic line failure also occurred. Delay of the feller-buncher was not significantly different by species (F=1.04; df = 5, 486; P = .3947), DBH (F= 1.00; df = 4, 486; P = .4091), or height (F= .93; df = 4, 486; P = .4475) with ranges of 0 to .91 minutes, 0 to .94 minutes, and .04 to 1.06 minutes respectively (Table 1).

Top/delimb – Top/delimb time was found to significantly differ by species (F=4.26; df = 5, 486; P = .0008), DBH (F=6.97; df = 4, 486; P = .0001), and height (F= 15.88; df = 4, 486; P = .0001) with times ranging from 1.53 to 1.79 minutes, 1.50 to 1.78 minutes, and 1.46 to 1.95 minutes respectively. (Table 1).

Top/delimb delay – Only 20 observations of delay were observed for top/delimbing. The main delay was chain sharpening and refueling. Top/delimb delay was found not to be significantly different by species ($F= .96$; $df = 5, 486$; $P = .4422$), DBH ($F= .69$; $df = 4, 486$; $P = .5989$), or height ($F= .45$; $df = 4, 486$; $P = .7149$) with times ranging from .06 to .44 minutes, 0 to .30 minutes, and .09 to .24 minutes respectively (Table 1).

Table 2. Models to estimate times and productivities.

	Models [a]	R^2	RMSE	P-value
Cut Time per tree (min)	$0.24-0.04DBH+0.007Length+0.0005DBH*L+0.0015DBH^2-0.00035L^2$	0.46	0.13	0.0001
Total felling time per tree	$0.367+0.0008DBH^2+0.00026L^2+0.02246 DistT+0.00679DistD$	0.61	0.45	0.0001
Feller-buncher productivity (ft^3/PMH)	$417.96+5.72DBH*L-1.44*L^2-17.77$Distance to tree	0.55	685.9	0.0001
Top/Delimb productivity (ft^3/PMH)	$365.95-56.19DBH-14.39L+3.81DBH*L+2.22DBH^2-0.63L^2$	0.83	248.36	0.0001

[a] DBH = diameter at breast height (in); L = merchantable length (ft); DistT = Distance to tree (ft); DistD = Distance to dump (ft);

RMSE = root of mean square error

PRODUCTIVITY AND COST

Felling Productivity – Productivity of the feller-buncher was significantly different among species ($F=5.22$; $df = 5, 486$; $P = .0001$), DBH ($F=87.91$; $df = 4, 486$; $P = .0001$), and height ($F= 89.35$; $df = 4, 486$; $P = .0001$) with ranges of 939.8 to 1478.7 ft^3/PMH, 428.9 to 2333.6 ft^3/PMH, and 638.4 to 2238.6 ft^3/PMH respectively (Table 1). A regression model was developed to estimate the productivity of the feller-buncher (Table 2). Factors that affect felling productivity are DBH, merchantable height, and distance between harvested trees.

Top/Delimb Productivity – Productivity of the top/delimber was significantly different among species, DBH, and height ranging from 400.3 to 989.7 ft^3/PMH, 178 to 2186 ft^3/PMH, and 326 to 1710 ft^3/PMH respectively (Table 1). A regression model was also developed to estimate the productivity of the top/delimber (Table 2).

Estimates of costs were done using the machine rate method (Miyata, 1980). The feller-buncher was purchased for $225,000 in 1998 and was in used condition with 2300 hours from the previous owner. After an anticipated economic life of 4 years, salvage value would be $45,000. Interest, insurance, and taxes were assumed to be 14% of the purchase price. Maintenance was estimated at 50% of depreciation. Operator cost was assumed to be $10/hr with fringe benefits of 35%. Fixed costs were calculated to be $51.58/PMH and operating cost were calculated at $27.33/PMH. Total cost was estimated to be $99.68/PMH. The chainsaw used to top/delimb costs $300 and has an economic life of 6 months, after which time there is no salvage value. Total cost was estimated to be $28.23/PMH. An average productivity of 1266.6 ft^3/PMH for felling and 726.3 ft^3/PMH for top/delimbing allowed an estimated average cost per volume of $0.08/$ft^3$ for the feller-buncher and $0.04/$ft^3$ for the top/delimber.

CONCLUSION

Total felling time was most affected by distance between harvested trees and significantly differed from .79 to 1.85 minutes among DBH classes. This can be explained by the fact that drive to tree was a major part of the work cycle making up nearly half of the average work cycle. Cut time per tree was most affected by DBH and was significantly different among DBH classes with a range from .07 to .61 minutes. Productivity of the feller-buncher was most affected by and differed significantly among merchantable height with a range from 638.4 to 2238.6 ft^3/PMH. Top/delimber productivity was most affected by and significantly differed among DBH classes and merchantable height with ranges of 178 to 2186 ft^3/PMH among DBH classes and 326 to 1710 ft^3/PMH among heights. Among species, yellow poplar yielded the highest productivity with 1478.7 ft^3/PMH for felling and 989.7 ft^3/PMH for top/delimbing. This was probably due to its large size and straight boles compared to other hardwoods.

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Hydrology of Forest Roads in the Oregon Coast Range

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Abstract
The spacing of cross drain culverts on forest roads has historically been determined using soil type, road grade, and design rainfall intensities in combination with the experience of the forest engineer. Design criteria for culvert spacing has implicitly been to minimize ditch erosion. Contemporary issues, including the effects of forest roads on watershed hydrology and the occurrence of road-related landslides, indicate a need to incorporate the hydrology of roads into road drainage design. We measured ditch flow from ten road segments in the Oregon Coast Range, and two distinct hydrologic behaviors were observed. For one subset of road segments, ditch flow was continuous throughout the wet season (intermittent), and it increased in response to regional, wet mantle storms. For a second subset, ditch flow occurred only in response to periods of high intensity rainfall (ephemeral). We hypothesize that the source of ditch flow drives the hydrologic behavior of the runoff. Intermittent flow in road ditches appears to be the result of intercepted subsurface flow by the road cutbank, while ephemeral flow appears to be the result of runoff from the road surface. At this time it is not possible for us to predict the hydrologic behavior of a road segment based on physical characteristics. However, it is obvious that these different hydrologic behaviors have different inherent risks and, as such, merit appropriate design and management considerations.

Introduction

Guidelines for the design of forest road drainage in the Pacific Northwest were first published over forty years ago (Arnold 1957), and modified versions of these guidelines are still used widely today. They incorporate information on soil texture, road gradient, and rainfall intensity to determine adequate ditch-relief culvert spacing. The goal of Arnold's (1957) guidelines was to minimize erosion from the road ditch, however concerns with watershed hydrology and accelerated erosion have changed the focus of the design of forest road systems.

Overland flow is rare in forests of the Pacific Northwest, so land managers' attention was first directed to sediment-laden surface flow from roads and ditches. Researchers characterized road surface hydrology, developed sediment-discharge rating curves, and showed that sediment production was linked to geology and traffic level (Reid and Dunne 1984, Vincent 1985, Kahklen 1993, Luce and Black 1999, Kahklen 2001). Other studies have indicated that road-related landslides in steep, landslide-prone terrain can generate orders of magnitude more sediment than road surface runoff (Beschta 1978, Grant and Wolff 1991). Road cutslopes can intercept large volumes of subsurface flow and cause it to be concentrated by culverts. Thus road-related landslides and interception of subsurface flow have been a recent focus of hillslope hydrology research (Megehan 1972, Wemple 1998, McGee 2000).

Arnold (1957) used empirical data to make basic soil science useful to forest engineers. Since then, it has become clear that the hydrology of hillslopes and forest roads are linked but not well understood. There is a need to further incorporate hydrology into road management; nevertheless no method exists. The first step in developing such a method is to collect data on the hydrology of forest roads. Our objective for these studies was to classify road segments based on hydrologic considerations. Specifically, we wanted to determine how the hydrology of the road was affected when the road ditch carried intercepted subsurface flow, compared to when it carried only runoff from the road surface.

Methods

This paper combines results from two road research projects in the Oregon Coast Range. We primarily chose road segments that were located on sandstone geology, although some were located on intrusive igneous material. Road segment length ranged from 40m to 200m, and width ranged from 4m to 6m. Roads were crowned with inboard ditches. In the first project, we installed six trapezoidal flumes to measure ditch flow on six road segments. We paired each flume with a tipping bucket rain gauge, so ditch flow and rainfall were measured from October 1999 to July 2000.

In the second project, we studied five road segments from October 2000 to May 2002. At each road segment, we installed a vinyl fence into the road ditch, longitudinally dividing it into two separate ditches. One carried intercepted subsurface flow, while the second ditch carried road surface runoff. We then installed flumes to capture flow from each ditch. Therefore total runoff from the road ditch could be separated into known amounts of surface and intercepted subsurface runoff. Runoff hydrographs from the road surface could be described exactly and then compared to hydrographs derived from hillslope runoff.

Results

One storm from December 2002 is an example of how the double-flume sites responded to precipitation. One of the five double-flume sites intercepted subsurface flow from the hillslope, and a hydrograph from that site is shown in Figure 1. The other four double-flume sites had only runoff from the road surface, a hydrograph from one site is shown in Figure 2. In Figure 1, during a 35 hour storm, in which 98 mm of rain fell, 520 m^3 of intercepted hillslope water flowed down the road ditch, and the peak discharge was 3.5 l/s. Discharge increased gradually in response to the storm, and the ditch continued to flow after the storm ended (Figure 1). In fact, it flowed throughout the rainy season and behaved like an intermittent stream. Discharge in the other four ditches flowed only in response to high intensity pulses of rainfall (Figure 2). These ditches behaved like ephemeral streams and did not flow at all between storms. For the storm in Figure 2, 70 mm of rain fell in 47 hours. Yet only 0.2 m^3 of road surface water flowed down the ditch, and the peak discharge was 0.04 l/s.

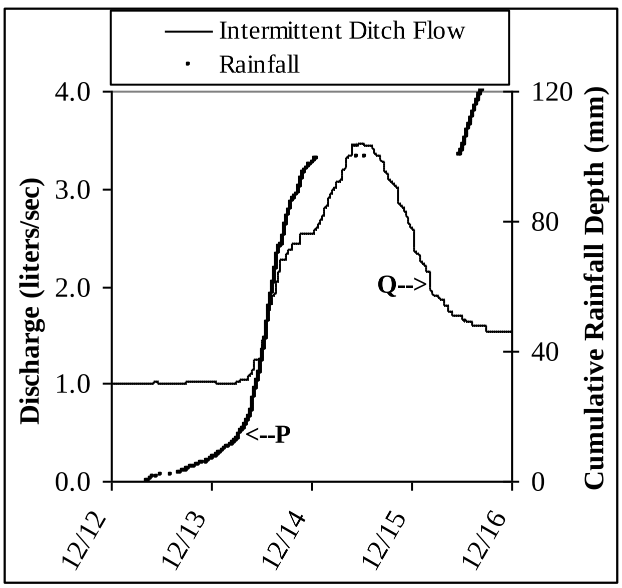

Figure 1. Intermittent ditch flow (Q) hydrograph for a forest road segment in the Oregon Coast Range, December 2001. Segment length is 72m. Each point on the rainfall curve (P) represents a bucket tip in the rain gauge. Infrequent tips indicate low intensity rainfall. Frequent tips show up as a steep curve, indicating high intensity rainfall.

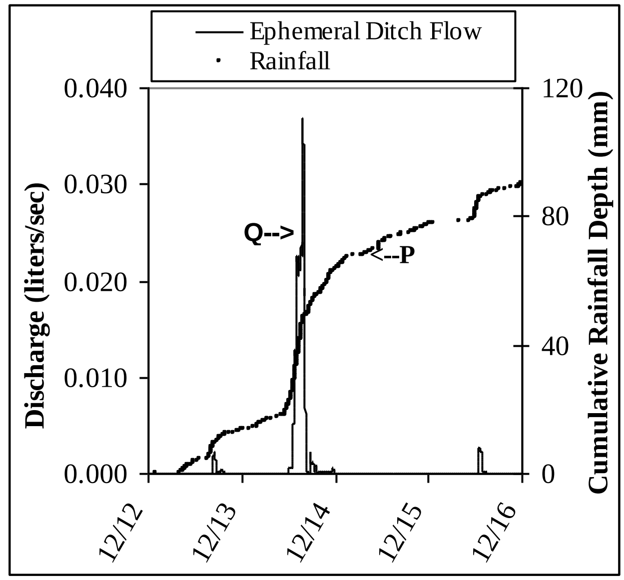

Figure 2. Ephemeral ditch flow (Q) hydrograph for a forest road segment in the Oregon Coast Range, December 2001. Segment length is 64m. Each point on the rainfall curve (P) represents a bucket tip in the rain gauge. Infrequent tips indicate low intensity rainfall. Frequent tips show up as a steep curve, indicating high intensity rainfall.

Precipitation and runoff data for both research projects are shown in Figures 3 and 4. For the project with double flume road segments, the source of the ditch water was known and labeled as such. For these data, the road segment with intermittent flow had a peak discharge and flow volume that were two to three orders of magnitude greater than roads with ephemeral flow. When the data from the single flume road segments were plotted and labeled with the hypothesized flow pathway, they followed the same pattern as the double flume segments. Where we hypothesized that hydrologic behavior was governed by intercepted hillslope water, these data had similar peak discharges and flow volumes to the intermittent ditch in the second research project. Where we hypothesized that hydrologic behavior was governed by road surface runoff, these data had peak discharges and flow volumes similar to ephemeral ditches from the second research project (Figures 3 and 4).

Road segments can be stratified by hydrologic behavior based on runoff response factor. We described the hydrologic behavior of each segment in the first project as either intermittent or ephemeral, and then we used a response factor to hypothesize the source of road ditch flow (Table 1). The runoff response factor is the total volume of ditch flow per storm divided by the volume of rainfall that fell on the road surface, and it's expressed as a percentage.

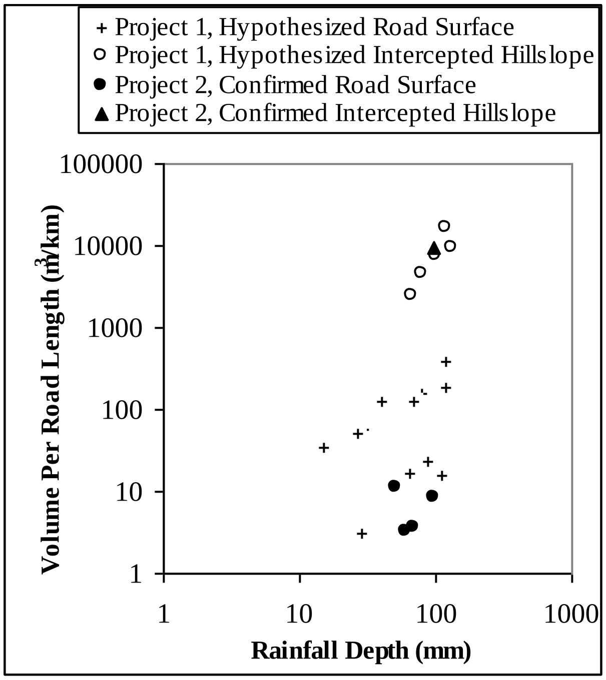

Figure 3. Storm flow volumes for forest road ditches in the Oregon Coast Range. Axes are logarithmic scale. The solid circles and triangle are from water year 2002, while the open circles and crosses are water year 2000.

It indicates what proportion of rainfall on the road surface actually flowed through the ditch as runoff. Roads with ephemeral flow had response factors of less than 100%. In other words, no more water flowed through the ditch than actually fell on the road surface. Roads with intermittent flow had response factors much greater than 100%. In other words, the source of ditch flow was more than just the road surface; it was the hillslope. Response factors for ephemeral ditches in the first project were less than 100%, similar to ditches with only surface runoff in the second project. Response factors for intermittent ditches in the first project were greater than 100%, similar to the ditch which carried intercepted subsurface flow in the second project.

Table 1. Response factor, expressed as percent, for ten forest road segments in the Oregon Coast Range. Number of segments per road type is given in parentheses.

Runoff Type	Confirmed	Hypothesized
Ephemeral, Surface Flow	1 - 20 (4)	7 - 70 (4)
Intermittent, Subsurface Flow	1200 (2)	800 - 3700 (1)

Discussion

We identified two types of hydrologic behavior in these roads in the Oregon Coast Range. Some road segments exhibit intermittent hydrologic behavior. Water flows in the road ditch throughout the winter rainy season, and the ditch flow is governed by intercepted hillslope water. Other road segments exhibit ephemeral hydrologic behavior. Road ditch flow is governed by road surface runoff, which only occurs in direct response to high intensity rainfall. There are roads that fall in between these two extremes (Figures 3 and 4). They may take mostly road surface water, but they intercept hillslope water only during the wettest storms of the year.

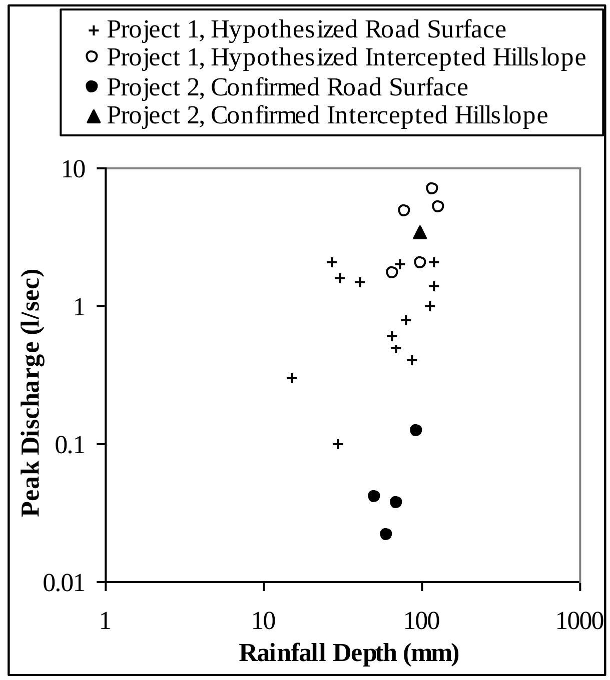

Figure 4. Storm flow peak discharges for forest road ditches in the Oregon Coast Range. Axes are logarithmic scale. The solid circles and triangle are from water year 2002, while the open circles and crosses are water year 2000.

In our study of ten road segments, those that exhibited ephemeral hydrologic behavior were most common (8 out of 10). Furthermore, this hydrologic behavior represents a lower risk of drainage failure for the road. Road segments that exhibited intermittent hydrologic behavior were less common (2 out of 10), and more likely, they represent a higher risk of drainage failure for the road. The data for these research projects has not all been analyzed, and more definitive results await that analysis. At this time, it is not possible for us to predict the hydrologic behavior that a road segment will exhibit without continuously monitoring the ditch flow. However, once identified, road segments that exhibit intermittent hydrologic behavior should require more attention and maintenance than road segments that exhibit ephemeral behavior.

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TWO YEAR - ROTATION PLANTATIONS OF POPLAR TREES FOR ENERGY

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ABSTRACT

Coppices of poplar trees (*Populus x euroamericana*) used for energetic purposes in short rotation plantations (two years), have been studied in Salamanca (Spain). Productivity assessment has been carried out, as well as an economic study in comparison with plantations of poplar I-214 aimed at wood production for classical industrial processes.

Author Keywords: Energy; Woody biomass; *Populus*; Short rotation coppice

INTRODUCTION

The Plan for the Development of Renewable Energy Sources in Spain (IDAE, 2000) is aiming at obtaining a siginificant increase in the energy coming from the biomass during the period 2000-2010. Table 1 presents these forecasts for the year 2010, in one of the hypotheses that have been considered. According to this table, 55.48% of biomass production in 2010 should come from energy crops.

Table 1. Foreseen biomass production in 2010 according to its origin. (Source: IDAE, 2000).

Production	Toe (*)	%
Forest residues	219.56	7.57
Woody agricultural residues	170.78	5.90
Herbaceous agricultural residues	658.68	22.72
Residues from forest & agricultural industries	241.55	8.33
Energy plantations	1,608.64	55.48
TOTAL	2,899.21	100.00

(*) Toe = Ton of oil equivalent = 10. 10^9 cal

This increase is thought to be obtained mainly from straw of cereals and thistle (*Cynara cardunculus* L). Fernández (2000) has studied the productivity of thistle biomass in some European locations throughout two campaigns showing that dry matter production is highly dependent on rainfall and thus is extremely variable from year to year.

Besides, thistle biomass presents some problems during combustion, unlike *Populus*. Studies carried out up to now with poplar biomass (San Miguel et alt., 1984, 1992, and Ciria, 1990) refer to short rotation (4-5 years) poplar plantations for energy production.

The objective of the present research is to consider the feasibility of producing *Populus* biomass at even shorter rotations (2-3 years). For this purpose, it is necessary to estimate the quantity of the resource (productivity of the crop expressed in tons of dry biomass), the energy expected from this resource, the revenues generated and the costs incurred during the production process. Some technical aspects regarding the available technology and the necessary activities must also be considered.

The field site is located in Cabrerizos (Salamanca, Spain), where a plantation of poplar *(Populus x euramericana* Dode, clone I-214) has been established. Density is 33,333 plants per hectare (pl/ha), as a result of a very close spacing (0.33 m x 0.90 m). A two year crop rotation has been set.

MATERIALS AND METHODS

Selected species, density of plantation and rotation

The clone which has been selected (*Populus x euramericana* Dode, clone I-214) presents a quick growth, a high content in carbon (about 50% dry mass) and a low density (about 0,3 g/cm^3). Although this clone has been chosen because of its versatility of uses, the selection of other clones of the same species should not be discarded. For example, the clones *Populus x euramericana* agathe F., Valiant, White Canada, Flevo, I-MC, I-488, Luisa Avanzo, Triple, *Populus deltoides x Populus* 114/69, *Populus deltoides* lux, *Populus nigra*, *Populus x interamericana* Beaupré and Raspalje could also be essayed in the future.

Besides the species from the genus *Populus*, other woody species are being used for energy production purposes, such as some species from the genus *Salix*, (Labrecque et alt., 1995 and 1998), *Eucalyptus*, (Marcos, 2001), *Robinia*, and *Acacia*.

According to FAO (1980), San Miguel & Montoya (1984) and Ciria (1990), for densities between 1,670 and 10,400 plants/ha, the higher the number of plants, the higher the production of biomass. Therefore, it seems interesting to essay very high densities well over the 15,000 plants per hectare. The density of plantation considered in the present research (33,333 plants per hectare) is high enough to search for the limits of biomass productivity

The spacing used (0.33 m x 0.90 m) is also a consequence of technical constraints. This way, the width of the machinery used inside the plantation is responsible for the separation of the rows (0.90 m), and competition becomes too high when there is less than 0.33 meters between two plants in a row. As a result, there are 33,333 plants per hectare, that is, 13,490 plants per acre.

The considered rotation period (two years) allows a very fast return on the investment made by the farmer (short pay back period).

Determination of 2-way volume equations

As stated in the objectives of the research, an assessment of crop productivity is absolutely essential. A way to perform this assessment is to estimate a volume equation which provides the volume of the tree (stem + branches) from its normal diameter and its total height. These crops are so homogeneous that it is adequate to calculate volume per hectare based on the volume of individual trees.

In order to obtain the volume equation, values of diameter at breast height (dbh) and total height have been measured for a total number of 250 trees. A value of total volume with bark has been obtained for each tree.

The use of the wood and bark is proposed, leaving the poplar leaves on the ground, allowing for their incorporation into the soil like organic material and maintenance of soil productivity. Besides, leaves are not profitable in combustion processes, because of their content of harmful elements that may result in ashes and solid particles present in exhaust gases.

The variables measured in the 250 trees of the sample have been the input of a regression analysis, in order to obtain an expression for volume. The independent variables considered have been 1) total height (H), 2) dbh to the square (D^2), and 3) product of dbh to the square, multiplied by total height ($D^2 H$).

The goal was to obtain some relationships between volume and the three independent variables. The functional forms of the essayed models are shown in table 2.

Table 2. Models used in the calculation of tree volume as a function of dbh D and total height H

Name of the model	Equation
Simple combined formula	$V = a + b\,(D^2 H)$
Complex combined formula	$V = a + b\,(D^2 H) + c\,(D^2 H)^2$
Complete Australian formula	$V = a + b\,(D^2 H) + c\,D^2 + d\,H$
Incomplete Austral'n formulae	$V = a + b\,(D^2 H) + c\,D^2$
	$V = a + b\,(D^2 H) + c\,H$

(Source: García Robredo et alt., 2001a)

Determination of the GHV_0

The next step is to evaluate the oven dry gross heat value (GHV_0). This parameter gives information about the energy expected from the dry biomass. The calculation of the GHV_0 has been performed by testing wood samples in calorimeter, IKO C-4000. First, chips from wood and bark have been carefully crushed in laboratory hammer into even smaller pieces. Later, these pieces have been pressed, and, as a result of the applied stress, a wooden cylinder test sample appears. Sample weight has been determined with a 0.1 mg accuracy. For the ignition, a 30 bar oxygen pressure in the chamber is required. Tests were made using samples from two poplar clones (I-214 and I-MC).

The final result of the GHV_0 is 4,294 $cal.g^{-1}$ for I-214, and 4,275 $cal.g^{-1}$ for I-MC.

Once the expected quantity of dry biomass (in tons per hectare) and the average GHV_0, (in cal/g) are calculated, it is possible to estimate the energy resources that a plantation like this can provide. These figures have been used in the calculation of the subsidy to biomass production.

Economic analysis

In order to perform an economic analysis of the biomass production process, it is necessary to define the sources of revenues and costs, the actual figures involved and the timeline of the process.

First of all, a clear definition of the activities involved is needed. Crop establishment is carried out by planting cuttings which have a 40 cm length and a 25 mm diameter.

Planting is carried out by means of a specialized equipment similar to those described by Abrahamson et alt. (1999) for willow crops. Crop management activities such as weed and pest control, fertilization and irrigation are also carried out. Harvest takes place every two years during the winter season, after leaf fall and before leaf set. The harvest is performed with a specially designed header attached to a standard forage harvester like the one shown in Figure 1.

Figure 1. Claas forage harvester with HS-2 header (Source: www.claas.com)

After four rotations (8 years), the stumps are extracted immediately after harvest, and the land is ready for a new 8-year cycle.

Revenues come from three different sources: the sale of the fuel (chips), the subsidy to fuel production and the subsidy to the maintenance of energy crops. In the Spanish market, the current price of poplar biomass is €24.04 per ton of dry matter, while the subsidy to the production (PRS) is €36.06 per ton of oil equivalent and the maintenance of the crop is subsidized with €63.00 per hectare and year (CMS).

The production costs are a consequence of the production activities listed in table 3.

Table 3. Biomass production activities

Year	Activities	
	Name	Code
0	Site preparation (Deep tilling)	SPR
	Preparation of cuttings	CUP
	Mechanized planting	MPL
1	Weed control	WCT
	Fertilization	FR1
	Irrigation	IR1
2	Fertilization	FR2
	Irrigation	IR2
	Pest & disease control treatments	PDC
	Harvest and transportation to landing	HTL
3, 5, 7	Same activities as year 1	-
4, 6	Same activities as year 2	-
8	Fertilization	FR2
	Irrigation	IR2
	Pest & disease control treatments	PDC
	Harvest and transportation to landing	HTL
	Stump extraction	STE

The actual cost figures of these activities are shown in the next section (Results). Once revenues and costs are known, the usual investment analysis indicators such as present net worth (PNW), Benefit-Cost ratio (B/C), internal rate of return (IRR) and payback period are calculated.

A comparison is made with the economic return of a twelve year rotation poplar plantation aimed at wood production for industrial uses.

RESULTS

Two way volume equations

For each one of the proposed models, the fitted volume equations, their determination coefficient R^2 and their standard error (SE), considering a sample of 250 trees, are shown in table 4.

Table 4. Fitted volume equations.

VOLUME	R^2	SE
$447.08+38.20\cdot(D^2 H)$	0.9852	304.38
$368.27+39.45\cdot(D^2 H)- 0.00394\cdot(D^2 H)^2$	0.9853	304.14
$-29.86+29.21\cdot(D^2 H)+77.97\cdot D^2+33.29\cdot H$	0.9861	296.90
$181.628+30.6542\cdot(D^2 H)+68.556\cdot D^2$	0.9860	296.54
$773.582+38.9633\cdot(D^2 H)-62.088\cdot H$	0.9854	303.46

(Source: García Robredo et alt., 2001b).

The best equation turns out to be

$$V = -29.862+29.2094\cdot(D^2 H)+77.9696\cdot D^2+33.2859\cdot H$$

These equations are a very useful tool to estimate the expected biomass in a poplar plantation (*Populus x euramericana* Dode, clone I-214), if plantation density is known, as it happens in the present communication. The regression models that have been considered are useful and, slightly modified, may be extrapolated to other species and locations.

According to the results obtained, this crop productivity (tons of dry matter per hectare) is similar or higher to that of thistle (*Cynara cardunculus* L.). However, it should not be forgotten that poplar plantations need watering during the dry season.

The production figures obtained range from 36 to 56 tons of dry matter per hectare, that is, annual productivity is between 18 and 28 odt·ha^{-1}·yr^{-1}.

Economic analysis

The revenues and costs per hectare of the different production activities are shown in table 5.

Table 5. Revenues and costs for poplar short rotation crops

Year	Activity code	Revenues (€/ha)	Costs (€/ha)	Net revenues
0	SPR		193.33	
	CUP		1,138.32	
	MPL		402.26	- 1,733.91
1	CMS	63.00		
	WCT		120.20	
	FR1		94.85	
	IR1		120.20	- 272.25
2	CMS	63.00		
	PRS	15.48·P*		
	FR2		94.85	
	IR2		120.20	
	PDC		94.85	39.52 P –
	HTL	24.04·P*	300.51	- 547.41
3, 5, 7	Same costs and revenues as year 1			
4, 6	Same costs and revenues as year 2			
8	Same costs and revenues as year 2			39.52·P -
	+ STE		1,322.23	- 1,869.64

* P: Biomass production (in oven dry tons/ha)

As described in the methodology, the usual investment analysis indicators have been calculated and a comparison has been made with the economic return of a poplar plantation aimed at wood production for industrial uses. A 6% discount rate has been used in the calculations.

The results obtained are summarized in table 6 and figure 2

Table 6. Investment analysis indicators for different biomass production levels.

Biomass production (odt/ha)	Discounted benefit (€·ha^{-1}·yr^{-1})	B/C	IRR (%)	Payback (yr)
36	-127.91	0.72	-	-
38	-89.53	0.80	-7.23	-
40	-51.16	0.89	0.19	-
42	-12.78	0.97	4.62	6
44	25.59	1.06	8.53	6
46	63.97	1.15	11.92	6
48	102.34	1.24	14.96	6
50	140.71	1.34	17.75	4
52	179.08	1.43	20.34	4
54	217.46	1.52	22.79	4
56	255.83	1.61	25.11	4
Ind´l Wood Production	499.10	2.05	14.01	12

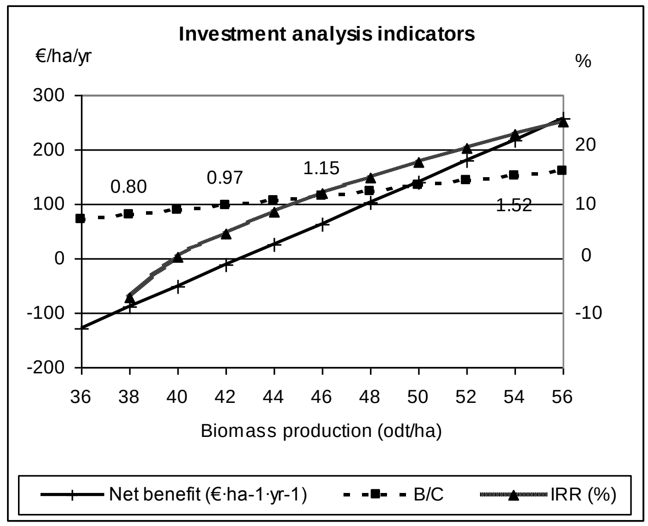

Figure 2. Economic return of poplar energy crops

When biomass production is under 43 odt/ha, the production costs are higher than the revenues.

CONCLUSIONS

From a technical point of view, poplar crops for biomass production are an alternative to traditional 12-year rotation plantations. Productivity is high and the necessary technology is available.

However, under the current subsidies and circumstances, poplar plantations aimed at wood production for industrial uses provide a higher financial return than energy crops of the same species. The annualized present net worth of the former is several times higher than that of the latter. Thus energy crops are not attractive for private investors.

Regarding energy production, the costs of biomass production by means of 2-year rotation poplar crops are also higher than those of fossil fuels and biomass residues. Thus, large scale introduction of energy crops on a commercial market cannot be achieved without further development. The financial feasibility could be improved by stimulating development of the bioenergy sector through biomass programs and investment incentives of the government.

On the other hand, energy plantations of poplar I-214 have a very positive effect regarding CO_2 fixation. Besides, an additional advantage of this kind of crops is the short payback period which allows investment recovery in just six years instead of the twelve years needed for industrial wood production.

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Causes and Costs of Unused Logging Production Capacity

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ABSTRACT – Over 80 logging crews provided weekly production data, business demographics, and quarterly expenditure information during 2000 and 2001. These weekly data serve as a quantitative narrative of the workweek, explaining the number and types of loads hauled, the amount of labor employed, the number of moves, and the extent of use of contract trucking. The crew also included an estimate of the number of loads that they could have produced but did not and the reason(s) for the loss production opportunity. During 2001, each crew also supplied cost information on a quarterly basis. This included the total expenditure of the crew, broken down into consumable supplies, labor, equipment, insurance, contract hauling, and administrative overhead. The causes of lost production were examined and reported. Using these same production data, the fixed and variable cost of each crew and the estimated lost production, we examine the potential impact on logging cost per ton caused by this underutilization of capacity.

INTRODUCTION

We report here the general findings of a study funded by the Wood Supply Research Institute (WSRI) to identify the causes and costs of unused logging capacity in the southern USA and Maine. The specific objectives of the study were to determine:

- What is the realistic capacity of the wood production system in the areas examined?
- What are the causes of capacity not being used?
- What are the costs of this unused production capacity and to whom do they accrue?

Additional information about this project can be found in the manuscripts of Chumbler *et al.* 2002 and Ulmer *et al.* 2002 contained in this same proceedings.

METHODS

Our study is unique in that it collected information weekly from both logging crews and mills in wood-using areas. In many cases, we were collecting information from a logging crew and most of the mills where it delivered wood. This allowed us to examine the magnitude and impact of market-caused lost logging production with quantifiable links to mill inventory or purchase practices. We used multiple methods to obtain information and insights that would not have been attainable using a single approach. We collected data using several techniques:

- Basic profile information from logging crews and mills,
- Field visits with every logging crew,
- Weekly reports of actual and missed production and causes for any missed production from logging crews,
- Quarterly cost reports from logging contractors,
- Weekly reports from consuming mills about usage, purchases, inventory, and short-term plans, and
- Mailed surveys of loggers in the southern region and in Maine to determine how representative our study group was of the logger population in each region.

We applied both econometric and statistical procedures to examine the impact of multiple variables on logging production levels and technical efficiency, causes of missed production, mill inventory/usage/purchase practices, and per ton logging costs. Stochastic frontier analysis was used to estimate the weekly capacity of logging crews that reported weekly production. Factors that explained observed inefficiencies were also explored. Multiple linear regression analysis was used to explore the relationship between the percentages of missed production each week and a wide range of potential explanatory variables. Survey data were analyzed using logistic regression and multiple linear regression techniques.

RESULTS

A total of 83 logging crews participated in the study and collectively provided 3,188 crew-weeks of production information between April 2000 and December 2001. Sixty-three (63) crews each provided at least 13 weeks of data. This large subset of data was used for most analyses. Of these 63 crews, 29 provided more than 52 weeks of data. Crews were well distributed geographically across the study region, with five or more crews reporting for at least 13 weeks from each of eight states (AL, FL, GA, ME, MS, SC, TX, VA). In addition, 152 mills from 12 states (AL, AR, FL, GA, LA, ME, MS, SC, NC, OK, TX, and VA) provided a completed mill profile. Of these, 130 mills provided weekly data for at least 26 weeks. We obtained a total of 8,212 weekly mill reports between April 2000 and December 2001.

Market factors were the most often cited (n=1206) cause of lost production by participating loggers (Figure 1) and caused the most missed production at 3.5 loads per week (Figure 2). Within the market causes, quota was cited far more often (n=637) than either mill handling (n=300) or mill closures (n=269). Quota losses (1.9 loads) were about twice as high as those for mill closures (1.0 loads) and three times the losses due to mill handling (0.6 loads). Weather causes were the second most frequently cited cause resulting in 2.7 loads per week being missed. Planning causes were the third most frequently cited, but created an average loss of 2.4 loads each week. Mechanical causes were cited as often as planning, yet resulted in only half the lost production (1.2 loads). Stand and tract issues were cited 385 times and accounted for 1.1 loads weekly.

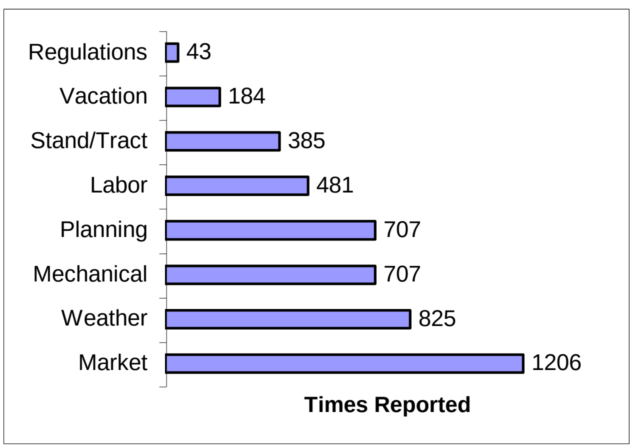

Figure 1. Causes of lost production and the frequency they were cited.

Preferred suppliers and crews that hauled their own wood lost less production than crews that were not preferred suppliers or utilized contract trucking (Figure 3). Preferred suppliers reported the lowest total cost per ton and the most consistent costs. Their median costs were 14% lower. Preferred supplier crews lost an average of 17.5% of their weekly potential compared to 22.8% for crews that were not preferred suppliers. In addition, preferred crews hauled significantly more wood (53.6 loads vs. 40.9 loads) each week while working slightly fewer days on average. They also utilized more markets and hauled a lower percentage of hardwood. The preferred supplier system appears to be commonplace with approximately half of the study

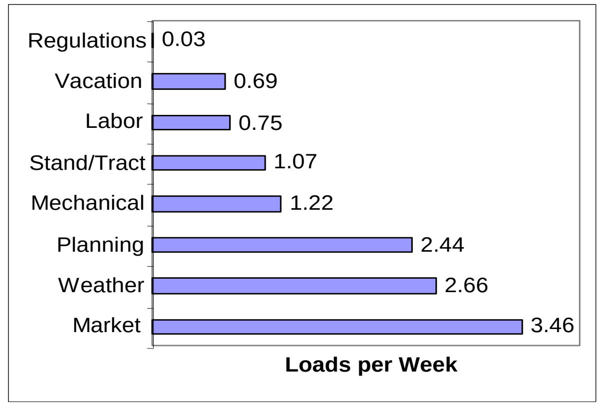

Figure 2. Causes of lost production and the mean amount of production lost each week.

participants and over half of the respondents to a survey of southern logging crews indicating that they are preferred suppliers to a mill.

The effect of dealers was not as clear. Crews that operated through a dealer missed slightly less production than other crews, delivered about six more loads per week, were less likely to have to make an undesirable move, and hauled less hardwood. Some of the highest logging costs reported, however, came from loggers hauling through wood dealers.

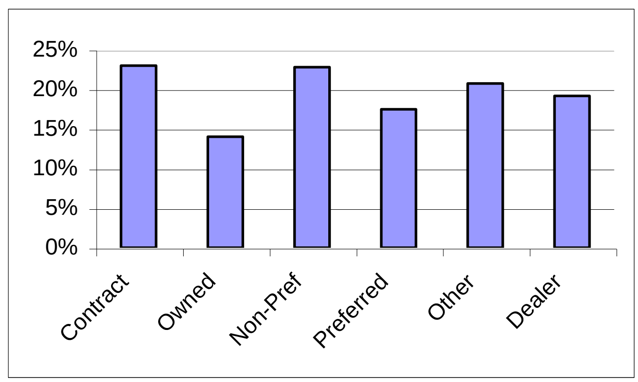

Figure 3. Missed production, % of potential, by logging crew subgroups.

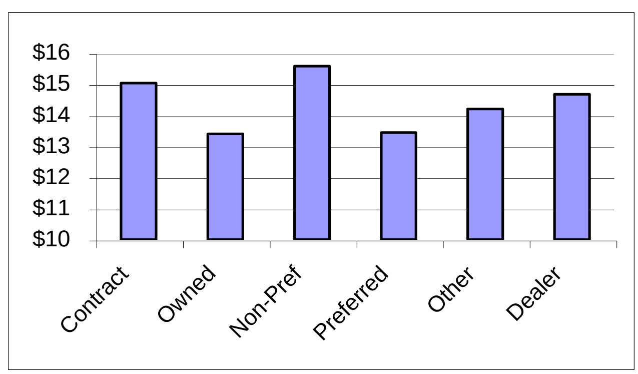

Figure 4. Total cost per ton for logging crew subgroups.

We measured the consistency of mill wood usage and purchases to examine their effect on logging production and cost. With our measure, a mill with no variation in usage or production is 100% consistent. We found that inconsistent (highly variable) mill wood usage tended to cause mill purchases to become less consistent. We further found that less consistent mill purchases led to less consistent production for logging crews delivering to those same mills. The exception to this was crews that were preferred suppliers. Their lost production due to market causes (quota, mill handling, mill closed) did not vary as the mills purchases became less consistent, due evidently to their preferred supplier agreements (Figure 5).

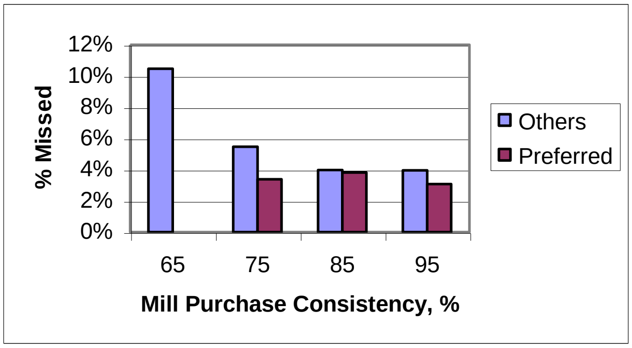

Figure 5. Percent of potential production reported lost to market causes for preferred suppliers and non-preferred supplier as mill purchase consistency changed.

We conducted a mailed survey of 7,115 logging firms in the South to assess how representative our study participants were of the overall population. We received responses from 2,555 loggers (a 36% response rate) of which 2,217 (87%) were currently in the logging business. The information obtained in this survey indicated that our study group of loggers was very representative of the population of full-time logging contractors in the southern USA, with one exception. Smaller crews that produce less than 30 loads per week were somewhat under represented in our study. A third of the crews responding to the survey produced 20 loads per week or less. Using survey data, we were able to estimate that full-time crews similar to those represented in our study, produce about 89% of the wood delivered in the region. The reasons cited for lost production by survey respondents mirrored those identified by our study participants.

Approximately 700 loggers who work in Maine responded to the Maine survey. Of these, 572 were residents of the State of Maine, and114 were residents of the Province of Quebec. The response rate for loggers who were residents of the State of Maine was 27 percent. A strong majority (77%) of logging business owners indicated that they experienced unused capacity. The primary causes of unused logging capacity cited by Maine logging business owners were weather, road conditions, equipment breakdowns, and mill-imposed quotas. Causes cited less often included regulations, moving equipment to other locations, inability to find stumpage, and mill closures.
Loggers who reported unused capacity had an average capital investment in their businesses of $382,288; those that did not report unused capacity had an average capital investment of $181,170. In addition, loggers who reported unused capacity harvested 33% of their wood on stumpage they purchased, versus 19% for loggers who did not report idle logging capacity. For those Maine logging business owners who experienced unused logging capacity, the average cost of this phenomenon was $40,257 per year, although this figure was highly variable from one respondent to another.

Overall, the wood supply system does not utilize approximately 35% of its capacity due to inefficiency. This inefficiency costs an average of $1.66 per ton or potentially as much as $430 million per year to the wood supply system in the southern USA (Figure 6). Of course, not all of this inefficiency could be removed. Conservative estimates place the potential savings generated by increased system efficiency between $135 million and $300 million per year.

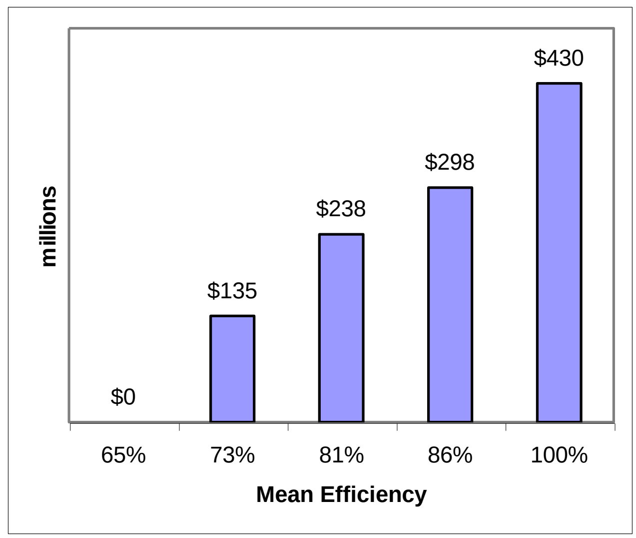

Figure 6. Potential cost savings to the wood supply system as mean efficiency increases. Current efficiency is 65%.

IMPLICATIONS

Many of the causes of unused capacity appear to be largely within the control of receiving mills, wood dealers, and logging firms in the wood supply system. Losses due to market causes, primarily quota, topped the list. Control of these will fall primarily on mills and dealers. Lost production due to mechanical and labor factors are issues for the logger to address.

However, addressing most factors will require joint, team efforts to be successful. For example, losses due to weather conditions were some of the most commonly reported causes of unused capacity. Planning was the third most important factor. While we cannot directly control the weather, better planning can help limit its effect on overall logging costs. Planning is typically a shared responsibility of mills, dealers, and loggers. Making this effort more efficient through better communication and decision-making could address these losses.

Significant savings will only result, however, from real system improvements. These improvements will likely be difficult to realize without cooperation among all wood supply system stakeholders. The relationships among participating parties are complex and continually evolving. System characteristics and traditions vary by region and location. Effective solutions will most likely be area specific and local in nature. Effective partnerships between stakeholders will be the key to efficiency improvements in the raw material supply chain for the forest products industry.

System savings cannot result until after system improvements are made. Simply reducing the rates paid for logging services and expecting the market to adjust unassisted is wishful thinking and probably counterproductive. All parties in the wood supply system (mills, dealers, and loggers) must work together to make structural changes that will produce improved efficiency.

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Systems Dynamics Simulation of Harvesting Systems

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ABSTRACT - The Harvesting System Assignment Model (HSA Model) is a computer-based simulation model that utilizes STELLA® systems dynamics software to evaluate ground-based forest harvesting systems. The purpose of the HSA model is to analyze harvesting system performance and present the output in a manner that can be used by managers and loggers to assist with tract purchase and assignment decisions. The HSA Model evaluates harvesting system production potential subject to key site, stand and system parameters, and over a range of cost scenarios.

INTRODUCTION

In the Southeastern United States, forest harvesting (logging) contractors typically have over $1.5 million invested in their business, with operating costs over $400 per hour. These systems typically contract with a wood-dealer or one consuming organization, with most timber stands assigned by this organization. In many cases, loggers are assigned to stands on a first-come-first-served basis, and as a result, mismatching of logging systems to stands occurs often (Rodgers *et al.* 2002). With the large capital investment and high operating costs, logging contractors cannot afford such assignment inefficiencies.

The HSA Model is designed to simulate the four common types of ground-based logging systems found in the Southeastern United States to determine production potential on a given stand. It allows the user to compare different systems, over a range of site, stand and system parameters, and cost scenarios.

The use of the HSA model to improve planning practices in the Southeast will support better logging system assignment decisions.

EXISTING HARVESTING MODELS

Existing harvesting models can be categorized by scope:

(1) Single machine (Eliasson and Lageson 1999; Eliasson 1998; Greene *et al.* 1987; Block and Fridley 1990; Wang *et al.* 1998; Bragg *et al.* 1994)
(2) Multiple machines/in-woods system (Randhawa and Olsen 1990, McDonald *et al.* 2001; Aedo-Ortiz *et al.* 1997; Wang and Greene 1999)
(3) Transportation system (Barret 2001; Feng and Douglas 1993; McCormack 1990; Shen and Sessions 1989)
(4) Tree-to-Mill systems (Randhawa and Olsen 1990; Goulet *et al.* 1980; Dremann 1986).

The complexity of trucking allocation and scheduling has been captured in computer simulation (Barrett 2001, McDonald *et al.* 2001). The HSA model focuses on the harvesting system without truck scheduling. Existing harvesting models capture aspects of the harvesting system/site interactions at a range of levels. However, there exists opportunity for a flexible model that provides feedback in the form of a range of comparative measures to facilitate outcomes. The HSA model will fill this need with a user-friendly computer analysis tool.

METHODOLOGY

The HSA model was developed using STELLA® systems dynamics simulation software. Systems dynamics simulation involves the modeling of dynamic processes through a series of cause-and-effect relationships with feedback, especially where multiple interdependencies are involved. The simulation method is continuous or mixed discrete/continuous in nature. This type of simulation has been applied to industry, natural processes and social dynamics (High Performance Systems: http://www.hps-inc.com).

The HSA model is purely descriptive in nature in its present form. The goal is to provide analysis of the system as defined by the user. The model treats the harvesting system as a single entity and cannot be used to improve the harvest system itself.

The HSA Model can simulate four common general ground-based harvesting system types (Sloan 2001):

(1) Manual chainsaw felling/Cable skidding
(2) Mechanized felling/Grapple skidding

(3) Shovel bunching/Grapple skidding
(4) Harvester/Forwarder cut-to-length

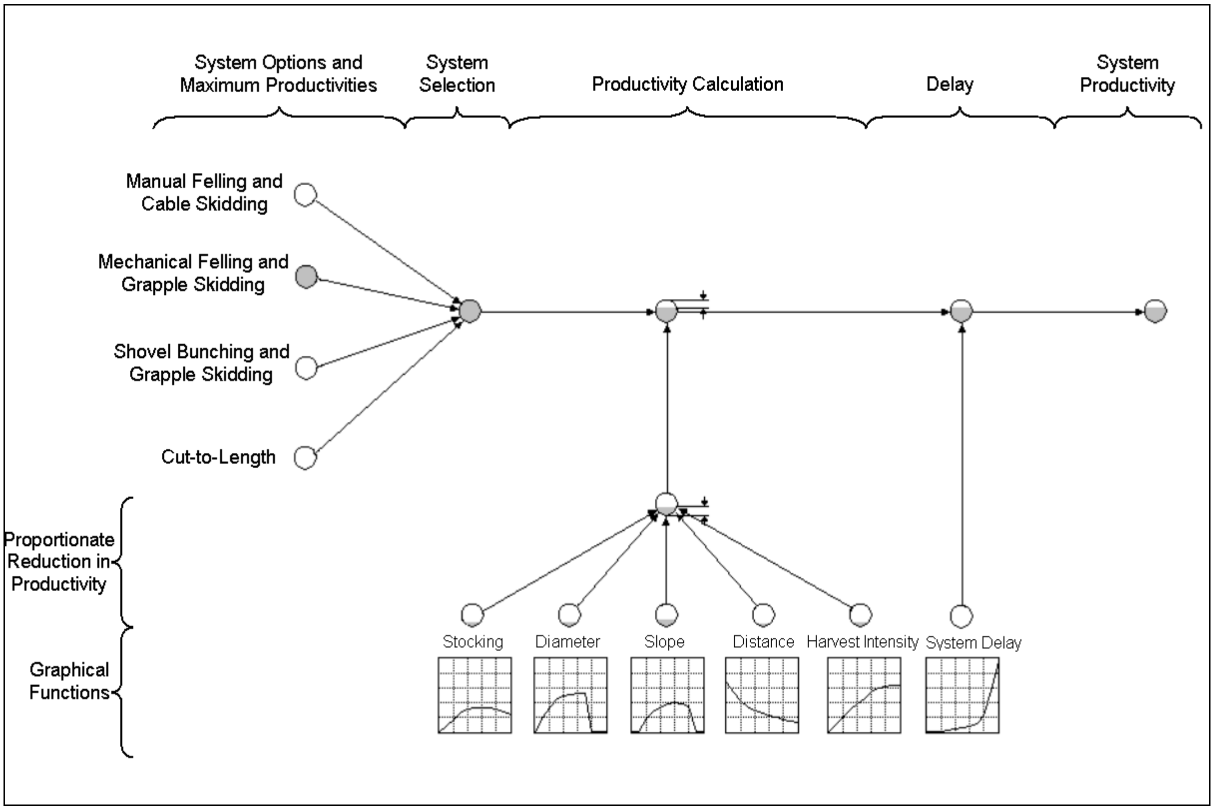

Figure 1: Schematic diagram of the HSA model.

There is significant variation in crew size and production capabilities within system type categories. The production rate calculation process is illustrated in Figure 1. HSA treats the system as having a maximum production potential, which is the productivity capability of the system when it is limited only by the machine capability and operator skill. When a parameter is within the optimal range for a system that parameter has no limiting effect on the productivity of the system. When the value of a parameter is outside the optimal range for the system, then that parameter becomes limiting.

The magnitude of the limiting effect from a non-optimal parameter is determined through parameterized production functions that calculate the proportionate magnitude of the limitation imposed by the parameter at the non-optimal level. The proportionate effect is then converted to an absolute production reduction for the system. The reduction in potential is then applied to the system production potential to generate the production rate of the system. This calculation process is repeated for each parameter for every iteration of the model.

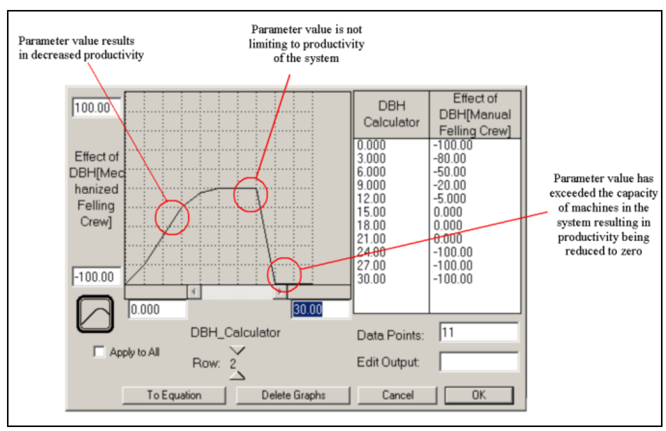

Figure 2. Graphical function of the effect of DBH parameter on productivity of a mechanized crew.

Figure 2 is a graphical function for DBH that demonstrates how the productivity calculation concept is applied in STELLA. The model generates a DBH value from the distribution specified by the user. The calculated DBH is the *x*-axis quantity in Figure 2. Each DBH value is input into the graphical function to determine the appropriate effect on productivity, which is shown on the *y*-axis. The scale on the *y*-axis is the percentage change in productivity from the system production potential. A value of –100 equates to a one hundred percent drop in productivity from the production potential, the result of which is a productivity of zero. In the optimal range for a parameter, the percentage change in productivity will be 0. An infinite number of intermediate possibilities exist depending on the parameter value range and the parameter production effect function.

Another system concept that the HSA model incorporates is system delays. Delays can occur for a range of reasons such as equipment malfunction, machine breakdown, weather related stoppages and injuries. When the system is in the delayed state the productivity is set to zero until the system leaves the delayed state. Delays are generated using a Monte-Carlo technique to initiate a delay and a probability mass function to calculate delay length possibilities. A delay length function is illustrated in Figure 3. When a delay is generated, a uniform random number determines the delay length. The likelihood of a short delay is proportionately much greater than that of a long delay in Figure 3.

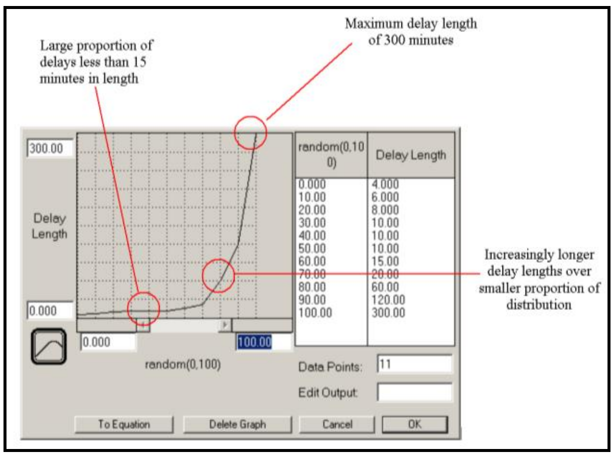

Figure 3: Schematic representation of delay length function.

Landing storage delays are treated in a similar manner. If the maximum landing storage is reached the system enters a delay state until the landing storage drops below the maximum level. The landing storage level is controlled by the loading rate and the availability of trucks. Trucks arrive periodically at an interval specified by the user.

RESULTS

Types of analysis that can be performed using the HSA model include:

- System comparison over site/stand parameter ranges.
- Determination of best operating range for a system (site and stand parameters).
- Determination of the cost of operating a system on an inefficient site.

Figure 4 illustrates the effect of piece size on the productivity of the four system types dealt with in the HSA Model. The magnitude is dependent on the production potential specified for each system in the simulation. The user can control the production potential for each system and the associated parameterized production functions to customize the simulation to a system of particular interest.

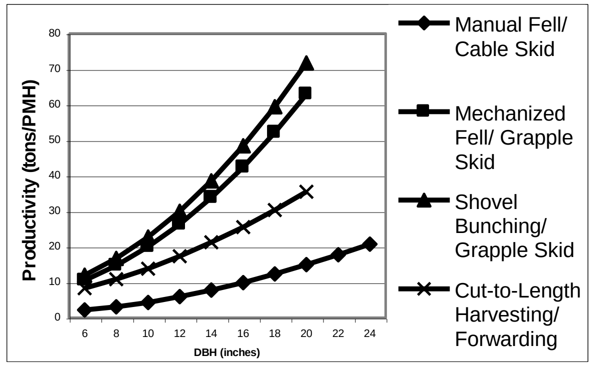

Figure 4: Piece size productivity curves.

The following is an example using four possible types of harvest systems that could be considered in the Southeastern USA:

(1) plantation clearcut for pine pulp and chip-n-saw products;
(2) plantation 5th row thinning for pine pulp;
(3) hardwood clearcut for hardwood pulp and sawlogs;
(4) hardwood 50% shelterwood for hardwood sawlogs.

In this example, the plantation harvests occur on flat terrain, while the hardwood cuts are on sites that have slopes up to 15%. The clearcuts have a larger piece size than partial cuts and the hardwood harvests have a larger average piece size than the plantations, but with much greater variability. Maximum skid distance is also greater for the hardwood harvests. Figure 5 is the result of four runs of the simulation and illustrates the sensitivity of the productivity of a Cut-To-Length system to some different harvest types.

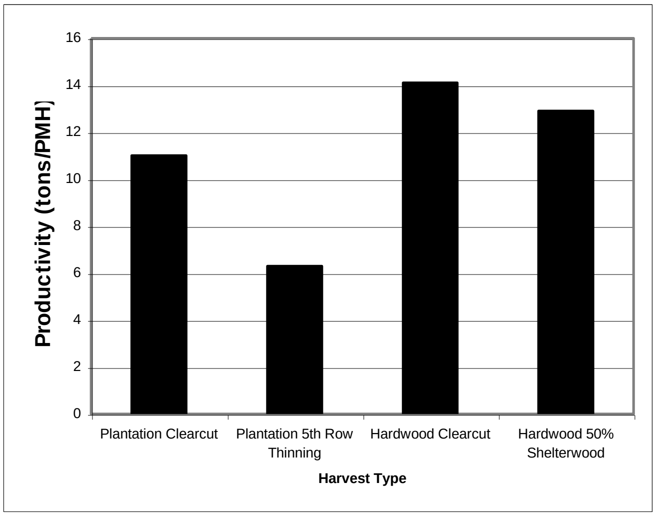

Figure 5: Production of cut-to-length system over a range of harvest types.

There is inefficiency inherent in each of the example harvests because of the associated parameter values. The cause of the inefficiencies can be inferred intuitively by comparing the parameters for various harvests. The power of the HSA model is that it attributes the contribution of each site, system and stand parameter to system inefficiency. In this example, all system parameters remain the same while site and stand parameters (piece size, stocking, slope and harvest intensity) change depending on the harvest type. Between harvest types, the absolute effect on productivity changes, along with the proportionate contribution of each site and stands parameter to the total inefficiency, can be determined. The cost of inefficiency for each parameter is exhibited in Figure 6. Overall, piece size is the dominating factor causing inefficiency. However, the presence of other parameters in causing inefficiency can be noted, such as the contribution of harvest intensity in the plantation thinning and shelterwood cut, while it is absent from the clearcuts.

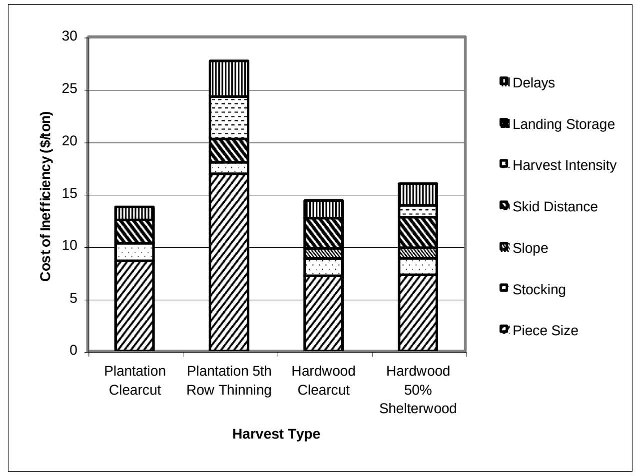

Figure 6: Cost of inefficiency of site and stand parameters for a cut-to-length system.

The HSA model presents information identifying inefficiencies in terms of production amounts and also translates this inefficiency into a parameterized cost per ton. An example of the cost of inefficiency is shown in Table 1, where the inefficiency costs are tabulated for a Cut-To-Length system performing a plantation clearcut. In this instance, the constant small piece size has resulted in an inefficiency causing a cost per ton of $8.62 to be added to the harvesting cost.

Table 1: Cost of inefficient parameters for a cut-to-length system performing plantation clearcut.

Parameter	Additional Cost/Ton
Piece Size	$8.62
Stocking	$1.67
Slope	$0.00
Skid Distance	$2.20
Harvest Intensity	$0.00
Landing Storage	$0.00
System Delays	$1.25
Total	$13.74

SUMMARY

This paper has presented an overview of the HSA model and some potential analyses that can be used to support the solution to a system assignment problem. The HSA model is a flexible system that allows the user to examine a system of interest with respect to an associated site and stand. The simulation predicts the production potential of the system and highlights inefficiencies that can be mitigated through better management of system assignments.

A key feature that provides much of the power of the HSA model is the ability to estimate the contribution to inefficiency of individual system, site and stand parameters. These inefficiencies are presented in a parameterized way through a graphical window analysis of production and in average cost of inefficiency per ton. The feedback from the simulation with respect to inefficiency allows users to determine the cause of inefficiencies and the effect of the inefficiencies on the effectiveness of the system. This information can be used to assist managers and loggers in stand purchasing and assignment decision-making.

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Variation in Skidder Productivity Over Time During Timber Harvest

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ABSTRACT – Time study was performed on a single skidder operating in a clearcut, tree length harvest over an entire 29-ha tract. The time study was performed using an automated data collection system and reported total time and distance for each skid cycle. The cycle was further broken down into time spent off the deck pulling bundles, and time spent on the deck delimbing, dropping, piling, and clearing. There was a linear relationship found between off-deck cycle time and distance. The variability in the data was indicative of a situation in which the operator was working near peak efficiency during most cycles, with obvious delays occurring in less than 10 percent of cases. Total cycle time as a function of skid distance was more variable, indicating that time spent performing functions on the deck was less predictable. Averaging over all cycles, time spent on the deck accounted for about 1/3 of the operator’s productive time. Increases in cycle times over the course of the harvest were consistent with expectations, increasing rapidly over the first few days of the harvest then leveling off.

INTRODUCTION

Logging rates in the Southeast have been flat or decreasing for many consecutive years, resulting in the closing of some logging firms and financial strain in most others. Justified or not, there is a general feeling among loggers that they shoulder a disproportionate share of the burden during hard economic times in the domestic wood products industry. The economic situation in the industry is unlikely to change, and will probably get worse before it improves. Loggers that will survive the downturn might either cut corners and operate on the fringe of legal and ethical constraints, or innovate to maintain their profitability. Some of this innovation will come in the form of more highly productive equipment, but our contention is that how equipment is applied, especially when operating so close to the margin of profitability, is as important as the machinery itself. There is a great need, therefore, to understand the limits of productivity of logging systems as a function of stand conditions or other external factors.

There is a large body of literature concerning production rates of skidders (e.g. Kluender and others 1997; Klepac and others 2001). These studies have used traditional time study methods and the results have been based on a statistically large-enough sample size of work cycles. The rule of thumb applied in studies from our own lab has been that a minimum of 30 work cycles be sampled in order to get an acceptably accurate measure of productivity. Assuming a 2.5-ton capacity skidder, 30 skid cycles corresponds to about 3 truckloads of wood, less than 1 day’s typical production for tree length systems in the South. By necessity, therefore, time study results are qualified by saying that they are appropriate ‘for the conditions tested’. If our goal is to test the limits of skidder production across a range of conditions, these types of studies will need to be repeated many times over, an expensive undertaking. Kluender and others (1997) observed over 1000 skid cycles and reported on production. Measurements were taken across many sites and multiple crews. The study provided broad insight into variability of production but did not reveal the root causes of variability. Linking cause and effect in productivity of harvesting machines will require in-depth study of representative logging systems over a long period of time.

An automated time study system for skidders was developed in order to make long-term study of skidder productivity variations possible. The system used Global Positioning System (GPS) technology to track skidder location over time then inferred work cycle elements from the motion of the machine. This report summarizes some preliminary results of applying the time study system during the harvest of an entire tract. The goal of the study was to understand how work cycle characteristics varied as the stand was cut. Our hypothesis was that utilization of the machine would increase as the cut block area increased because of longer turn distances. We also were interested in examining how much time the skidder spent performing chores other than hauling wood, typically cleaning the deck area or around a delimbing gate. The hypothesis was that the absolute amount of time spent performing these functions would remain constant during the progression of the harvest, but that the proportion would be smaller as turn distances became longer.

EXPERIMENTAL METHODS

Other publications (e.g. McDonald 1999) have identified the detailed methods used to monitor time productivity of skidders from GPS data. The process involves collecting positional data at short (in our case, 2 sec) intervals for the entire time the machine is in use. These data are filtered using a custom program to identify measurable events, primarily crossing boundaries of polygons or lines and reversing direction of motion. The order and frequency of these events are analyzed to reconstruct the functional activity of the skidder.

For this study, a tree length logger operating in the vicinity of Auburn, AL agreed to allow the GPS system to be placed on one of his skidders. The logger operates two logging crews in parallel, each with a single skidder and loader (equipped with a pull through delimber), with a single feller-buncher cutting for both crews. The systems were operating in a 29-ha clearcut harvest of a loblolly pine plantation, 21 years old with approximately 60 percent chip-n-saw stems and the remainder pulpwood. There was a very small hardwood component on the site. The entire operation was limited to a 45 truckloads-per-week quota, except for week 3 of the study when the quota was reduced to 30 because of maintenance on the woodyard at the consuming mill. The GPS was mounted in a Cat 525 skidder equipped with a 110-inch grapple, about 4 years old, and with an experienced operator.

GPS data were collected during a 4-week period, mostly in May 2002. The data collection equipment was placed on the skidder about 4-5 days after the crew moved onto the harvest site. Data for short skid turns were therefore missing, so to compensate for the loss the monitoring was continued when the crew moved to a second site. This second site was adjacent to the original, and stand and operating conditions were essentially the same.

Each working day a computer data acquisition system was placed on the skidder to record the GPS positions. The crew started work normally around 7:30 – 8:00 AM, with the computer put on the machine typically around 9:00 AM. The system worked well except for two days during week 3 of the study when a loose power connection resulted in loss of data.

To track the progress of the area in which the skidder operated, the boundary of the cut block was mapped using a hand-held GPS on an intermittent basis. Figure 1 shows the boundaries as measured during the study, including the area used in the second site to substitute for the missing time on the first. Also included in the figure were example GPS data from the skidder recorded on three separate days.

Analysis of the GPS data focused on identifying two types of events: a) work off the deck area, which included out- and inbound travel to tree bundles plus time to grapple the load, and b) time spent on the deck. Time on deck included delimbing (using a gate), plus time to pile wood for the loader, clear out the deck, gate, and trailer loading areas, plus travel time within the deck perimeter.

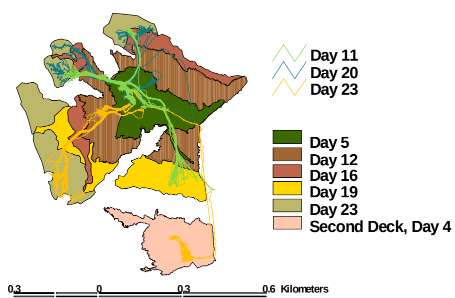

Figure 1. Map of the harvested tract, including example days of machine tracking data. Color of the map indicates boundary position as of the day indicated in the legend.

A verification of the time study analysis was carried out. An entire day of skidder activity was monitored using an observer with a stopwatch. The observer attempted to measure the same type data as were being collected using the GPS system, i.e. time on and off the deck. There were some inevitable discrepancies between the two systems because of the imprecise knowledge by the observer of the 'deck' boundaries, but overall the verification indicated that the GPS data collection system worked well. A total of 51 skid cycles were observed on site and 48 of those were detected using the automated analysis. Skid cycle time was consistent between observed and calculated versions in all but about 6 cases where the difference was greater than 10 secs. Causes of the discrepancies between the two systems were not investigated to a great extent, but were probably indicative of general limitations of the automated analysis system. The skid cycle elements were identified using a rule-based approach. For cycles deviating from normal procedures, the approach broke down unless some time was invested to find out how the skidder motion was different in a particular instance and then write a rule to account for it. Only the most general rules were used in this investigation and the subsequent loss of data for some cycles was accepted.

In addition to the GPS monitoring, each machine on the logging job was outfitted with an electronic service recorder (Thompson 2002). These devices recorded the total time spent by each machine in some state other than off or idling. This was assumed to be work time for the purposes of this study.

RESULTS AND DISCUSSION

Data were collected for a total of 18 working days. Reduction of the positional information to skid cycles resulted in identification of 467 turns, each having a corresponding total time and distance covered. Of the cycles detected, 448 included a discernible time on the deck, or encompassed the entire skid cycle of traveling empty, retrieving a bundle, delimbing, and dropping it on the deck.

Figure 2 shows total distance covered as a function of time working off the logging deck. The largest portion of this time was spent in traveling out and returning with tree bundles, the remainder being time spent grappling the load. The very long skid cycle noticeable at the upper right of the plot was the result of the deck being too crowded with trees to drop any more and the operator spotting several consecutive bundles just short of the deck.

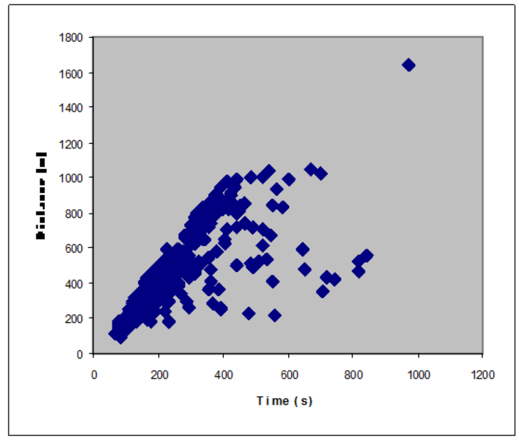

Figure 2. Plot of round-trip skid cycle distance as a function of cycle time. Time included only that portion of the cycle spent in working off the deck.

There was a very clear upper bound to the data in the figure, indicating that either a limit of the machine or the operator was controlling productivity during this part of the cycle. The productivity of this part of the skid cycle was surprisingly consistent. Less than 10 percent of the total cycles could have been considered outliers (far to the right in the figure), and most of those were special circumstances involving stops by the operator during the grappling process. Figure 3 shows total skid distance as a function of cycle time, including time and distance spent on the logging deck during the turn. Total cycle time was less consistent, indicating that the portion of the cycle spent on the deck would be the likely part of a skid turn to look for increases in skidder efficiency.

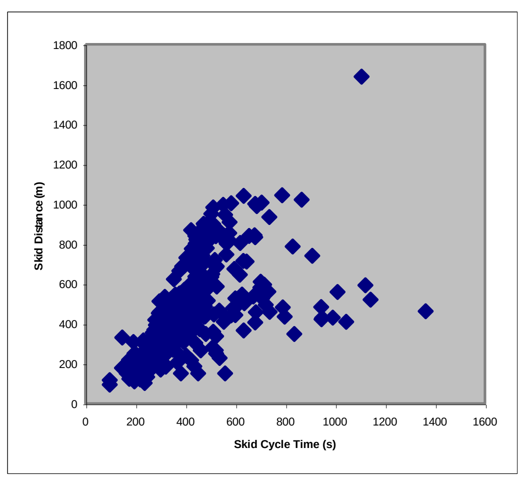

Figure 3. Plot of round-trip skid distance as a function of total cycle time.

The feller-buncher operator stayed ahead of the skidders during this study, but never by more than a couple of days. Tree bundles to be skidded then were normally located around the perimeter of the cut block area. Skid cycle times, therefore, should have increased over time during the harvest, and this should have been most apparent for the portion of the cycle spent off the logging deck. Figure 4 is a plot of average off-deck skid cycle time as a function of day of harvest. There was a definite nearly linear increase in cycle times during the first 4-6 days on site, but the times tended to level off after that, even decrease some days. There were some operational conditions that favored this result. The two days with the longest cycle times coincided with a request for more pulpwood by the consuming mill. Because pulpwood was relatively scarce in the stand, the operator had to look at specific locations somewhat far removed from the deck to find high proportions of it, increasing cycle times for those days. For ‘regularly-shaped’ tracts, however, cycle times should have been proportional to the square root of distance to the edge of the cut block. For this tract, shape was close enough to circular to not impact cycle times to any great extent and they remained fairly uniform during most of the harvest. This result would tend to not support the notion that, for this tract, there were any potential increases in skidder productivity that could be gained by changing the operator’s methods.

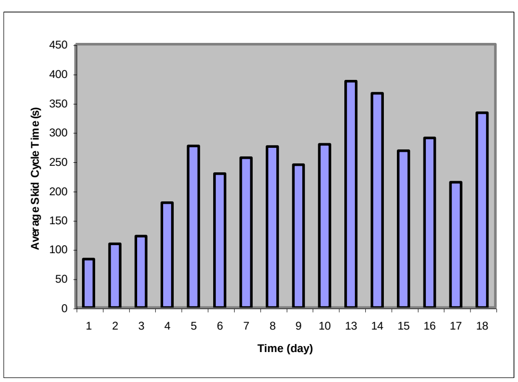

Figure 4. Off-deck skid cycle time as a function of day of harvest.

For the purposes of this study, the skid cycle was broken down into two components: time off the deck (traveling to and from bundles plus grappling), and time on the deck (delimbing, piling, clearing). The assumption was that the proportion of time spent off the deck would be initially low when first moving onto the site, but would increase steadily over the course of the harvest. It was also assumed that a relatively low percentage of time would be spent on the deck because it was small relative to the size of the tract. Figure 5 is a plot of the ratio of time off deck to on by day of harvest. As expected, the trend of the ratio mirrored that of the total off-deck time seen in Figure 4. There was an initial linear increase followed by an extended period of time when the ratio did not change systematically. The magnitude of the ratio, however, was somewhat surprising. Averaging over the entire harvest, the amount of time spent on the logging deck delimbing, piling logs, and clearing slash represented about a third of the productive time of the skidder.

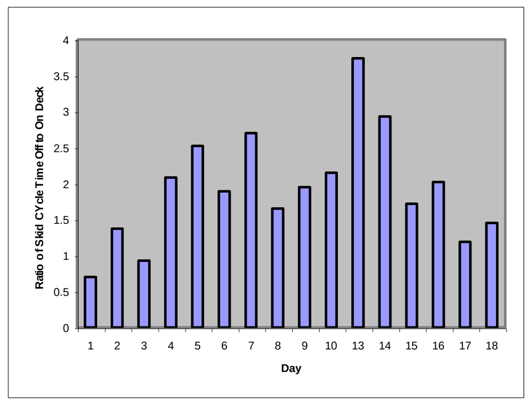

Figure 5. Ratio of off-deck to on-deck time as a function of day of harvest.

The skidder averaged 6.4 hours per day working, except on those days when the quota was running out or weather forced a shutdown. On those same days, the loader averaged 4.5 hours working. This result implied that about 30 percent of the loader’s capacity was not being used despite the best efforts of the skidder operator. Although the logger could easily meet his quota with the system as it was configured, the setup did not make full use of the potential productivity of the equipment. Ignoring transport, skidding was the limiting factor in this system. Increasing productivity would have required matching available skidding to loader capacity. The simplest way to achieve this would have been to combine the crews and assign specific tasks to the loaders: one to delimb, one to load trucks. Both skidders could then pull to the same deck, more fully utilizing the loaders.

The harvesting operation studied in this test was limited by skidding capacity. Utilization of the skidder was not an issue – the skidder remained active as long as was necessary to achieve a daily objective. When limited by quota, this objective was met when all log trailers available at the end of the day had been loaded. Utilization of the machine, therefore, varied over time during the harvest of the block, but primarily in response to wood demand factors rather than changes in operating conditions. Day-to-day, total time spent working by the skidder was remarkably consistent except for a couple of instances of shortened workdays because of maintenance performed on the machine. Utilization was an imperfect measure of performance under the circumstances of this test and did not reflect total system efficiency, but rather efficiency of the transport system.

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The Evolution of the Forest Logging Mechanization in Brazil
The Logging Mechanization Processes and Phases at Rigesa

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ABSTRACT - This document describes the sequence of the major evolution of Rigesa's logging activities since 1974, when Rigesa's paper mill initiated its operations in Três Barras, Santa Catarina State, Brazil. These evolution's can be divided into four phases: Phase I - The first adaptation of small agriculture tractor for tree skidding, and the intense use of labor for felling, delimbing, bucking and manual loading of pallets. Phase II – A period characterized by a transition from a practical mechanical manager to the introduction and addition of a mechanical engineer to develop new equipments. The first engineer established partnership with Implemater to build hydraulic grapple for mini-skidders and construction of a pulpwood loader. Phase III - Year 1993, the period where adapted agriculture tractors for logging operations were abandoned, because the opening for machinery importation with free taxation from the Brazilian Government. Phase IV - The present period, which has been the continuation of the current free tax importation incentives. Period that has leveraged the Brazilian's pulp and paper industry to a worldwide leader in the sector, applying the most advanced mechanization processes available in forestry logging.

The logging mechanization at Rigesa started with the operation of its paper mill in Três Barras, Santa Catarina State, in 1994. During the early 1970's this region was largely characterized by wood extratevism with a large focus on native species such as Brazilian pine Araucaria and Imbuia. Wood harvesting systems were quite primitive during this period, consisting of chainsaws and agricultural tractors with 85 to 100 hp. Agriculture's tractor with winches were adapted to reach a total capacity of 15 ton of traction and wood transportation was carried by average truck trailers of two axles with approximately 18.0 ton load which were loaded manually.

In Rigesa's initial logging activities, only a few items from the local empirical methods were adopted. Chainsaws were used to cut pine plantations, with horses hauling the trees onto the road, and chainsaws again to cut the logs into 1.20 meters long.

At the time of the Três Barras paper mill operation began, half of Rigesa's logs came from pine plantations and half from residues of Araucaria solid wood. Initial production reached 100 tons of linear board daily compared to our current average of 600. This production demand requires 200,000 and 900,000 metric tons of wood per year respectively.

With continuous increase of paper production we began the process of evolving our logging harvesting system. Although the region had been characterized as being traditional in saw log production of noble species, lacking specialized labor was one of the major limitations to improve logging operations. In efforts to move forward, Rigesa imported labor from up to 200km away. These laborers were managed throughout the week and food, lodging, and an infrastructure to accommodate them were one of the major driving costs for logging operations. The evolution of the logging operation at Rigesa can clearly be divided into four phases:

First Phase

The first phase of the logging mechanization was from 1982 to 1983. With the help of Rigesa's mechanics and foresters, we developed and adapted agricultural tractors to handle our logging activities at that time. Some major achievements for the time was an adapted third point of a Valmet 65 hp. An iron bar with fissures where chains were attached to handled hauling up to 10 delimbed trees onto the side of the road. Once this was accomplished, trees were bucked with chain saws and loaded manually into iron pallets, which carried up to 6 to 7 tons of wood. These pallets were then pulled onto the loading trucks by winch connected to power take off.

This system was improved significantly with the introduction of hydraulic grapples substituting the iron bars and metal chains. The manual loading onto the pallets was replaced by imported Munck-Johns loaders, which were adapted to Brazilian agricultural tractors. The most difficult barrier of this phase was standardizing the hydraulic grapples that were developed in house. Hydraulic grapple maintenances were difficulty and with a high cost because of the difficulty to find high quality hydraulic cylinders and other spare parts with high quality also. At that time, Rigesa’s logging system was composed of 36 mini-skidders and 14 Munck-Johns cranes.

Second Phase

The second phase started with hiring of a mechanical engineer for the mechanical maintenance shop, where he was initially involved with developing new systems. In 1994 Rigesa started seeking partnerships from companies in the agricultural field with experience in hydraulic machinery, which led to manufacturing hydraulic grapples for the mini-skidders. This change improved maintenance availability of our logging equipment, reducing cost and increasing our harvesting productivity substantially.

From 1983 to 1993, a partnership was established with Implemater, which resulted in marked improvement for our national brand crane and mini-skidders. They were the first one to introduce the joystick control systems replacing the manual hydraulic commands to control the hydraulic grapples. From our standpoint, Implemater was a pioneer during this period. Caterpillar did not participate directly with these developments because of the high taxation applied on imported equipment at that time.

A remarkable innovation in this period was the Implanor Bell Tricycle. For this important technological advance at the time, we invested $35,000 just for the development that was carried out by Implanor. Implanor was already working a long time with developing equipments for sugar cane harvesting operations in Brazil and already had about 800 units operating. When we started operating our first unit, the mechanical availability was around 25% and it reached 75% at the end of a year. It was the first unit with a directional cutting head coupled with a saw. A Brazilian company located in the northeast of the country was the responsibly for developing this chainsaw cutting head, that for several years was the most mechanically dependable piece in its category. Tricycle replaced five to six chainsaw operators in the tree felling activity.

During this period we redirect and establish a new program for training our logging crews by focusing on selecting operators that could easily adapt to new sophisticated machinery that may be introduced in the future. Along with this training plan, we revised our logging operational planning system to better understand our needs for future necessity of new technology. Obviously, that to introduce this new technologies, we would need to control a range of variables involved in the process, like tree height, minimum/average/maximum tree weight, average hauling distance to the roadside, site characteristics, and several other factors directly involved with logging operations.

A small but important item was also introduced during this period, the Delimbing Gate. The Delimbing Gate was responsible for a significant increase in the productivity of the logging operations at that time.

During this period the pine plantations harvesting system was changed. From the two thinning interventions and the Clear Cut of 20 years old plantations, Rigesa adopted only the Clear Cut at age 18. This change was driven by the focus of only maximize the pine to the Três Barras paper mill. Pine sawlog sales was zero.

Third Phase

Year 1993, the period where adapted agriculture tractors for logging operations were abandoned, because the opening for machinery importation with free taxation from the Brazilian Government. The logging mechanization significantly intensified during this period that started in 1993. Around the same time Rigesa started adopting OSHA safety guidelines, which had more demanding criteria than the Brazilian legislation. Since the mini-skidders were adapted agricultural tractors in a monoblock chassis, our first change was to replace them by Caterpillar articulated skidders (models 518 and 525). The 17 units purchased in that time replaced the 36 mini-skidders units. The next change was to implement a system to mechanically prepare 2,2 meters logs with Prentice loader and CTR hydraulic slashers. With this replacement, manual chainsaw operation was faded out, therefore eliminating a system responsible for the most reportable accidents in the forestry sector. Adopting this system the Rigesa Forestry Division reached more than 365 days without reportable accidents.

Also, in this period we introduced the feller hydro-ax 611 EX tractor with a cutting disk. This feller replaced all Implanor fellers, increasing operational productivities and mechanical availability.

The introduction of these new equipments required an intensive/extensive mechanical knowledge for an area that were continuously demanding more accurate organization and diligence. At this time a new mechanical engineer was hired, along with the restructuring of the mechanical shop and the mechanics involved with the more sophisticated equipment.

Also during this period, a more elaborated PESA – Paraná Equipamentos S/A (Cat dealer) technical assistance was required. At the end of the period (1996/1999), the environmental pressure and the necessity of using logging machinery that would cause less environmental impact became more primordial. For logging using chainsaws, which were considered to be disturbing to the surround environment because there was not a practical way to control where the trees would fall, this way damaging native forest fragments bordering the forest plantations. In order to overcome this problem, Fellers could direct the fall of the trees being logged and this way justifying even more the replacement of chainsaws.

Fourth Phase

It started when the pine solid wood market in Brazil became an attractive business. It represented an increase in the return worth for fiber and solid wood production to aggregated value. The market demand for solid wood products was increasing the demand for pine logs becoming a market opportunity for Rigesa, which before 1999 was not a representative. Since 1999 our log sales market share has been increasing and the perspectives for the following years seams promising. In the process of increasing demand for pine logs sales, Rigesa decides improving its logging system. In addition to the need for enhancing the logging operation productivity, problems with the quality of the logs due to damages caused on the first log of the stem by the feller (with cutting disks) and also due to delimbing process using grapple skidders, were the first to be assessed.

After assessing the mechanical and economical issues related with this problem, Rigesa decided giving the opportunity for all forest machinery makers to present a renovating logging system package. This package took in consideration the following requirements:

- ✓ Improve the quality of logs for sales;
- ✓ Increase the operational efficiency of the skidders currently in use;
- ✓ Consider a new equipment for felling that can be used for two working shifts;
- ✓ Assurance of compatible return on investment;
- ✓ Improve ergonomic features;
- ✓ Even if an improved equipment, that the maker would commit to supply the mechanical pieces for replacement in the country;
- ✓ Reduce forest residues to less than 2.5% loss;
- ✓ Reduce the current loss of productive hours from 8% to the minimum possible related with rain, when compared to the equipment currently being used;
- ✓ Cost reduction of US$ 1.00/ton in the logging operation;
- ✓ Improve energetic efficiency by increasing the machines operational hour per diesel consumption;
- ✓ Increase mechanical efficiency of other aspects involved with increasing the performance of the equipment;

From the several companies that were willing to work on these requirements, the PESA - Paraná Equipamentos S/A and Caterpillar Brazil teams, were the ones that introduced the CAT 320 CL excavator with the harvesting head Logmax-750. The Caterpillar machine was selected for several reasons, but among them was the fact that their excavator CAT-320 CL was totally assembled in Brazil and reached the desired productivity following the ergonomic requirements specified. The logging Logmax head, considered one of the best in the world, fit the criteria established according to the parameters for performance, logging production, and the quality of logs delimbing.

With the introduction of the harvester, the skidders production improved 70% the hauling efficiency, since the delimbing operation no longer required the Delimbing Gate. The new system also reduced the risk of accidents involving back pain with the operators that was caused by the need of operating the skidders forward and backward frequently (now only forward operations). This change has also improved the skidder usage by allowing it to operate in two shifts. The harvester machine has definitely contributed to make the two working shifts possible at Rigesa.

An important factor that counted for the selection of PESA and CAT, was the capability of provide immediate support and its multi-disciplinary team that was always prompt to solve problems and provide technical assistance to their costumers in Brazil. Along with completely fulfilling all the requirements for a new logging system, the commitment with the customer by PESA/CAT was certainly mostly relevant in Rigesa's evaluation.

Currently Rigesa has four harvester units in full operation and with 2/3 of the logging infrastructure working in two shifts. Rigesa is also currently replacing the Prentices/Slashers with the CAT 320CL on trails and replacing the slasher CTR by PESA slashers.

Next Changes

Rigesa's forestry division is currently allocating 1/3 of its wood production to pine logs sales. From the total harvesting operations only 1/5 is produced with our own resources. We believe the next phase will involve the system cut-to-length with the Harvester and Forwarder. In this scenario, a Harvester would select the logs in the field and a Forwarder would haul the logs to the road the log products segregated by different quality classes. In order to adopt this system, the solid wood market will need to reassess the potential value gain that a segregated product can aggregate to their end product and be willing to pay for this gain in the log purchased.

Rigesa’s main vision for now is to continue focusing on the production of pulpwood for our mill, and embraces new market opportunities for forest products as it unleashes.

Opportunities to Increase Productivity of the Industrial Wood Supply System Through Improved Planning and Communications

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Abstract

Planning in the forest industry takes on many forms. From planting to harvesting to site preparation, planning has the ability to improve the efficiency of an operation and reduce costs. Due to the dynamic nature of many of the parameters in the forest industry planning is often poorly done (or not done at all). The goal of the study was to (1) determine the level of planning and communication present in the forest industry and (2) provide a decision framework for planning and communication in the forest industry. During the summer of 2001 researchers from Virginia Tech's Industrial Forestry Operations Group, in cooperation with the Wood Supply Research Institute, collected information to determine the level of planning and communication present in the forest industry. Loggers, consumers, and wood dealers from the southeast and northeast regions of the United States volunteered information. This paper presents the different levels of planning and summarizes key findings from the interviews about the current state of planning and communication.

Levels of Planning

There are three recognized levels of planning. Each of the three levels, (strategic, tactical, and operational), relate to different time frames and aspects of an organization. In theory, each level of planning helps guide the organization toward its future goals and ensures that all of a company's resources are being employed to make reach those goals.

Strategic Planning

Planning at the strategic level should answer the "what, where and when" questions). Strategic planning does not attempt to make decisions, but rather guide the manner in which they are made. Strategic planning is an attempt to plan the future on paper and deals with the interrelationship of the individual parts of an organization. A strategic plan focuses on the long-term goals of an organization and is concerned with relating the organization to the environment. Strategic planning offers a basis for preparing a comprehensive system of plans and can reach into the future 5 years or more. The exact length of time horizon varies by industry and company. Strategic level planning generally deals with large geographic areas while other levels of planning may relate to smaller geographic regions. In many cases strategic planning is the most challenging to carry out because the planner needs to think in terms of the future. Obtaining agreement between multiple departments, on the future path of the organization can be challenging at best. It may also be found that the environment that was planned for is different from the one that evolved.

Tactical Planning

Tactical planning is used to integrate the internal activities of the organization, and is considered an intermediate stage between strategic and operational planning. Tactical planning is concerned with the allocation and uses of resources. Tactical planning provides input for compiling annual budgets, and ensuring that financial requirements are met in the coming year. Tactical planners translate the paper plans created in the strategic phase into medium range plans that serve as guidelines for the short-term operations of the organization. Tactical planning has control over areas such as products, research, utilization of equipment, and personnel.

Operational Planning

The most commonly recognized level of planning is operational. Operational planning relates to the day-to-day functions of the operation and is more detailed than the other levels of planning due primarily to the increased availability of information. Operational plans are generally developed for, and only valid for, a fixed period of time and are used to implement portions of strategic and tactical plans. Examples of benefits of operational planning include minimization of road construction cost resulting from proper layout techniques, maximum return on capital invested in road construction by serving the highest number of acres, increased efficiency of harvesting operations resulting from properly matching the harvest systems to the characteristics of the harvest block.

Planning Tools

With the continual improvement and cost effectiveness of technology, an increasing use of Geographic Information Systems (GIS) and more interactive tools is being seen. These tools are becoming available for use in planning activities and can improve the quality of planning that is performed. Most currently available tools reduce the amount of work required in the office and in the field. While these tools offer time saving advantages, results must still be field verified to ensure that the information is correct and the corresponding decision reflects reality.

GIS tools have been developed to aid in the planning of roads, harvest areas, drainages, etc. Rogers *et al.* (2001) describes a tool that utilizes a digital quadrangle map in a GIS to calculate road grades and layout options. Users determine the beginning and ending point of a proposed road by selecting nodes. The application will determine the best road location based on parameters defined by the user. Field verification will be necessary, but the amount of time spent manually locating a road and determining grade on a topographic map will be greatly reduced.

The Study

During 2001, Virginia Tech Forestry Operations researchers completed a study to assess the current state of planning and communication in the industrial wood supply process and to identify opportunities for improvement. Researchers performed interviews with 169 individuals representing three distinct segments of the wood supply system. Interviews were performed during the summer of 2001 in the southeast and northeast regions of the United States. Figure 1 depicts states where interviews were performed.

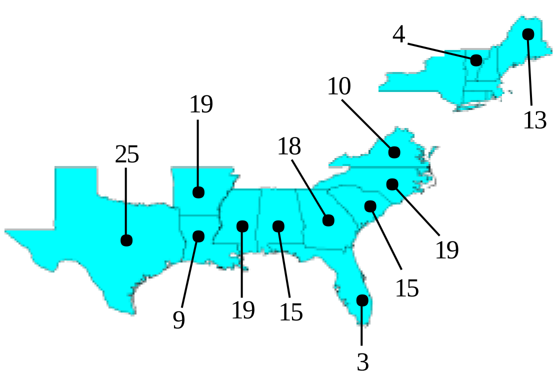

Figure 1. States interviewed and number of interviews performed.

The overall findings of this study showed that current planning in the wood supply system is primarily 'reactive' rather than proactive, resulting in extremely short planning horizons for all segments of the supply chain. This is due in some part to the high degree of uncertainty facing the forest and logging industries in today's business climate, but is also a result of a continuation of traditional business practices that promote inefficiencies. During the course of the study five key planning opportunities were identified. Key planning opportunities identified were: wood flow planning, communication, tract allocation, production monitoring and rate setting, and transportation system allocation. These planning opportunities impact each level of the wood supply system differently

Wood Flow Planning

Frequent, short term changes in mill requirements, including delivery schedules, inventories, and specifications, drive many of the constraints to planning in the wood supply system. Thirty-five percent of the wood procurement organizations interviewed reported that the consumption mix at their mill often changed on a weekly basis. These same individuals reported that they typically receive only one or two week's notice prior to significant changes in mill wood requirements (Figure 2).

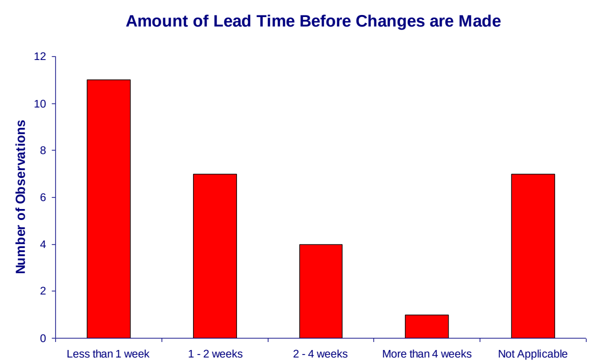

Figure 2. Lead time provided prior to mill changes.

With short lead times and low inventories companies are forced to react to changes rather than plan for them. The result is inefficiency being built into the harvesting and transportation functions to service constantly changing demands. In some manner, producers must be compensated for this inefficiency; otherwise they will be forced out of business.

Communication

Advances in communication technology (such as cell phones) are facilitating frequent verbal communications between the different segments of the wood supply chain. This frequent communication is a factor in reducing the planning horizons for suppliers. Improved communications technologies are being used to actively manage daily (rather than weekly, monthly) wood flows as "just-in-time" inventory management goals.

Communication between the consumers and producers is frequent (in many cases two or more times per week). Even though high levels of communication are present suppliers interact with and exchange information with those responsible for planning on a less frequent basis.

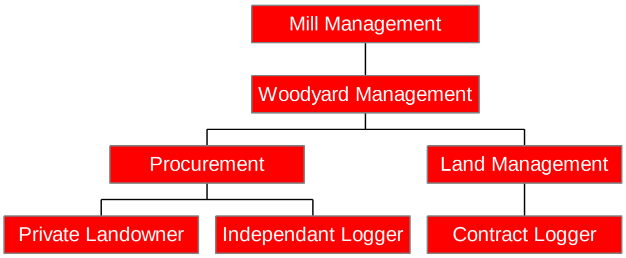

Figure 3. Wood supply system information flow example.

Communication between suppliers and middle or upper level management (those with the ability to enact changes) occur less frequently than with front line foresters. As Figure 3 demonstrates, information exchange in the forest industry is generally carried out from the top down. The result is that the individuals with the ability to implement change (woodyard and mill management) do not directly interact with those who a responsible for the implementation of the plan. Without a closed feedback loop between the affected parties a true planning cycle do not exist.

Tract Allocation

With increased communication capability has come a reduced emphasis on allocation practices to producers from both the consumer and the wood dealer. As Figure 4 shows, one third of the contract loggers that were interviewed know the location and characteristics of the next tract that they will harvest more than one week in advance of moving to it. The majority of loggers interviewed also stated that they are offered tracts on a time. Without better information about tracts to be harvest the ability to plan for wet weather, dry weather, and annual production is virtually impossible.

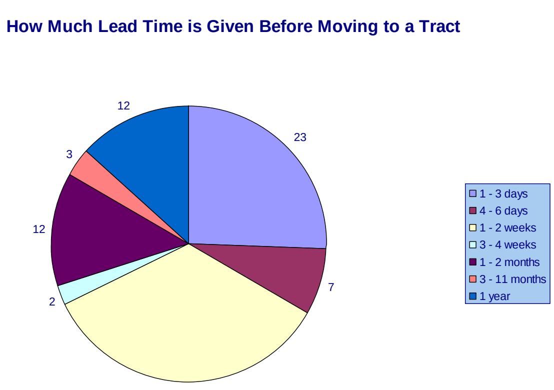

Figure 4. Amount of Lead Time Provided to Loggers

The result is that loggers are unable to effectively plan their harvesting or trucking systems because needed information is unavailable. Likewise, consumers are unable to accurately plan wood flows because they have no way to predict the amount of wood flow that will come from a tract or logger. Very few of the consumers interviewed determined production targets for the contract crews that were supplying them. This lack of information further reduces the consumers ability to accurately predict wood flow. Removal of these barriers may prove to be some of the greatest opportunities for substantial cost savings through improved planning and communications.

Production Monitoring and Rate Setting

The increasing use of matrix pricing systems has added instability to the cash flow for logging contractors in the study area. Almost two thirds of the loggers that were interviewed stated that their compensation rate was determined with a logging cost model or dealer's "market" rate. Determining compensation rates in this matter facilitates little if any true negotiation for the costs associated with harvesting.

Models of this type are based on "average" production rates that determined by analyzing past performance of the logging operation or by calculating optimal production for the equipment mix. Average rates do not reflect consumer-imposed constraints such as quota reductions, mandated moves, or tract allocation "mismatches". The result is that rates that are calculated are adequate only if the underlying parameters (such as days worked, hours worked, etc.) are satisfied. If any of the parameters is not satisfied the corresponding rate is invalid. As shown by Figure 5, rates are normally determined immediately prior to the start of a tract. The rate then remains in effect through completion of the tract.

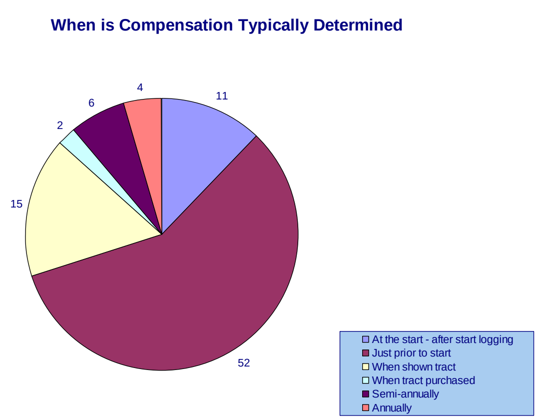

Figure 5. Amount of time prior to start that compensation is determined.

Transportation System Coordination

For the majority of the loggers that were interviewed transportation costs were incorporated into the overall rate. Since most loggers were allocated tracts one at a time less than one week in advance of moving the corresponding trucking rate was only known after the tract was allocated to the logger. The short amount of time between starting the tract and knowing the transportation rate limited the ability of the logger to plan long term trucking assets or to identify and secure markets for the production. Furthermore over three quarters of the loggers interviewed stated that someone other than themselves determined the delivery point for their production. This fact combined with short lead times and single tract allocations make it virtually impossible for the logger to design and maintain an adequate logging system. It also makes securing needed contract trucking difficult and reduces bargaining power that loggers may have had with contract trucking operations.

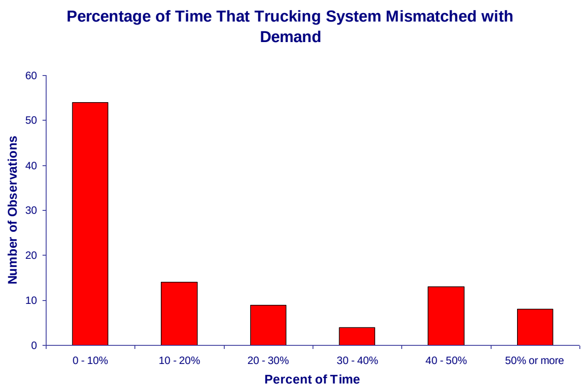

Figure 6. Percentage of time that trucking and harvesting are mismatched.

The end result is trucking capacity that is mismatched to the harvest block. Whether the mismatch is related to distance, equipment setup, etc there is inefficiency generated that adds cost to the overall system. Figure 6. describes the percentage mismatch of trucking to demand documented in the study.

Recommendations

Efficient and predictable wood flow is critical to a stable and profitable forest and logging industry. Without a planned supply both the consumer and the producer suffer be being forced to operate in a reactive rather than proactive manner. Mill management and wood procurement personnel should plan their wood requirements, inventory and delivery schedules on an annual basis and effectively communicate these plans to the appropriate suppliers to facilitate their (suppliers') ability to conduct meaningful long-term strategic and tactical planning.

Suppliers and dealers should maintain records of costs that could be used to substantiate claims of profit and loss. Loggers should also maintain records regarding production based on the characteristics of the stand being harvested. Prices should be based on the characteristics of the tract and the associated logging system. Consumers should base decisions on logging systems on more than cost. Low cost systems are not always the best-suited operations to perform harvesting work, especially in sensitive areas such as swamps, steep slopes, and areas of high visibility.

Conclusion

The primary focus of commercial forestry operations is to generate a profit for its shareholders using available resources. Plantation life cycles can range from 12 – 80+ years depending on species and stand characteristics. The actual function of harvesting can take as little as two weeks (less than 1% of the total life cycle of the plantation), and has as much influence on the end value of the resource as the growth cycle itself. Harvesting also has a major impact on the residual site and can greatly impact the productivity of future rotations. Proper planning can produce monetary savings in the cost of transportation and can reduce the total amount of time necessary to complete the harvesting function. Planning increases the likelihood that obstacles will be identified and their negative affects will be minimized or eliminated all together.

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Comparison of Timber Utilization Between A Tree-length and An In-wood Chipping Harvesting Operations

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ABSTRACT: Two 25-year old pine plantations in Alabama, one for in-wood-chipping (IWC) and another for tree length (TL) harvesting operations, were selected to determine the proportion of the standing merchantable timber resource and value that got to a manufacturing facility. Amount of sawtimber after merchandizing in the woods was found to be 80.6 percent of inside bark volume as compared to potential volume for trees from the IWC operation and 103.4 percent for TL. The TL operation merchandized sawtimber tops that were smaller than specified by mill. Pulpwood inside bark volume after merchandizing in the woods was 163.4 percent in the IWC harvesting operation and 38.6 percent for the TL as compared to potential pulpwood. The percent of potential volume for pulpwood and sawtimber that was not recovered from the woods was 9.5 percent for TL and 2.9 percent for IWC. At current market price for pine sawtimber and pulpwood, the TL harvesting operation had an increase of 0.4 percent of value and the IWC harvesting operation had a reduction of 15.9 percent of value from final products as compared to potential value.
Keywords: tree-length, in-wood-chipping, cut-to-length, harvester, skidder.

INTRODUCTION

In the United States, Finland, and Sweden, private ownership types control large amount of forestland, while in Canada most is owned by the government (Koskela and Ollikainen, 1999). There are 13 million hectares of plantations in the southern region of the U. S., which is one sixth of total forest area of this region. By the year 2000, plantations are expected to provide 43 percent of the South's total softwood supply and expected to provide 65 percent by 2030 (Stokes and Waston, 1997).

The 22 million acres or 95 percent of timberland in Alabama is privately owned out of which 70 percent is owned by NIPF (Zang et al. 1998, Forestry Facts, 1997). In 1995, Alabama forest industries produced approximately $13.2 billion, of which $8.5 billion worth from pulp, $3.6 billion from lumber (Forestry Facts, 1997).

Landowners desire maximum returns for their stumpage, the value of the standing trees. Procurement organizations for mills want to maximize profit on trees they buy. Increasingly, loggers are being required to merchandise for maximum utilization. Often harvesting systems, which are designed for high productivity with minimal merchandising are being asked to extract highest values, which jeopardizes profits of logging contractors. Dykstra and Heinrich (1996) have emphasized that properly conducted cutting operation should maximize the value of the logs prepared for extraction and facilitate extraction activities. Lanford and Stokes in (1996) concluded that a forwarder system harvesting cut-to-length (CTL) wood had lowest cost per cord but was only 1 percent less than the skidder system cutting 7.5-foot wood, and the skidder system produced 1 percent more wood than the forwarder with CTL wood. Also in this study, it was concluded that there was no significant difference in the tree volume recovered between the forwarder and skidder systems. Favreau (1998) found that a tree length (TL) system had significantly more breakage of trees during harvesting than a CTL system.

Available literature reflects that research has been conducted on the productivity and costs on the different harvesting systems in the US South, but there is little information on levels of timber utilization from different harvesting systems.

OBJECTIVES

Compare utilization of timber resources among tree-length (TL) and in-woods chipping (IWC) harvesting systems[3]. Specific goals were to:
1. Determine the proportion of the standing merchantable timber resource that gets to manufacturing facilities using the two harvesting systems.
2. Compare the revenue per unit of wood that is generated by the two harvesting approaches.

METHODOLOGY

To properly determine the level of timber utilization from the harvesting systems trees were measured at the stump and followed through to the first point of manufacturing. The TL harvesting system produced tree lengths in the woods for saw timber and pulpwood trees. Sawtimber trees were topped at a target of 5.0 inches top diameter inside bark (d.i.b.). Tops were left in the woods for possible recovery with another operation. Pulpwood trees were topped at 2.5 inches top d.i.b**.** The IWC system merchandized sawtimber trees in the same

[3] Funding for this research was made possible by grant from the U.S. Forest Service.

way and tops were not chipped. The pulpwood trees were chipped in their entirety. The CTL system was not studied during this phase of this study. By measuring each tree to its highest value use prior to processing and after it had been delivered, a degree of utilization could be determined for the two harvesting approaches.

Selection of sample plots:

In order to reduce bias, trees for this study were selected from similar stands. Mead Coated Board Corporation provided the TL and IWC harvesting operations. Both TL and IWC crews were considered some of the best for overall performance and quality of work. Two25-year old pine plantations were selected. Trees were selected to get a representative sample from each 1-inch DBH class. Prior to felling, each tree was assigned an identification number, which was followed throughout the study.

Harvesting system machines:

The TL operation had a sawhead feller-buncher, two grapple skidders, a delimbing gate, and a hydraulic knuckleboom loader with a pull-through delimber. The IWC operation had two sawhead feller-bunchers, three grapple skidders, a hydraulic knuckleboom loader with a pull-through delimber, and an in-woods flail chipper. All sawtimber and pulpwood from the TL operation was hauled on tractor-trailer style haulers; chips were transported in chip vans.

Measurement methods:

1) Measurement before and after felling: Before felling, DBH outside bark was measured to 0.1 inch with a caliper. The highest level of utilization was identified which classified each tree as pulpwood or sawtimber. After felling, down tree measurements of outside bark diameter, bark thickness and lengths were recorded at various points on the tree. At each measurement point, diameter and bark thickness was measured and recorded. Stump height plus the felling kerf was considered to be 6 inches above the ground, so DBH measurements were taken at 4 feet from the butt end (Figure 1).

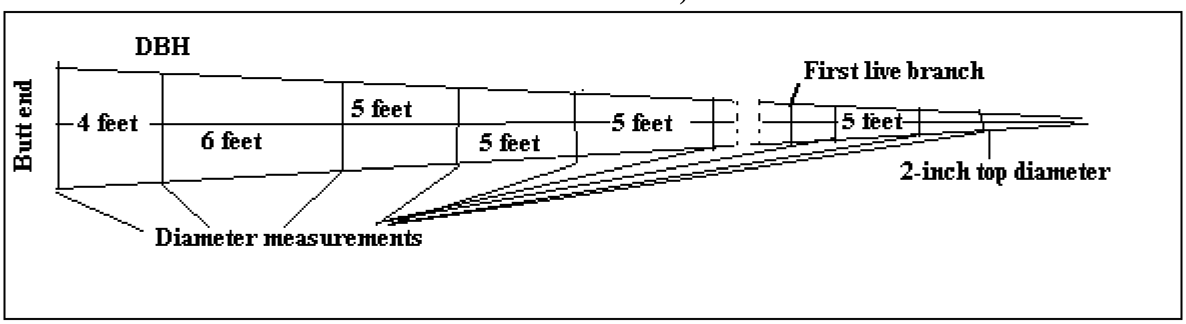

Figure 1. Measurement of tree after felling.

The butt end was measured for diameter and bark thickness and served as a reference point for all the measurements. The third set of measurements were taken at ten feet from the butt. Thereafter, outside bark diameter and bark thickness were measured at five-foot intervals (Figure 1) up the bole to a point where the top was either broken and lost or the top diameter was 2 inches outside bark. Product quality identified as sawlog or pulplog were recorded at each measurement point. Height to the first live limb and the total height were also recorded.

2) Measurement at the landing: Measurements were taken after TL material was delimbed and merchandized in the woods. Both length and outside bark diameter at the small end after merchandizing TL logs were recorded for each sawlog and pulplog. No additional measurements were taken of pulpwood trees for the IWC operation since they were chipped in their entirety.

3) Measurement at the mill: Random length TL sawlogs for both TL and IWC operations were delivered to sawmill and stored separately so that they could be processed at one time. Bucking at the mill was conducted by an experienced merchandiser. The sawmill had cut off saws mounted at 2-foot intervals from 10 feet and beyond to 16 feet. Saw kerf was 7/16 inch for each cut. A trim allowance of 3 inches for each cut and 4 inches for the fixed 16-foot length between two saws. Bucking at mill for TL sometimes required squaring of the butt and cutting of a pulplog portion from the top. Trees were processed linearly through the merchandiser. The operator was responsible for cutting the highest value from each TL piece.

Field measurement procedures:

1) Potential sawtimber and pulpwood: Down tree measurements taken immediately after felling allowed potential highest utilization to be calculated for each tree. In this regard, volume of sawlog down to five inches top d.i.b.

from the butt for sawlog trees were calculated as potential sawlog volume and the remaining portion down to 2.5 inches top d.i.b. was taken as potential pulplog volume. For pulpwood trees, all volume down to 2.5 inches top d.i.b. from the butt was calculated as potential pulpwood volume. Cubic volume calculations were calculated for each segment of the tree bole. Where field measurements were not taken at the each diameter needed, diameter and length interpolation were made. This was used to determine sawlog top end.

2) Sawtimber and pulpwood volume after merchandizing at the landing: Full trees were skidded from the stump area to the landing for processing and loading and chipping. For the IWC chipping operation, trees deemed pulpwood quality were chipped directly into vans and no additional measurements were taken. For these trees, the down tree measurements taken at the stump were considered indicative of the volume that was chipped. While some small limbs may have been lost in the skidding and handling during chipping, their volume was too small to measure accurately.

On the IWC operation, trees considered to be sawtimber quality were skidded and delimbed with a pull-through delimber. The loader operator estimated where 5-inch top d.i.b. occurred and topped the tree accordingly. As noted, tops from sawtimber trees were left in the woods and were not chipped. Resulting top diameter and merchantable length were recorded for the appropriate tree identification.

For the TL operation, all trees were skidded in full tree form to the landing for loading. Prior to arriving at the landing, trees were backed through a delimbing gate. Trees considered to be only pulpwood quality were finish delimbed and topped with the pull through loader. The loader operator estimated where a 2.5-inch top occurred. Top diameters and merchantable length were recorded for each tree. Sawtimber trees were processed and measured in the same manner except 5.0 inches top d.i.b. was the target. While target top diameters were theoretically inside bark measurement, bark at these tops was only 0.1 to 0.05 inch thick which is too precise for an operator to distinguish accurately from a position inside a loader cab. In practice, outside bark diameter was not distinguished from inside bark. Tops from sawtimber trees were left in the woods.

3) Sawtimber merchandizing at the mill: For both IWC and TL operators, TL sawtimber was hauled to the sawmill. Study trees from these truckloads were accumulated at the mill yard so that they could all be merchandized at one time. Tree lengths were bucked to log lengths by a single operator on the mill's feeder conveyor. The trees were moved lengthwise to a series of cutoff saws creating log-lengths varying from 10 to 16 feet in length. A three-inch trim was left on each log and four inches trim for those logs that were bucked in the 16-foot fixed saws. Where the butt had an uneven cut or damage, the butt was "squared up" prior to bucking into logs. Butt trims were sent to make boiler fuel. After all sawlogs were cut out any remaining top piece was sent to be made into pulpwood chips. Sawlog lengths were recorded including trim and saw kerf with appropriate tree identifications.

Office calculations procedures:

Interpolation of diameter and lengths was done by the simple method of ratio and proportion of lengths and diameters. Calculation of volume was done by taking an average radius of big end and small end for each segment. Potential volume for sawtimber was calculated by adding calculated volume of each segment of the tree from butt to 5.0 inch top d.i.b. The rest of potential volume from 5.0 inches d.i.b. up to 2.5 inches was assigned as the potential pulpwood volume. Likewise, potential pulpwood volume for pulpwood trees was determined by adding calculated volume of each segment of the tree from butt to volume up to 2.5 inches top d.i.b.

RESULTS

In-wood-chipping harvesting operation

All together 86 pine trees were taken for IWC harvesting operation. Potential sawtimber trees that were chipped for pulpwood resulted volume loss for sawtimber. Amount of sawtimber after merchandizing in the woods was found to be 80.63 percent inside bark volume compared to potential volume for trees in IWC harvesting system. This was due to error in the merchandizing as targeted to 5.0 inches top d.i.b. and due to sending potential sawtimber TL logs to the chipper. Top d.i.b. from IWC harvesting system for sawtimber was 49 percent below 5.0 inches and 51 percent above it (Figure 2). However, it was found that 19.47 percent of potential sawtimber volume was chipped or portion of it left in the woods, compared to potential sawtimber as designated at the time of felling. The portion of tree that was left in the woods after merchandizing the sawtimber was considered pulpwood. There was decrease by 19.66 percent of inside bark volume of sawtimber in the mill compared to the potential sawtimber calculated originally in IWC harvesting system (Table 1). Loss of volume as kerf and squaring the butt was only 0.32 percent compared to sawtimber as merchandized in the woods.

Tree length harvesting operation

All together 71 trees were observed in TL harvesting system. The TL harvesting system had 103.4 percent inside bark volume of sawtimber after merchandized at the landing and

103.3 percent in the mill compared to potential sawtimber for trees. This was due to the fact that 59 percent of TL stems that were merchandized in the woods had less than the targeted 5.0 inches top d.i.b. and 41 percent at 5.0 inches targeted diameter or above (Figure 2). However, the volume of pulpwood remained 39.5 percent after merchandizing in the woods as compared to potential pulpwood volume estimated. Decrease of sawtimber in the mill for kerf and squaring the butt was only 0.14 percent inside bark volume as compared to volume that was merchandized in the woods.

Pulpwood left in woods from top and other

The percent of potential inside bark volume for pulpwood and sawtimber that was left in the woods after merchandizing at the landing was 9.48 percent for TL harvesting system and 2.87 percent for IWC harvesting system. There was no loss of top leftover for pulpwood that was chipped in the woods because whole trees were chipped in IWC harvesting system.

Final change in volume and value

Average prices for three quarters as published in Timber Mart-South for southeastern pine pulpwood and sawtimber were \$6.71and \$36.08 per ton respectively (Timber Mart-south, 2002). The average weight for one cubic foot of green loblolly pine was calculated to be 69.19 pounds (Saucier et al. 1981). Calculations of potential values for IWC and TL logging operations were done based on unit price of sawtimber and pulp log per ton. Higher value of sawtimber compared pulpwood caused more monetary loss in IWC harvesting compared to TL harvesting system though overall loss of volume was higher in TL harvesting system. There was loss of 15.89 percent in monetary value for IWC operation compared to potential sawtimber and pulpwood calculated. However, TL logging operation had an increase of 0.45 percent of monetary value compared to potential volume for sawtimber and pulpwood calculated (Table 1). IWC logging operation had 97.13 percent volume recovery compared to potential wood volume, but TL logging operation had only 90.52 percent of potential volume recovery.

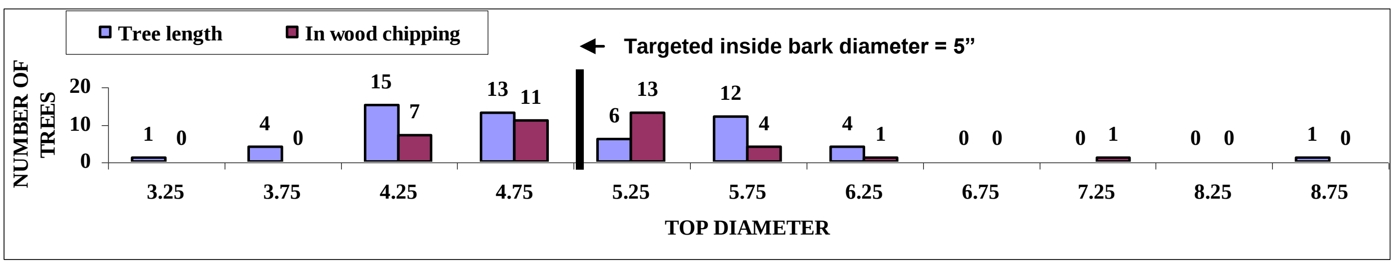

Figure 2. Distribution of inside bark top diameter after merchandizing at the landing.

Table 1. Potential and final units of wood and value in TL and IWC harvesting systems

Harvesting operation	Product	Price/ ton ($)	Potential wood volume, weight and value				Final wood volume, weight and value				Change in value (%)
			Cubic feet	Ton	%	Total Price ($)	Cubic feet	Ton	%	Total Price ($)	
Tree length	Sawtimber	36.08	1,090.0	37.71	80.0	1,423.82	1,125.8	38.95	91.3	1,430.19	+0.45
	Pulpwood	6.71	272.7	9.44	20.0		107.7	3.73	8.7		
In-wood-chipping	Sawtimber	36.08	706.6	24.45	79.9	923.35	567.7	19.64	66.1	776.31	-15.92
	Pulpwood	6.71	178.2	6.16	20.1		291.7	10.09	33.9		

Figures 3 and 4 show the final change in percent of potential pulpwood and sawtimber as the end product by one inch DBH classes for TL and IWC logging operations. For up to 8-inch DBH class, 83 to 100 percent of potential sawtimber was converted to pulp logs or pulp chips in TL and IWC harvesting operations. As the DBH class increased from 8-inch, the proportion of potential sawtimber that was converted to pulp log or pulp chips was reduced. However, most of the potential pulp log portion from 13-inch and above DBH class trees contributed in increase of sawtimber compared to potential sawtimber. This was due to both harvesting operations merchandizing less than 5-inch top d.i.b. for sawtimber. This contributed up to 14 percent increase in value in the 16-inch diameter class for TL and up to five percent in 15-inch diameter class in IWC logging operations. This increased value of wood by 0.45 percent for TL logging operation compared to potential value calculated.

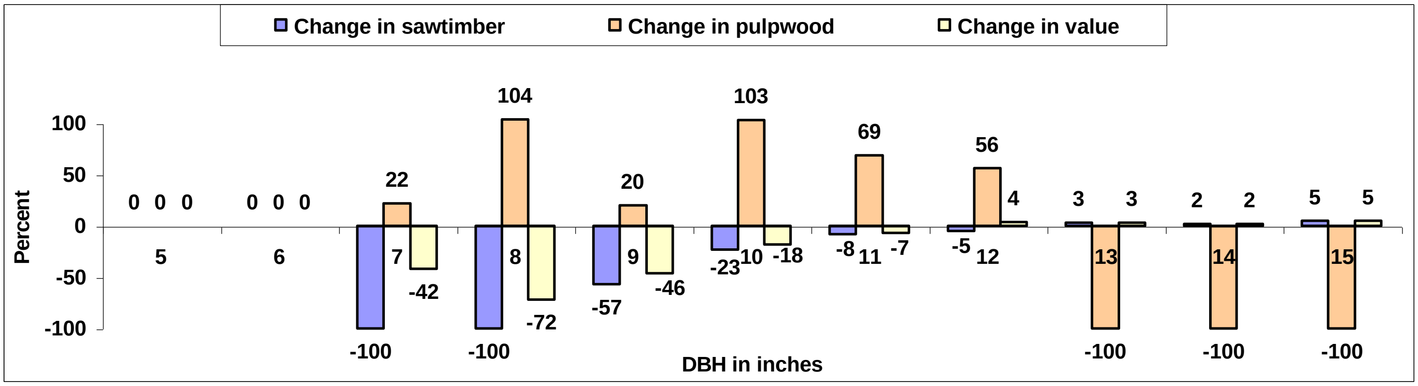

Figure 3. Change in percent of volume and value of potential pulpwood and sawtimber for IWC.

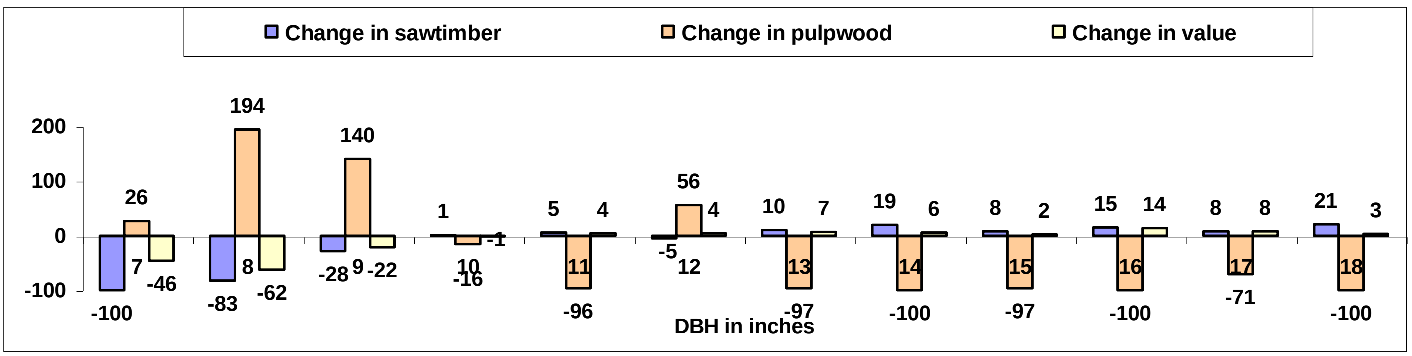

Figure 4. Change in percent of volume and value of potential pulpwood and sawtimber for TL.

CONCLUSION

This study showed that wood recovery was higher from IWC harvesting as compared to TL harvesting operation in clear felling for 25-year old pine plantation. However, monetary wise, landowners will have more income from TL harvesting operation as compared to IWC harvesting operation. DBH classes 13-inch and above were profitable to both operations as compared to potential value calculated.

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IMPROVED LOG HAULING PRODUCTIVITY

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BACKGROUND

The Western Division of FERIC serves members in Alberta, Saskatchewan, British Columbia, the Yukon and the Northwest Territory. Although there have been recent efforts to increase margin-adding products, the mills in these regions primarily produce the commodity products of pulp and lumber. None of the companies or mills produce enough product to have an influence in the market place. Consequently, the mills are "price takers" rather than "price setters." This being the case, the mills focus on increasing productivity and reducing costs of their operations in order to improve profitability. With this type of market strategy, the cost savings are quickly passed to the consumer rather than staying with the producer. This leads to further pressure to reduce costs and increase productivity even more. This constant pressure is the main reason that about 60 percent of the Western Division's research program is directed at reducing delivered wood costs. As over 50 percent of delivered wood cost is due to log hauling, one of the Western Division's larger research groups is the Transportation Group. This presentation's intent is to describe some of the improvements in log hauling productivity that have come about as a result of the transportation research program.

TRACTION IMPROVEMENT

In the mid-1990s the Western Division members asked FERIC to research ways to improve the traction of logging trucks in order to improve performance on steeper terrain and to increase the hauling season. In its efforts to improve productivity, industry had been adding axles to the log trailers in order to increase the legal load capacity. However, the improvements had reached a capacity limit – the tractor's ability to pull the load.

The Western Division examined various techniques and technologies for improving traction and decided to focus on two – Central Tire Inflation Systems and Tridem Drives. In the presentation I will describe the two technologies and the developments that resulted.

Central Tire Inflation Systems

Central Tire Inflation Systems (CTI) allow the tire pressures to be varied by the truck driver from the cab of the truck while the truck is in motion. It allows the driver to adjust the tire pressures to best suit the load, road conditions, and truck speed. It is not new technology but had not been applied to log hauling until the US Forest Service at San Dimas began its development program in the late 1980s. We contacted them and began sharing information. From this exchange it appeared that CTI would allow increased floatation, less rutting, reduced grading schedules and road maintenance costs, up to 50 percent increase in traction, lower road building costs, and a longer haul season. Longer haul season would mean reduced log hauling costs and fresher wood to the mills. We partnered with the B.C. Ministry of Forests to purchase a system from the US

Forest Service and began a pilot test program. We were somewhat concerned how well the system would work in conditions that had much colder temperatures than California, and included ice, snow, and road salt.

Our first installation and field trial was with a Tolko Industries Ltd. hauling contractor in southeastern British Columbia. The company operates in steep terrain. Approximately eighty percent of the wood is logged during a winter season of three months. The field trial lasted two years and went very well. To measure traction improvement, we conducted tractor pull tests and found a traction improvement of 35 percent at low inflation pressures. The truckers were able to operate without tire chains when hauling on ice and packed snow. This was a real improvement, and reduced truck cycle times. A surprise to us was a significant increase in tire life and the large increase in the number of times the drive tires could be recapped. Rock chipping and drilling of the tire and casing were reduced significantly. Unfortunately, when we asked for approval from government on the changes to the truck's air system to accommodate CTI, we met strong resistance, even though a Professional Engineer had approved the system. FERIC then embarked on a process with the government of B.C. that would take two years before CTI was approved for use.

Fortunately, Alberta-Pacific Forest Industries Inc. asked FERIC to assist in applying CTI at its new pulp mill and woodlands operation in northeastern Alberta. The company's intention was to log 12 months a year, in an area where historically a three month per year logging and hauling season was the norm. To undertake this project required FERIC to work with a manufacturer to make the CTI hardware and electronics simpler, more rugged, more reliable, and less expensive.

The Alberta government was also supportive of our efforts to extend the working season and to establish a new manufacturing facility. Alberta-Pacific required that all its regular truckers install CTI systems as the full benefit of CTI is difficult to achieve unless all trucks operating on a haul are CTI-equipped. With the Alberta-Pacific’s successful installation, CTI became more widely known and FERIC worked with other Alberta member companies such as Weldwood of Canada Limited and Weyerhaeuser Company Limited as they implemented CTI systems. CTI systems were also being installed in other Alberta applications, for example, on B-Train chip vans hauling year round on bush roads from in-woods, whole-log chipping installations. FERIC was involved in these applications in a technical role, and used them to show the road friendly aspects CTI technology and its application for year round hauling on bush roads. We also held field days and prepared videos to spread the message to contract truckers.

One of the attractions of CTI to FERIC members was the potential for reduced road maintenance and construction costs. FERIC’s members with CTI-equipped fleets have documented reduced road grading costs. They have also reported that CTI-equipped trucks will improve the running surface of a road. FERIC did not have to undertake field tests to demonstrate cost savings in road grading and they were clearly evident. To examine road construction costs, FERIC conducted a major road building project with Alberta-Pacific. Alberta-Pacific operates in areas with little or no local gravel and with native soils that are moist, fine textured silts or clays. We built two test sections of road with one section to be to be hauled on immediately and the other to be used after a year of seasoning. Each test section had three different road building designs repeated twice so that one of the pair could be tested with full tire pressures and the other with CTI-reduced tire pressures. The results of the tests have been analyzed and published. The study demonstrated the potential reduction in road construction and maintenance costs available through the use of CTI equipped trucks operating on very low quality bush roads in unfrozen conditions. Only CTI trucks could haul on these roads.

At FERIC we feel that CTI is a mature technology in off-highway log hauling. Through reduced tire costs, increased haul season, lower road building and maintenance costs, and shorter cycle times our members that use CTI have reduced their log haul costs by 10-20 percent. What limits further application of CTI is regulatory approval to haul full loads on thawing, thin pavement roads. When thin-membrane paved roads are thawing in the spring, weight restrictions are put in place that reduce maximum allowable weights by one third to one half. In most cases this type of road links the gravel logging road to the all weather highway where there are no weight restrictions. Thus, these thin membrane roads become a impediment to fuller application of CTI technology. FERIC has supported the US Corp of Engineers in its test program to demonstrate the road friendliness of CTI on thin pavement roads. We have conducted one major trial with Riverside Forest Products Limited and the B.C. Ministry of Highways. In this study we demonstrated we could haul an additional 25 days before the weight restrictions needed to be put in place. The additional 25 days of hauling reduced haul costs by $0.50 per cubic meter hauled. We have another major trial in place with Weyerhaeuser Company and Alberta Transportation to demonstrate the same thing in Alberta. Once these trials are completed, industry will request that the highways departments in B.C. and Alberta allow CTI-equipped trucks to haul on thin pavement roads during spring thaw and FERIC will support this request with field test results. Once the regulations are changed then further application of CTI-equipped log trucks will occur.

TRIDEM DRIVE TRUCKS

The idea for a tridem drive truck to improve traction was suggested to FERIC by a group of contract truckers. They felt adding a third driving axle would increase traction significantly. With the logging truck's longer-than-normal wheelbase, the truckers felt the steering would not be affected adversely. FERIC asked Dr. Joe Wong, a terramechanics specialist at Carleton University, for his comments and advice on the truckers' suggestion. He recommended we proceed. One of our Alberta members, Vanderwell Contractors 1971 Ltd., was interested in the concept and had actually modified one of its trucks to tridem drive. However, this truck operated only in off-highway applications and did not have the regulatory approvals necessary for on-highway operation. FERIC worked with Vanderwell and Kenworth on the truck's specifications for on-highway application. FERIC then used its truck dynamic performance simulation models to predict the truck's safety performance with respect to the nine factors the regulators use to evaluate and approve new truck and trailer designs. Based on the simulation results, the Alberta government gave us permission to do a two truck test over a period of three years. Vanderwell had Kenworth build the trucks and they were put into operation. As part of Alberta's approval we had to measure and demonstrate how well the trucks could make slow speed turns on low friction or icy surfaces. We did this by undertaking tests in freezing conditions on frozen lakes. The results of the low friction surface trials were used to specify safe weights and dimensions in the regulations that permit and recognize the tridem drive tractor-pole trailer in highway applications. The regulation specifies axle spacings, wheelbase dimensions, and axle loads.

Truck regulators write regulations for specific truck trailer combinations. Therefore, each new tridem configuration the industry wanted to use on public highways had to go through a process similar to the tridem tractor-pole trailer combination. To facilitate this process, FERIC developed a set of procedures with the Alberta government to follow in order to get regulatory approval of any new truck trailer combination. The procedure was:-

1. Specify the weights and dimensions of the new configuration.
2. Use the dynamic performance simulation models developed by the National Research Council of Canada and the University of Michigan's Transportation Research Institute to rank safety performance against the nine safety performance factors used by government regulators in Canada.
3. Either recommend operational field testing, recommend rejection of the configuration, or recommend modifications of the weights and dimensions specification to improve safety performance before full operational field testing.
4. Institute a two to three year operational trial to establish long term benefits, operational feasibility, and the value of the configuration.
5. Conduct specific field tests to improve, for example, low friction surface steerability or some other safety feature, and to upgrade components of the dynamic performance simulation model.
6. Submit a technical report to government that justifies the new configuration being recognized for on-highway operation in the regulations.

This procedure has been used in Alberta over the last eight years to gains regulatory approval for the tridem tractor and:-

1. tandem and tridem pole trailers
2. tandem and tridem semi-trailer
3. super B and B-train trailers
4. quadaxle trailers

It has also been used to get a twin steer, tridem tractor semi-trailer configuration approved.

When FERIC began introducing these combinations in B.C. at the request of its members, FERIC had to re-do the dynamic performance simulation trials it had done in Alberta. Weights and dimension regulations are slightly different between provinces as are the roads and hauling conditions. Regulators are typically conservative and requested that this work be done. As well they requested field performance trials that validated the computer simulation predictions. As more combinations were approved, the amount of re-work FERIC had to do to has decreased. The last combination, the B-train, may be accepted in B.C. based solely on the original Alberta work. It takes time but FERIC is gaining the confidence of the B.C. vehicle regulators.

The tridem drive truck has been very popular with the drivers. FERIC did tractor pull tests on the first tridem tractor Vanderwell put into operation and a 50 percent increase in traction was obtained. This improved traction has been appreciated by the truckers as they get stuck less, have to use tire chains less, and have fewer gear shifts to make. The tridem tractor, tridem pole trailer is a safer, more stable configuration than the six and seven axle combinations it has replaced, and the truckers really appreciate this. In fact, tridem drive trucks have improved overall safety performance. As well, our member companies report a 10-15 percent reduction in haul costs, primarily because of lower cycle times and increased load capacity. When the truckers are replacing their tandem drive trucks, 90 percent of them are tridem drive trucks.

In B.C. other industries have noted the tridem drive logging trucks and are applying tridem drives to their application. The tridem drive can't be applied everywhere because a longer wheelbase and a loaded steering axle are needed to overcome the aligning moment inherent in the tridem drive. However, recent non-logging applications have been:-

1. tridem drive tow trucks
2. tridem drive quadaxle trailer tanker trucks
3. tridem drive B train trailer ore carriers
4. tridem drive tridem semi-trailer redi mix truck

In conclusion, the foregoing has been a description of two developments the Western Division of FERIC has undertaken to improve the productivity and reduce the costs of log hauling in Western Canada. Cost savings have been of the order of 10-15% which is significant when log hauling typically constitutes 50 percent of delivered wood costs.

Precision Forestry: Operational Tactics For Today And Tomorrow

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ABSTRACT - The term "Precision Forestry" is being used more frequently in the forest products industry. This paper defines two broad categories of precision forestry as 1) using geospatial information in forest management and planning, and 2) site-specific silvicultural operations. One case study is presented for site-specific application of herbicides and fertilizers in herbaceous weed control activities. In this case study, the operational characteristics and application costs are discussed for a new machine capable of applying both broadcast and banded herbicides and fertilizers. When compared to conventional systems, the precision forestry techniques reduced herbaceous weed control costs by as much as 47% and chemical use by one-third.

INTRODUCTION

"Precision forestry" is a relatively new term that is undergoing a rapid increase in use in the forest engineering - forest operations community. This term is similar to those frequently used in agricultural production circles, i.e. "precision agriculture" or "precision farming." Over the last 20 years, the concepts of precision agriculture have been refined into a definition that most people will accept. That is, precision agriculture can be defined as managing crop inputs, such as fertilizer, herbicide, etc. on a site-specific basis to reduce waste, increase profits, and maintain the quality of the environment.

To bring together researchers and practitioners to discuss precision forestry, the first International Precision Forestry Symposium was held one year ago in Seattle, Washington (Farnum, 2001; Becker, 2001). Initially, one would think that the term "precision forestry" should have a very similar meaning to the frequently used "precision agriculture" term. Yet, as the symposium attempted to synthesize the current body of knowledge on precision forestry, it became evident that the term precision forestry has many different meanings depending on who uses the term. While many of the aspects of precision agriculture can be applied to forest management, the considerable differences between the two industries require a different, broader definition for precision forestry. The objectives of this paper are to:

1) Discuss and define the term precision forestry in the context of forest operations, and
2) Present one precision forestry case study for the application of fertilizer and herbicides.

BACKGROUND

Precision agriculture techniques are centered around a database of geospatial information including soil fertility, crop yield and in some cases crop quality. Many harvesting machines now have yield monitors that collect continuous data on the amount of the crop being harvested as a function of location in the field. When yield maps are combined with soil fertility and soil type maps, management units within a field can be defined. Then, each management unit can have its own prescribed rates of fertilizer, herbicide, and pesticide. Using variable rate controller technology, the rates at which these inputs are applied can be changed as the applicator moves across the field. The ability to change fertilizer and herbicide application rates to suit the needs of each management unit leads to a more efficient use of these inputs and therefore reduced production costs and environmental impacts.

PRECISION FORESTRY DEFINED

Since there are many differences between the forest products industry and the agricultural sector, all of the concepts of precision agriculture are not directly applicable to forest production systems. Moreover, there are different applications in forest management that can be considered part of precision forestry. We propose to define precision forestry as planning and conducting site-specific forest management activities and operations to improve wood product quality and utilization, reduce waste, and increase profits, and maintain the quality of the environment. Further, we propose that the general field of precision forestry be separated into two main categories:

1) using geospatial-information to assist forest management and planning, and

2) site-specific silvicultural operations.

Geospatial-Information-Based Forest Management and Planning

This area of precision forestry encompasses a wide variety of activities that use geospatial information to assist in the site-specific management of forests and planning of future operations. This actually encompasses many current management and planning activities since many industrial and private landowners use geospatial tools to manage their landbases. Traditional examples would include using GIS to help develop management plans for forested areas; however, what makes these activities fit under the precision forestry would be an emphasis on site-specific management.

New examples of this type of precision forestry include the use of information technology to optimize the transportation of wood products from the forest to their most appropriate processing location. Advances in wireless communication are at the point where much of this information can be shared from the harvesting machine directly to transportation dispatching services and to the manufacturing facilities.

Site-specific silvicultural operations

Site specific silvicultural operations involve the use of geospatial technologies, such as GPS and GIS, to improve operational efficiency and reduce the cost of wood fiber. This involves using much of the technology developed for precision agriculture. Example technology includes using GPS and variable rate controllers to improve the efficiency of herbicide spraying or fertilizer application. This technology is readily available and is currently being used in forest operations on a limited basis. New technology has been developed to provide automated machine guidance for agricultural tractors that could also be adopted in certain forest operations.

Although the concept of yield maps as used in agriculture has not been attempted in forest production, it is technically feasible given the advanced product size sensors used on current cut-to-length harvesting systems. Also, research at Auburn has been developing similar instrumentation that can be placed on traditional wheeled feller bunchers to measure tree size. Combining the tree or log size data with GPS position will make possible the development of forest yield maps.

Discussion

There are several key components of both of these two categories. The primary component that is common to all forms of precision forestry is the use of geospatial technologies such as GPS, GIS, remote sensing, LIDAR, etc. as tools to assist in site-specific forest management, planning or silvicultural operations.

A second component in precision forestry is the development and use of an extensive information base to help make management and operational decisions. This information base could include data on product growth and yield, product quality, and environmental conditions as a function of location and time. A critical part of this use of information is the feedback mechanism that is possible. In other words, it is possible to take the spatially attributed data on yield and use it to validate and refine growth and yield models so that future management strategies can increase return on investment for the landowner.

A final concept in precision forestry is that of defining the the most appropriate management unit. As a start, this would involve examining stand maps, terrain information, soil maps, and soil fertility maps along with other information such as wildlife habitat, etc. Eventually, this should incorporate the development of yield maps but with additional information on product quality. Once the size or number of management units is determined, more focused management and operational decisions can be made on site-specific bases.

Precision forestry should not mean that every operation is computerized or automated. Many site-specific silvicultural operations can be conducted in a cost effective manner without being automated. What it should mean is that the management process or operational activity is focused on making decisions for the smallest practical management unit area or number of management units within a given tract or management area. For example, this could determine how much fertilizer or which herbicide is applied at a particular location on a tract.

Using many of the methods from precision agriculture, we can envision that these geospatial technologies can help the forest products industry adopt a scenario like the following :

1) Develop yield maps during harvesting operations. From the yield maps, begin to quantify variability in wood quality and wood fiber production rates as a function of location.

2) Once variability is quantified, identify site conditions that contribute to that variability (e.g. soil type, soil fertility, moisture conditions, etc.).
3) Track the types and dates of operational practices and prescriptions that are carried out during the rotation (fertilization, herbicide application, seedling quality, planting methods, etc.). It may be possible to track tree growth during the rotation using remote sensing data or other methods on the ground.
4) With a record of these data, begin to conduct comprehensive analyses to determine what contributes to spatial and temporal variability in seedling survival rates, wood fiber growth rates, and final wood quality.
5) Using these conclusions, determine the most appropriate management unit size or number of management units for the operations.
6) Using these management units and the previously collected data, plan future silvicultural operations for the same rotation or the subsequent rotations. Fertilizer and herbicide application rates, planting density, etc. can be varied as a function of location depending on the site conditions.
7) At the time of the next harvest, product type and quality can be recorded and even used in determining the optimal use for the product as well as the optimal destination for further processing of the product.

CASE STUDY: SITE-SPECIFIC APPLICATION OF FERTILIZER AND HERBICIDES

A case study is presented here as an example of the use of precision forestry techniques for site-specific silvicultural operations. This example shows how herbaceous weed control costs can be reduced and chemical use efficiency improved by using precision forestry techniques.

Operational Description

During 1999 and 2000, Woodlands Specialists, Inc. in Chapman, Alabama began developing the concepts for a new type of sprayer for application of herbicides and liquid fertilizers. Tigercat of Brandford, Ontario, Canada performed the detailed design and subsequent fabrication of the machine during 2000, with delivery and first use of the machine occurring in the fall of 2000.

The machine, referred to as the WS Sprayer, is shown in Figure 1 and is constructed on the same chassis used for a wheeled feller buncher. Using the feller buncher chassis provides several advantages. First, the cab-forward design inherent in a feller buncher allows greater visibility for the operator. Second, the weight distribution of the feller buncher chassis allowed the designers to place a large water tank on the front of the machine where tanks and pumps are more accessible.

Herbicides are not tank mixed, rather the machine contains one main 500 gallon water tank with chemicals injected at the nozzles. This design allows many different chemicals to be placed on the machine and used only when determined by the operator or the spray controller. Variable rate pumps are used to deliver chemicals to the spray nozzles.

An additional 250 gallon tank is mounted on the rear of the machine. This tank allows liquid fertilizer to be applied. When not in use for fertilizer, the tank can hold additional water for herbicide spraying.

A Midtech spray control system is used to monitor navigation of the machine and control injection of chemicals. The controller uses GPS to determine the location and speed of the machine. The controller also monitors water flow rate, band width, and herbicide application rate. Using these inputs, the control system then determines how much herbicide to inject into the spray pump for application to the site. This variable rate control is critical to efficient use of the chemical as the ground speed of forestry sprayers can be highly variable.

Herbicides are injected in their original concentration from the manufacturer, except for dry flowable formulations such as Oust, Oustar, and Velpar. Using the injection system means that there is no measuring or mixing of chemicals, which minimizes exposure to the operator. Also, there is no leftover tank mix solution to dispose of at the completion of the tract; only the amount of product needed on the tract is applied. In its current configuration, the sprayer can inject three different products; however, up to six injection pumps can be used on the machine. Spraying prescriptions can be easily changed using the control console.

The spray control system provides a field computer display and a light bar so the operator can see where they have sprayed and where they need to steer the machine. By comparing this real time map to maps provided by the customer, the operator can insure that all designated areas are treated. There is also the capability to download a digital tract map from the customer to the field computer before beginning the tract. Finally, an "as-applied" map is stored in the controller that can be downloaded and provided to the customer for incorporation into a GIS database. A typical spray map is shown in Figure 2. This map shows the machine path as it is spraying and it indicates areas that were not sprayed.

The machine has been configured for two types of operation: 1) broadcast spraying and 2) banded spraying. In broadcast spraying, two Radiarc nozzles are mounted on the upper rear portion of the machine so that a 50-ft-wide strip can be sprayed during chemical site preparation or during understory release spraying. The Radiarc nozzles provide a uniform spray pattern and they provide uniform droplets of large diameter to reduce drift. In banded spraying, booms with six Teejet spray nozzles on a common manifold are mounted on the front of the machine. These nozzles are shielded, positioned close to the ground, and operated at low pressures to reduce drift. The booms are configured to spray a band of herbicide directly over each of three rows. Also, liquid fertilizer can be applied along the row using the same booms.

Cost Comparison of Herbaceous Weed Control Methods

Table 1 contains a comparison of costs for the WS Sprayer to those of three other herbaceous weed control methods. These methods are: 1) helicopter broadcast application of herbicide and fixed wing aircraft broadcast application of fertilizer, 2) a single pass of a modified skidder applying herbicide and liquid fertilizer in a band on a single row, 3) a combination of banded backpack sprayer application of herbicide and fixed wing broadcast application of fertilizer, and 4) a single pass of the WS sprayer applying herbicide and fertilizer in bands over three rows.

The cost data in the table are based on herbicide application rates of 48 oz/acre for Velpar and 3 oz/acre for Oust. Herbicide costs were assumed at $0.39/oz and $10.50/oz for Velpar and Oust, respectively. Fertilizer was assumed to be either DAP or Liquid Green applied at rates of 125 lbs/treated acre and 155 lbs/treated acre, respectively, which results in 57 lbs of phosphorous per treated acre. Unit costs of the fertilizers were assumed at $0.11 and $ 0.12 per lb for DAP and Liquid Green, respectively.

By applying the herbicides and fertilizer in a band over the row, only those areas close to the tree are treated, thereby reducing by approximately 2/3 the amount of herbicide and fertilizer that is applied to the tract. Studies have shown that by applying the herbicide in a 4-ft-wide band around the tree, the growth response is the same as in broadcast herbicide applications. Also, by applying the fertilizer in a band, it is left in a concentrated stream a few inches from the tree, where it will be most effective. In addition, by applying the fertilizer in a band, the total amount of fertilizer applied to the tract will be much less than needed in a broadcast application. The effect of this method of fertilization on growth rates has not been quantified.

The data in the table indicate that an operation like the WS sprayer combined herbicide and fertilizer treatment has the lowest total cost of the four methods. The estimated cost for the WS Sprayer was $48 per acre compared to $91 per acre for the aerial applications of herbicide and fertilizer. If the objective was only to apply herbicide, the backpack sprayer method has a lower cost. However, this method has several issues that relate to health concerns for the workers. Clearly, by performing a more site-specific application of herbicides and fertilizers, and by combining operations to limit machine passes, the cost of herbaceous weed control can be reduced significantly. Perhaps just as important as reducing cost, the use of herbicides and fertilizers can be reduced by two-thirds in this operation.

An additional benefit of this type of operation is that the locations of the rows are established by the GPS track of the sprayer. This map can now serve as the beginning of the complete geospatial history for the tract. In fact, the machine is capable of using a dye to mark the potential locations of tree seedlings and record this in the GPS map. This ability to mark the recommended tree location is important for manual tree planting operations since during winter planting operations, it is often difficult to distinguish the location of the herbicide treated row because all the surrounding vegetation is dead as well.

SUMMARY

Precision forestry is a rapidly developing field but there is no universally-accepted definition of precision forestry. We defined precision forestry as planning and conducting site-specific forest management activities and operations to improve wood product quality and utilization, reduce waste, increase profits, and maintain the quality of the environment. Precision forestry can be catergorized into two main areas: 1) using geospatial-information to help make forest management and planning decisions; and 2) conducting site-specific silvicultural operations. Finally, we reviewed one case study of a sprayer performing herbaceous weed control that uses many of the site-specific silvicultural operations techniques. In this case, the precision forestry techniques resulted in cost savings up to 47% and chemical use reductions of two-thirds when compared to traditional application methods of herbicide and fertilizer.

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Table 1. Cost comparison of various herbaceous weed control methods.

Application & Materials - Cost Per Acre(US Dollars)				
	Helicopter & Fixed-Wing	**Skidder Single Row Combo**	**Back Pack & Fixed Wing**	**WS-Sprayer Three Row**
2-Pass	**Broadcast**	**Banded**	**Banded**	**Banded**
Helicopter				
Application	**$19.00**			
Velpar	**$18.75**			
Oust	**$31.50**			
Subtotal	**$69.25**			
Farm Tractor				
Application			**$17.00**	
Velpar			**$6.25**	
Oust			**$10.50**	
Subtotal			**$33.75**	
Fixed Wing				
Application	**$8.00**		**$8.00**	
Fertilizer	**$13.44**		**$13.44**	
Subtotal	**$21.44**		**$21.44**	
1-Pass Banded				
Application		**$32.00**		**$25.00**
Velpar		**$6.25**		**$6.25**
Oust		**$10.50**		**$10.50**
Fertilizer		**$4.48**		**$5.94**
Total	**$90.69**	**$53.23**	**$55.19**	**$47.69**
WS Sprayer Savings	**47%**	**10%**	**14%**	

Figure 1. Photograph of WS sprayer configured for banded spraying. Inset shows the cab with field computer and other spray controller equipment.

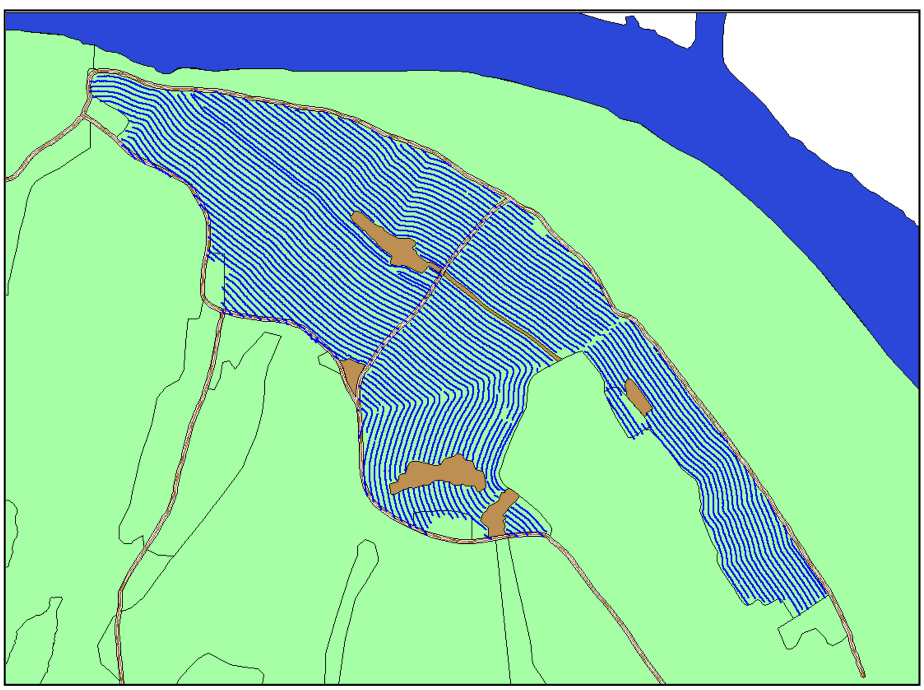

Figure 2. Typical "as-applied" map showing results from spraying operations. The blue line indicates sprayer path when spraying activated. Brown regions show areas not sprayed.

Productivity of Swing-to-Tree Harvesters Performing Thinnings in Natural Pine Hardwood Stands

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ABSTRACT- Cut-to-length (CTL) systems are not common in the southern United States. Currently CTL systems in the South generally work in first and second thinnings of pine plantations. This paper reports on two tracked swing-to-tree harvesters thinning natural pine/hardwood stands in west central Georgia. The two harvesters were a Timbco 415D fitted with a Quadco Ultimate 5600 processing head and a John Deere 653E fitted with a Fabtek 18-inch four roller processing head. A detailed time study was performed using a video camera and post data analysis. Stand data and detailed productivity data for both harvesters is reported. Average tree dbh for the Timbco was 18.7 cm (582 trees/ha) and the calculated productivity was 109 trees/PMH (44 tons/PMH). The John Deere's calculated productivity was 96 trees/PMH (52 tons/PMH) with an average dbh of 21.9 cm (420 trees/ha). Machine costs were $109 and $113/PMH for the Timbco and John Deere respectively. Productivity was best predicted by the square of dbh for the John Deere and the square of dbh and number of bucks per tree for the Timbco.

INTRODUCTION

Cut-to-length (CTL) systems have been employed on the Ft. Benning Military reservation in west central Georgia since 1996. CTL systems are specified in timber sales on the reservation that contain sensitive sites. Archeological sites (Native American habitation sites), endangered species (Red Cockaded Woodpecker (RCW), *Picoides borealis*) and sites with erodable soils are all present on the reservation. Other management constraints relate directly to the presence of the military. These include certain terrain features, land navigation courses, and cantonment and recreation areas (Trawick, 1998).

Tree length extraction is the most common harvesting system in the South due to several factors such as high production potential and generally favorable terrain, which is suitable to rubber tired feller-bunchers and skidders. There are very few CTL systems working in the South and these are generally found working in first and second thinnings of pine plantations. Many reasons are commonly put forth for the slow acceptance of CTL. These include high purchase price, too complicated, limited production potential, and too great a variety of timber sizes and species (Stevenson, 1989, McCary, 2001).

CTL systems can offer advantages over tree length systems. For example, reduced damage to the residual stand, less site damage, ability to merchandise at the stump, recovery of higher value products, and increased operator safety (Stevenson 1989, Tufts 1990, McCary, 2001). By using a modified excavator or purpose built tracked carrier with a third party processing head as the harvester the purchase price of a CTL system can also be reduced compared to the cost of a rubber tired Scandinavian designed harvester.

These advantages are the primary reasons why CTL systems have been specified as a condition of sale on tracts containing sensitive sites on the Ft. Benning Military reservation. The concern when operating in an archeological site is disturbance and specifically the movement of artifacts from their point of origin. Skidding tree length timber has the potential to move artifacts a significant distance. This problem is overcome with a CTL system and offers the additional benefits of lower ground pressure, fewer machine passes with reduced potential for rutting and disturbing surface soils. The reduction in site damage via the elimination of skid trails, large slash piles and loading areas within active military training areas is another advantage of CTL systems (Trawick, 1998).

METHODS AND MATERIALS

The Ft. Benning military reservation is located at the juncture of the Piedmont and Coastal Plain regions fall line near Columbus, Georgia, USA. The reservation consists of approximately 74,000 hectares with approximately 52,000 hectares of forestland under management. The study sites were located on gently rolling terrain with sandy soils. The timber stand was natural pine/hardwood.

At the time of the study (May 2001) there were two CTL systems working on the Ft. Benning reservation. Both systems employed tracked swing-to-tree harvesters. A production study on the harvesters for both systems was performed. Study blocks were established in the stand ahead of the harvesters. Tree data recorded for each block included species, diameter, and height for all trees marked for removal. Species and diameter was recorded for all remaining trees. A video camera was used to record the activities of the harvesters as they worked through the study blocks. Post analysis was performed to extract elemental cycle times for each harvester.

A work cycle for the harvesters was defined as beginning when the machine started moving from one location to the next and ends immediately before the machine moved to the next location. Several trees may be felled and processed during a work cycle (i.e. at one location). The work cycle was broken down into the following elements:

Move: Starts when the harvester's tracks begin to move and ends when the machine arrives at the next location and the tracks stop.

Reach: Starts from the time the machine stops moving and ends when the harvesting head is attached around the tree to be felled.

Fell: Starts when the saw is activated to cut the tree and ends when the tree is laid on the ground.

Buck: Starts when the harvesting head starts to process the tree and ends when the tree has been completely processed. The *Buck* element ranged from 1 to 5 separate elements according to the number of pieces produced per tree.

Delay: All time that does not fall within the other elements.

Regression analysis was performed to produce prediction equations for total cycle time per tree. Additional prediction equations were produced for the processing times per tree for each harvester.

The analysis and results for each harvester will be reported separately in the following sections. No attempt is made to directly compare the two machines. The stands differed in composition and the harvesting systems differed with one harvester working alone and the other working in conjunction with a small feller-buncher.

RESULTS

Timbco 415D/Quadco Ultimate 5600*

The Timbco 415D tracked carrier was fitted with a Quadco Ultimate 5600 processing head. The harvester worked in conjunction with a Franklin 170B forwarder. The harvester worked through the stand in swaths based on compartment boundaries, terrain and machine reach. It felled and processed all marked trees. The forwarder followed the harvester loading and then removing the processed timber to the log landing where it was directly loaded onto log trailers.

The stand composition is described in Table 1. The pine to hardwood mix was 58 percent hardwood and 42 percent pine. The main species were loblolly pine, sweetgum, and water oak. The average basal area per hectare was 22.1 m^2 with 6.1 m^2 (27%) marked for removal. The average stand dbh was 18.7 cm and 22.1 cm for trees marked for removal. Dbh ranged from 13.7 to 38.6 cm and total height averaged 16.7m with a range of 9.1 to 27.4 m.

Table 1: Stand Data for Timbco 415D harvester.

	Trees/ha	DBH (cm)	BA (m^2)
Pine	243	22.8	12.5
Hrdwd	339	15.7	9.6
Marked	145	22.1	6.1
Unmarked	437	17.6	16
Total	582	18.7	22.1

Five study blocks with a total area of 0.28 ha were established. The harvester cut and

* The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

processed 38 marked trees in the blocks. Twenty one percent of the time the harvester cut and processed two or more trees at a time. The average number of pieces processed per tree was 1.76 and average weight per tree was 0.4 tons. No delays were recorded during the time study.

Regression models were developed for the processing time per tree and the total cycle time per tree (Figure 1). The processing function included the elements *Reach*, *Fell*, and *Buck*. For processing cycles where more than one tree was felled and processed the time was divided by the number of trees. Dbh squared and number of bucks per tree best modeled the harvester's processing time per tree ($Process = 1.04 + 0.0202*DBH^2 + 6.02*Buck$, $R^2=0.76$, $P=0.0001$). The average processing time per tree was 23.4 seconds.

The total cycle time per tree was best modeled by the square of dbh and the number of bucks per tree ($Total\ Cycle = 8.06 + 0.0195*DBH^2 + 7.59*Bucks$, $R^2=0.65$, $P=0.0001$). Total cycle time included all cycle elements. Move time was divided among all trees felled and processed at one harvesting location. Move time per tree averaged 9.4 seconds. The average total productive time per tree was 32.8 seconds, which equates to a production rate of 109 trees/PMH or 44 tons/PMH.

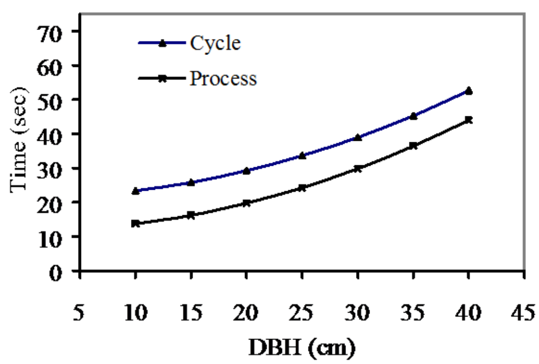

Figure 1: Processing and total cycle time vs. DBH for Timbco 415D harvester (Bucks= 1.76).

A machine cost was calculated using the machine rate method (Brinker, et al, 1989). Using a purchase price provided from the dealer of $230,000 (including the Quadco 5600 processing head) a machine life of 5 years and salvage value of 15% of purchase price the total cost was calculated to be $109/PMH ($2.47/ton). A labor and benefits cost of $15/hr was assumed.

<u>John Deere 653E/Fabtek</u>

The John Deere 653E carrier was fitted with a Fabtek 18-inch four roller processing head. The harvester worked in conjunction with a Hydro-Ax 222 rubber tired shear feller-buncher and two forwarders, a Franklin 670 and a Tree Farmer C7. The feller-buncher worked through the stand felling all small trees and bunching them next to large pulpwood and saw timber trees. The harvester followed the feller-buncher through the stand processing the piles and felling and processing all remaining trees. The two forwarders removed the processed timber to the log landing.

Stand composition is given in Table 2 below. The stand basal area was 20.9 m^2 with 7.3 m^2 (35%) marked for removal. Hardwoods made up 38 percent of the stand. The average dbh was 21.9 cm and ranged from 12.95 to 49 cm. The average diameter of trees marked for removal was 24.1 cm. Tree height averaged 16.6 m with a range of 7.2 to 26.3 m.

Table 2: Stand Data for John Deere 653E harvester.

	Trees/Ha	DBH (cm)	BA (m^2)
Pine	259	25.6	17.3
Hrdwd	161	15.9	3.6
Marked	138	24.1	7.3
Unmarked	282	20.8	13.6
Total	420	21.9	20.9

Four study blocks totaling 0.4 hectares were established. The feller-buncher cut and piled 42 of the 54 marked trees within the blocks. The harvester cut and processed the 12 remaining trees and processed the piles. There were no delays recorded. The average number of pieces processed per tree was 2.0. The average weight per tree was 0.54 tons.

Regression models were developed for processing and total cycle time per tree using the same methodology described for the Timbco 415D. From the time study data it was known which trees were in which piles, but it was impossible to identify each individual tree as it was being processed. Therefore, the total time to process the pile was divided by the number of trees in each pile. The average diameter for all trees in the pile was also calculated. The average time per tree and the average diameter of trees in the pile was used in the regression analysis. Moving time was also divided equally among the number of trees felled and processed at each harvesting location.

The square of dbh best modeled the total cycle time and processing time per tree for the harvester. Figure 2 shows the relationship between time and diameter. The regression equations are listed below.

Process $= 2.07 + 0.0491*DBH^2$, $R^2=0.74$, $P=0.0001$

Total Cycle $= 6.61 + 0.0513*DBH^2$, $R^2=0.74$, $P=0.0001$

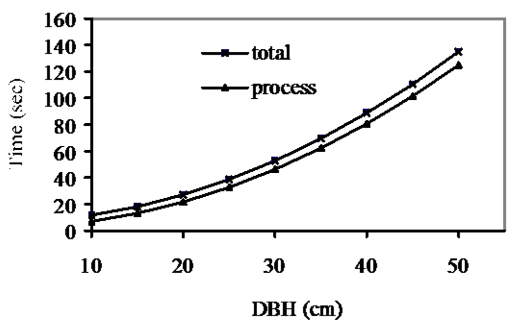

Figure 2: Processing and total cycle time per tree for John Deere 653E/Fabtek harvester.

The average time per tree to process all trees was 32.9 seconds. While the total cycle time per tree was 37.4 seconds. This equates to a production rate of 96 trees/PMH (52 tons/PMH).

The calculated machine cost was $113/PMH based on a dealer provided purchase price of $260,000 (including Fabtek processor), a wage and benefits cost of $15/hr and a fuel cost of. This equates to $2.17/ton (52 tons/PMH).

CONCLUSIONS

This paper reported the productivity of two swing-to-tree harvesters thinning natural pine/hardwood stands in west central Georgia, USA. Both harvesters work in CTL systems operating on the Ft. Benning military reservation on sensitive sites. CTL systems are specified as a condition of sale on tracts within the reservation containing sensitive sites. Tracts including archeological sites, endangered species, erodable soils, and military infrastructure are considered sensitive.

The machines worked well in meeting the silvicultural prescriptions. The Timbco/Quadco harvester worked in combination with a single forwarder while the John Deere/Fabtek harvester work in conjunction with a Hydro-Ax 222 feller-buncher and two forwarders. No attempt was made to directly compare the two harvesters.

Regression analysis performed on detailed time study data for both machines showed that processing time and total cycle time per tree was best predicted with the square of dbh for the John Deere 653 and square of dbh and number of bucks per tree for the Timbco 415. The average cycle time per tree was 32.8 and 37.4 seconds for the Timbco and John Deere respectively. Productivity was calculated as 109 trees/PMH (44 tons/PMH) for the Timbco and 96 trees/PMH (52 tons/PMH) for the John Deere.

There are many questions that still need to be answered. For example, how do tracked harvesters compare to rubber-tired harvesters in similar stand conditions. Additional studies are required to fully document the productive potential and environmental benefits that CTL systems may offer in various stand types in the South.

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A "Misery Index" to Assess the Impact of Variations in Mill Demand on Logging Crew Production and Cost

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ABSTRACT – High utilization of production capacity is often critical to individual logger's success. Market variation can be a key cause of lost production. Mill procurement practices can exacerbate these market impacts. We used data envelope analysis to measure and benchmark the consistency of a mill usage and purchases for 130 mills from Maine to Texas between mid-2000 and the end of 2001. Logging crews that were not preferred supplier to mills saw their production drop and their per ton costs increase as the mill purchase consistency declined. Mills can use these benchmark measures to compare their performance to other individual mills or groups within the industry.

INTRODUCTION

While there are many factors that affect capacity utilization by individual logging crews, among the most important are the dynamics and characteristics of the wood market in their area of operation. These market characteristics include not only the number and type of wood receiving mills but also their wood procurement practices and approach. Of special importance is the stability of wood purchases experienced by wood producers within each wood area.

This study was a component of the logging capacity utilization study funded by the Wood Supply Research Institute (WSRI) at the University of Georgia, LSU, and the University of Maine (Mayo, *et al.* 2002). The study collected information weekly from both logging crews and mills in wood-using areas. In many cases, we were collecting information from a logging crew and most of the mills where it delivered wood. This allowed us to examine the magnitude and impact of market-caused lost logging production with quantifiable links to mill inventory or purchase practices. We used multiple methods to obtain information and insights that would not have been attainable using a single approach. We collected data using several techniques:

- Basic profile information from logging crews and mills,
- Field visits with every logging crew,
- Weekly reports of actual and missed production and causes for any missed production from logging crews,
- Quarterly cost reports from logging contractors,
- Weekly reports from consuming mills about usage, purchases, inventory, and short-term plans, and
- Mailed surveys of loggers in the southern region and in Maine to determine how representative our study group was of the logger population in each region.

We applied both econometric and statistical procedures to examine the impact of multiple variables on logging production levels and technical efficiency, causes of missed production, mill inventory/usage/purchase practices, and per ton logging costs.

RESULTS

In addition to the profile information sheet, each mill submitted weekly activity reports. A total of 8,212 weekly mill reports were received from April 2000 until December 2001. Not every mill contributed every week but there were 138 mill reporters with at least 13 weeks of data, and 97 reporters with at least 52 weeks of data (Figure 1). On each weekly report, participants gave us information about their weekly operations for each raw material product. From this weekly information, we were able to investigate specific areas that affect wood purchase levels. Every week our participants indicated their quota status (Figure 2). According to the mill weekly data, overall, our participants were on quota 36% of the weeks reported. Chip and pulp and paper mills issued weekly wood quotas most frequently at 57% and 50% respectively. OSB mills issued quotas 32% of the time, plywood mills 26% of the time, and lumber mills 21% of the time.

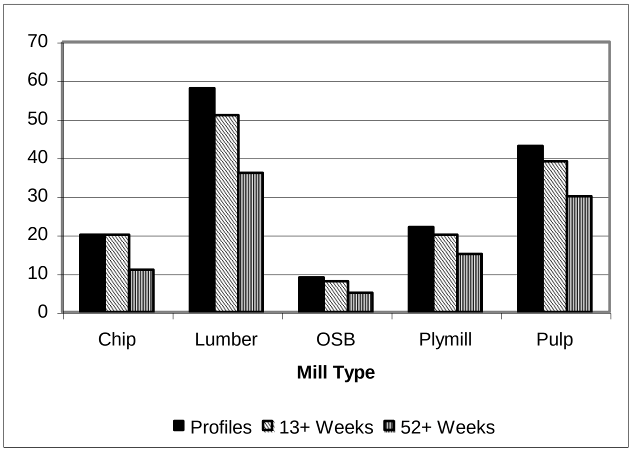

Figure 1. Number of mills that gave profile information or reported at least 13 or 52 weeks.

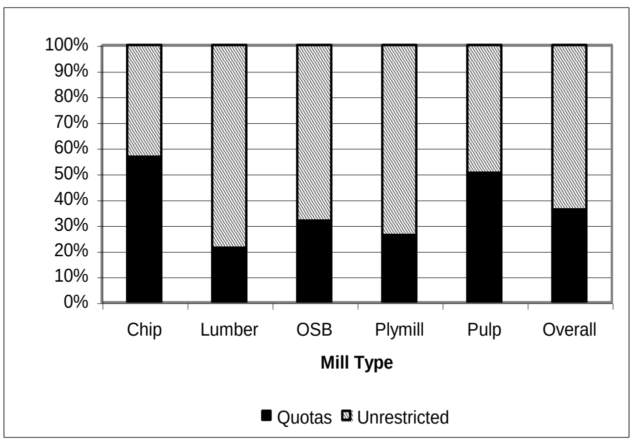

Figure 2. Percentage of weeks where mills issued quotas.

Weekly mill participants also indicated which factors, other than quota, was restricting wood flow. There were six options from which to choose: Weather – precipitation, Weather – temperature, Mill Woodyard – unloading, Mill Woodyard – Processing, Scheduled Mill Outage, or Other. Mills cited 2,563 instances in 31% of the reported weeks where an issue other than quota restricted wood flow. They indicated that 53% of the time precipitation influenced wood flow. They further reported 13% due to temperature, 4% due to woodyard unloading problems, 5% due to woodyard processing problems, 9% due to a scheduled mill outage, and 16% due to some other factor. From comments included on the weekly reports, it seems that most of the "other" instances were due to unscheduled mill outages, holidays, or market conditions.

Each week our mill participants indicated their current week's plan regarding wood inventory management, wood usage, and direct wood purchases for each wood product purchased. As an inventory plan, the mills were asked if they were planning to reduce, hold, or build for each of their inventories (Figure 3). In 18% of instances reported (n=12,766) our participants reported that they planned to reduce their inventory, 35% of the time they planned to hold their inventory, and 47% of the time they planned to build inventory. OSB, lumber, and plywood mills indicated they were planning to build their inventories 66%, 53%, and 48% of the time, respectively. In contrast, chip and pulp mills reported the highest incidence of planning to reduce their inventories at 21% and 21% of the time, respectively. These differences are supported by the previously discussed quota data, which suggested that chip and pulp mills also issued quotas most often.

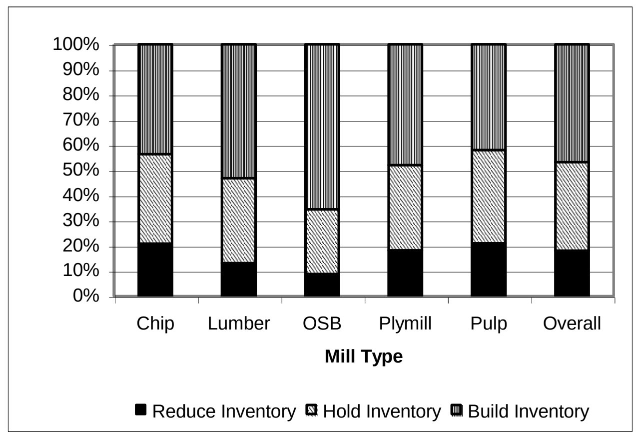

Figure 3. Average weekly inventory plans.

In addition, mill reporters were asked to indicate each week if mill consumption was below, at, or above the planned level for each of their raw material products (Figure 4). In 27% of instances reported (n=12,434) our participants reported they were below their planned level of consumption, at their planned level 60% of the time, and above their planned level 13% of the time. Of all the mill types, plywood mill consumption had the highest percentage of being at their planned level with 77%. Pulp mills had the lowest percentage of being at their planned level of consumption with 52%. They were also above their planned level the most at 16% of the time. OSB and pulp mills had the highest percentage of being below their planned level of consumption with 33% and 32% respectively.

Mill participants were also asked to indicate each week for each of their raw material products if direct wood purchases were below, at, or above planned level (Figure 5). In 35% of total instances reported (n=11,463), our participants indicated that their direct purchasing was below their planned level, at their planned level 56% of the time, and above their planned level 9% of the time. OSB, Plywood, and Lumber mills most often cited their direct wood purchases below their planned level at 47%, 37%, and 37%

of the time respectively. Chip mills most often purchased direct wood above their planned level at 14% of the time.

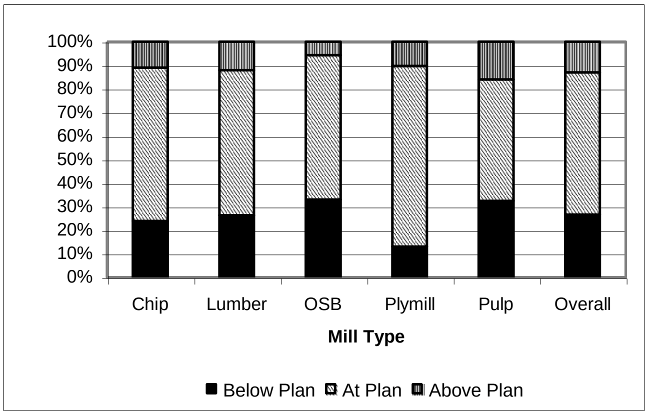

Figure 4. Average weekly usage plans.

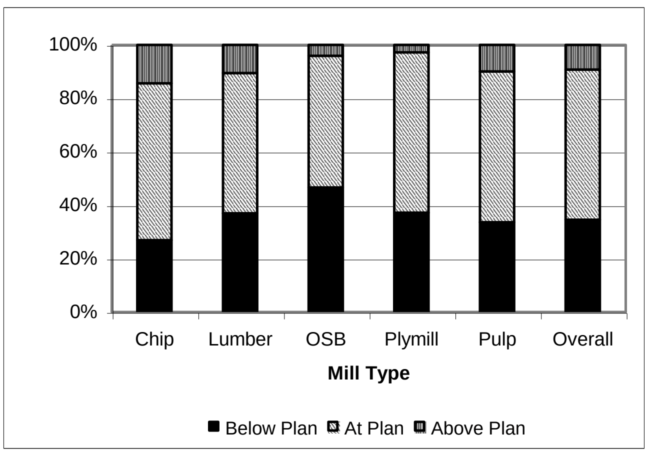

Figure 5. Average weekly direct purchase plans.

INVENTORY, PURCHASE, AND USAGE PATTERNS

Our participants also reported their actual beginning and ending inventories, purchases, and wood consumption for the week. We wanted to use this information to describe the strategy of our participating mills for each of the aforementioned variables and further investigate how these factors affect logging production and capacity utilization.

One of our first objectives was to evaluate the inventory practices of mill participants. In order to deal with the wide range of mill, and subsequently inventory sizes, we scaled each mill's inventory quantity by its long-term average mill usage. The long-term average mill usage was simply defined as the average usage reported by an individual mill during the study period. Using the long-term average usage of each mill we created the weekly variable Inventory Usage Weeks (IUW) where:

IUW = Mill Inventory / long-term average mill usage**.**

IUW can be viewed as the number of weeks of inventory available given the long-term average usage reported by the mill. This allowed us to more appropriately compare mills of different type and size. Averages and coefficient of variations (CV) were calculated using IUW for each mill type (Figure 6). Chip mills reported the highest average with 3.1 weeks and a CV of 76%. OSB mills had the next highest average at 2.1 weeks and a CV of 79%. Plywood mills had an average of 2.1 weeks and a CV of 46%. Pulp mills had an average of 1.5 weeks and a CV of 80%. Lumber mills had an average of 1.5 weeks and a CV of 92%.

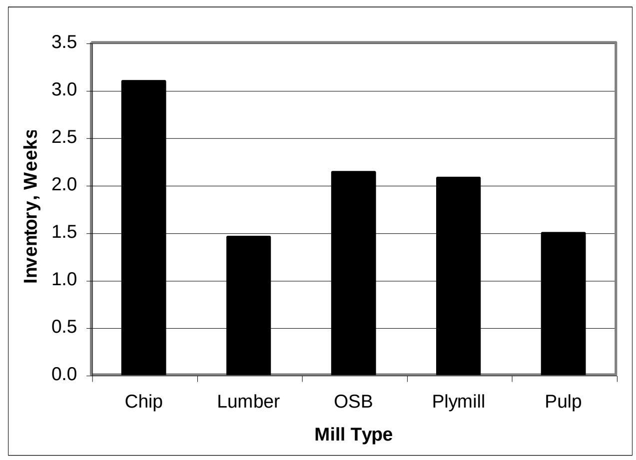

Figure 6. Average inventory (usage weeks).

We also wanted to make inferences about the purchase and usage strategies of the mills participating in the study and compare them to trends in their inventory strategies. We again used the long-term average usage of each mill to scale their purchases and usage. In order to get a better perspective of our reporters' variability for their purchases and usage, we calculated CVs for each mill type (Figure 7). In each case, the CV for purchases is higher than the CV for the usage. The purchase and usage means were then plotted, and overlaid with means from the inventory data by month (Figure 8). While in many cases the weather patterns during the study period were not "normal," the mill inventory, purchase, and usage levels displayed trends consistent with the generally accepted beliefs. The downward slope of the "decline to summer", and the upward slope of the "fall buildup" are clearly visible on the inventory line. Although not shown in this paper due to space limitations, the inventory curves differ dramatically by mill type.

After plotting each inventory trend by mill type, inventory patterns were investigated further. We hypothesized that IUW would differ by mill type and the graphs suggested such differences, at least on average. To investigate these hypotheses statistically we developed a series of nonlinear regression models to test for differences in mill type. Trends in these data indicated that a minimum IUW was attained between April and August depending upon mill type. Additionally, the relationships around the minimum may not be symmetric (i.e. the trend toward the minimum

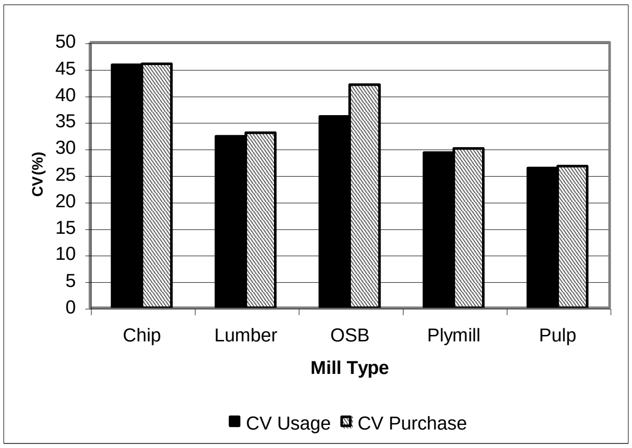

Figure 7. Coefficient of variation (%) for mill wood purchases and usage.

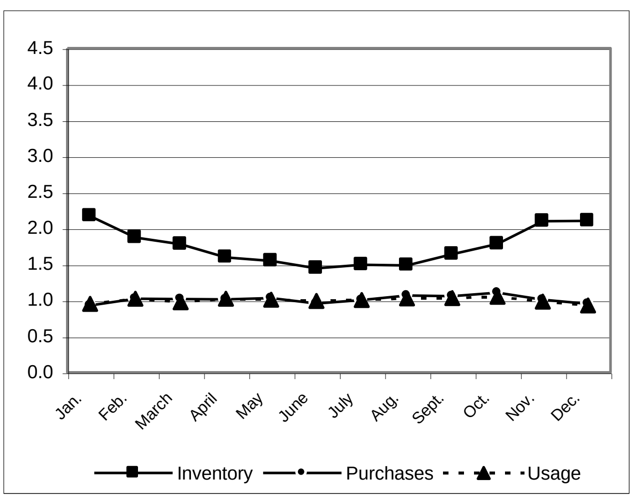

Figure 8. Inventory, purchase, and usage patterns (usage weeks) for all mill types.

IUW may be different than the trend away from the minimum IUW). To explore these possible relationships, the following regression model was hypothesized:

$$IUW = \beta_0 + \beta_1(month - \beta_2)^{\beta_3}$$

Due to convergence problems with the nonlinear model we set β_3 to 2. The model was fitted by mill type and was significant for all mill types although the fit statistics indicated a substantial amount of variation within mill types. To explore differences in mill type the following model was estimated using the mill inventory data:
The Zs are indicator variables for mill type (pulp, lumber, plywood, OSB, chip). The full model showed no increase in predictive power indicating that the hypothesized trends by mill type were not supported by these data. While the average trends by mill type show apparent differences among the mill types, these data are quite variable making statistically significant differences hard to uncover. We believe that in practical terms each of these various mill types “draw down” inventory during the traditionally dry summer month months and build inventory during the fall. However, the timing of these decisions appears to be quite variable among the participating mills in the study. Additionally, there are large differences among chip mills, in particular, as to how they manage their wood inventory. Several of the chip mills in the study were basically off-site “surge or overflow” yards for pulp and paper mills and displayed substantially different inventory strategies. This made trends for that mill type quite variable. As expected, however, the pulp and paper mill type exhibited the lowest variability and most consistent trends.

MILL CONSISTENCY RATING

The next objective was to further investigate purchase and usage variability, and its subsequent effect on logging production. Usage variability directly affects purchase variability since mill consumption tends to drive mill purchases. Purchase variability may directly affect the loggers. Greater mill wood purchase variability can produce difficulties for loggers. Conversely, consistent levels of wood purchase create a more predictable and desirable market environment. Specifically, when a mill’s purchases are below its average purchases, its impact is likely greatest on the logger (i.e. quotas).

To quantify the level of market volatility faced by the logging production force, a consistency rating was calculated for each mill. This purchase consistency rating was determined as a function of the semivariance or downside variability of each mill’s purchases. The semivariance of purchases was defined as the average of the squared deviations between a target quantity and those observations that fall below that target.
It was expressed as:

$$S^2_h = 1/m\ \Sigma^m_t \max\{0, (h-R_t)\}^2$$

where
m = number of time periods
h = target or mean purchases
R = random variable
t = time period.

The "target" for our analysis was the long-term average of wood purchased during the study period by a given mill. If the purchase level exceeds the target h, the difference is negative and the observed value is 0. Thus, only below-target purchase levels provide a positive deviation, which is squared and added to the calculation of semivariance (Caulfield and Meldahl 1994). The consistency rating was calculated by dividing the semivariance by the mean, multiplying it by 100%, and subtracting it from 100 (similar to a coefficient of variation) as follows:

$$\text{Consistency Rating} = 100 - \{(S^2 / X) * 100\%\}$$

where
X = Mean
S^2 = Semivariance

This same method was applied to develop consistency ratings for both purchase and usage levels for each participating mill on a quarterly basis. Higher consistency ratings were associated with less downside variability in a mill's purchases or usage. High values of each index indicate consistent performance with low downside risk. Since ultimately usage drives purchases, mills with a purchase consistency rating (PCR) above their usage consistency rating (UCR) were providing a more consistent market environment than those whose PCR were below their UCR. We illustrated this by plotting PCR versus UCR, and then adding a 45^o line with an intercept of zero (Figure 8). Mills that fall above the line are providing a more consistent market given the consistency of their usage situation.

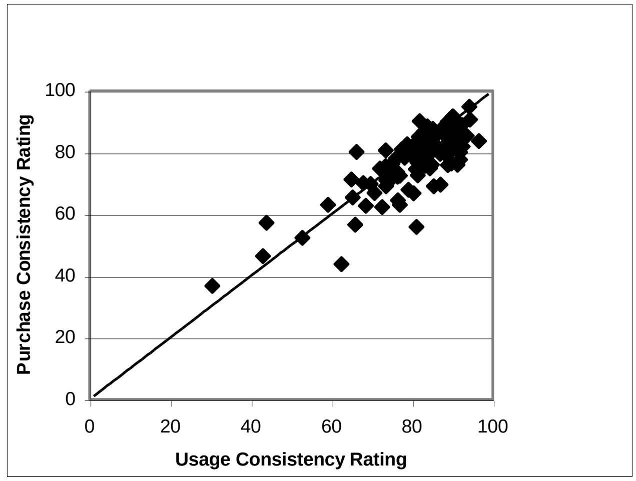

Figure 8. Purchase consistency rating versus usage consistency rating for mills.

LOGGER MARKET-CAUSED MISSED PRODUCTION AND MILL CONSISTENCY RATING VALUES

We next examined the missed production due to market causes experienced by loggers to see if this was affected by the consistency rating of the mills where they delivered wood. We assumed that loggers delivering to mills with lower consistency rating values would experience more missed production due to market factors, unless they had preferred supplier agreements that minimized their exposure to production quotas.

A quarterly consistency rating was calculated for each mill that had reported at least eight weeks of purchase, usage, and inventory data during the quarter. This resulted in consistency rating estimates for 614 combinations of mill and calendar quarter. A total of 130 mills were represented in this dataset.

We next selected data from logging crews that had reported at least 26 weeks of data with at least 50% of their total production during the study delivered to mills of WSRI member companies. These provided 1,815 crew weeks combined into 366 crew-quarters. For each crew-quarter, we calculated the average consistency rating at receiving mills weighted by the number of loads delivered. Only mills with an available consistency rating were used in this calculation. From these 366 crew-quarters, we further screened the data selecting those quarters where we had at least 10 weeks of reported production for the crew and where 70 percent or more of the crew production that quarter went to mills for which we had a calculated consistency rating value. This ensured we had a consistency rating for most mills receiving wood from each crew selected for this analysis. This yielded 68 crew-quarters with 23 logging crews represented, evenly divided between preferred supplier crews (12) and other crews (11).

We examined the statistical correlation between the percent missed production due to market causes and the weighted average consistency rating loggers faced at receiving mills for both preferred and non-preferred suppliers. Correlation was measured by a Pearson correlation coefficient [R] where a value of +1 implies perfect positive correlation and a value of –1 suggests perfect negative correlation. A value of 0 indicates the two variables are not correlated at all. Such correlation values are statistically tested to see if their value is significantly different from zero. If not, no correlation can be said to exist. Otherwise, it can be said that the two variables are statistically correlated at some level of statistical confidence. This level of statistical confidence is measured by a p-value. The smaller the p-value, the higher the level of statistical confidence (1 minus the p-value) provided. For example, a p-value of 0.05 indicates a statistical confidence level of 95 percent (1-0.05). In short, R values that approach zero or p-values that exceed 0.10 indicate low levels of correlation.

For preferred suppliers, we found no correlation between the percent of production missed due to market causes and the average consistency rating of the mills receiving their wood. The correlation coefficient was 0.0836 with a p-value of 0.6129. These clearly indicate that no correlation between these two measures exist for preferred suppliers (Figure 9).

For those crews without preferred supplier status, we found that the consistency rating was significantly correlated with the percent of market-caused missed production for logging crews. For this group of crews, the correlation coefficient was 0.3970 with a p-value of 0.0364. For crews without preferred supplier status, the percentage of missed production attributable to market causes is significantly correlated to the consistency rating at the mills where they deliver.

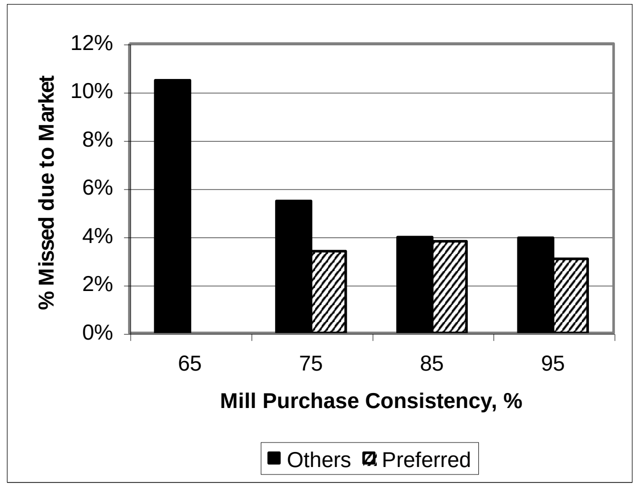

Figure 9. Relationship of missed production due to market causes by logging crews and the purchase consistency at mills where they delivered by preferred supplier status.

BENCHMARKING MILLS

In order for the consistency rating to be useful to a mill, there should be a standard by which the mills can measure their performance. A standard is usually set by using the top performers in a given system. To assist the mills in measuring their performance, we took the best performing mills using the consistency rating data and created a standard or benchmark. These top performers create a frontier by which all the other mills are measured. From this information, mills can see how they are performing compared to the benchmark, and to other mills of the same type.

We used data envelope analysis to develop the frontier for the consistency rating's top performers. The Data Envelop Analysis Program (DEAP) (Coelli 1996) performed the frontier calculations. For this analysis, we used the consistency rating for each mill by quarter. The data were aligned into two columns: an input column and output column. Each column was organized by mill type to compare differences among them. The input column was the UCR data since usage drives purchases. The output column was the PCR data since purchases are a function of usage. The measures used in the program were output oriented because we consider a mill's usage to be constant, and their purchases variable. For these data, the technical efficiency of a firm was defined as the amount by which PCR can be increased without changing UCR.

The DEAP program used for these data was set to use variable return to scale (VRS) instead of constant return to scale (CRS). CRS assumes that all units are operating at an optimal scale. In our data, not all units were operating at the optimal scale and use of CRS would result in technical efficiencies confounded by scale efficiencies. We used VRS to permit the calculation of technical efficiencies devoid of scale efficiency effects. VRS draws a complex hull around the data and always gives equal or higher technical efficiency scores as CRS (Coelli 1996).

Once the consistency rating data was properly aligned, a program was created and the DEAP program returned technical efficiency scores for every consistency rating data point. The average VRS technical efficiency for all of the data was 86%. The average technical efficiency was also calculated for each mill type using the frontier for all of the mill types: 82% for chip mills, 87% for lumber mills, 80% for OSB mills, 89% for plywood mills, and 86% for pulp mills. Lumber, pulp, and plywood mills were all at or above the average. Chip and OSB mills had the lowest scores.

Using the DEAP program outputs, we created a frontier around the quarterly consistency rating data (Figure 10). The output shows which data points set the standard to which the other data points are compared (peers) to subsequently issue their technical efficiency rating. These peers have a technical efficiency rating of one, and make up the interior pieces of the frontier. The first and the last sections of the frontier run parallel with the vertical (PCR) and horizontal (UCR) axis respectively.

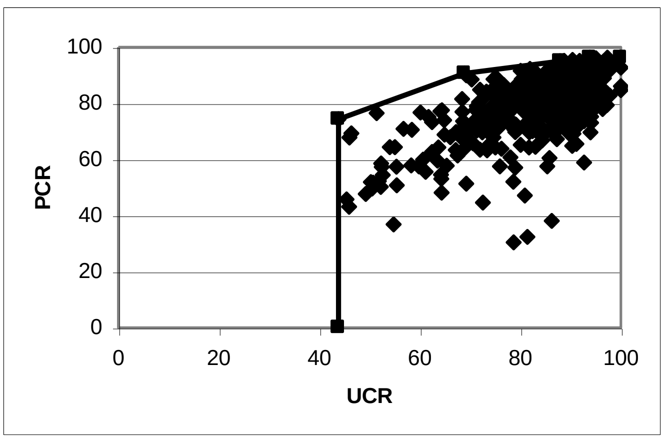

Figure 10. The consistency rating frontier generated using DEAP for all mill types.

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A Simulation-based Optimization Model for Planning Forest Operations

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ABSTRACT

An essential problem in planning forest operations involves the allocation of scarce and expensive resources to specific tasks. The allocation of transport, for example, among several competing locations and functions is critical in managing an efficient forest operations company. Transportation costs represent a significant portion of the total operating cost of a forest products company. Trucks are needed for delivering timber to mills and for carrying machinery between worksites, which can be located anywhere within a large geographic area. A transportation management system that allocates scarce truck resources optimally among competing interests could increase the total operational efficiency of a procurement entity, lowering delivered costs of wood. The main difficulty in developing such a system is finding an optimal transport schedule while handling complicated constraints, such as precedence and temporal relations among forest operations, project due dates, truck routing, weather conditions, and other operational conditions. It is well known that finding an optimal solution to these types of problems involves high computational complexity. They are usually NP-hard. For this reason, we propose to use a meta-heuristic optimization approach that interacts with a network simulation model of the system in which the precedence and temporal relations among forest operations and logistics are explicitly accounted for. The approach has been tested using data provided by a silvicultural services company located in Alabama.

INTRODUCTION

Operational planning in a forestry services company involves the allocation of scarce resources to individual tasks comprising multiple projects. The allocation of resources to tasks over time with the goal to optimize one or more objectives is known as *scheduling* [3]. The typical goal of a scheduling problem is to determine how to assign resources to tasks such that the completion time of the last activity is minimized. However, one could also be interested in maximizing the utilization of the resources and/or minimizing the total costs of the project. The simplest scheduling method is the Critical Path Method (CPM) [8]. In this method, the set of tasks are represented as a network to denote the precedence relations among pairs of tasks. The goal of the CPM is to determine the smallest possible project completion time without violating the precedence constraints of the tasks. The method ignores constraints on resources. A more realistic variant of the CPM is the Resource-Constrained Project Scheduling problem (RCPS) [4]. Several approaches have been proposed to solve the RCPSP. Pritsker et al. [6] proposed one of the first mathematical formulations, a 0-1 linear programming model to solve the RCPSP. The formulation requires the definition of up to nT binary variables, where n is the number of activities and T the number of time periods. The complexity of the model is $O(n^2+mT)$, where m is the number of renewable resources. More 0-1 linear programming models can be found in [5, 1]. Although the RCPSP is more realistic, it still has some limitations. One of the drawbacks of the RCPSP formulation is that it assumes constant availabilities of the resources during the planning horizon, but it is common in practice that machines are scheduled for maintenance or required for other projects. Also, due dates cannot be considered within RCPSP. The Generalized Resource-Constrained Project Scheduling Problem (GRCSP) [4] overcomes these limitations and has been successfully used in manufacturing applications [2]. Despite its high practical relevance, the GRCSP is still not a good model for use in planning forest operations. Silvicultural services companies are characterized by simultaneously operating multiple projects with tasks spread over large geographic areas. This characteristic makes transportation costs important in determining the optimal allocation of the resources over time. Unexpected breakdown of a truck or machine and unpredictable changes in weather may also have effects on how the resources are efficiently allocated. Moreover, forest companies have to deal with multiple objectives and due date violation costs.

This paper proposes an efficient computer algorithm for planning forest tasks by considering transport schedule and task precedence constraints. The resulting optimization problem is a nontrivial generalization of the GRCSP. We have developed a meta-heuristic procedure for solving this time-resource-cost-tradeoff optimization problem. The approach consists of a simulated annealing algorithm (SA) [7] that interacts with a network simulation model of the forest system. In the following sections, we describe the proposed procedure. First, we describe the optimization model, the forest system, the simulation model, and the meta-heuristic optimization algorithm. Second, we describe our experimental methodology and present an overview of the numerical and performance results. In the Appendix following the concluding section, we provide a tabulated set of the experimental results.

OPTIMIZATION MODEL

The proposed approach consists of three main components, a simulation model, an optimization model, and an animation procedure. The simulation model is used to evaluate performance measures such as traveled distances and completion time of the tasks for a given solution. The function of the optimization component is to find a good solution and it is implemented by a SA algorithm. The SA algorithm starts by generating an initial solution to the transport allocation scheduling problem. In our approach, the initial solution can be either provided by the user or generated randomly. The simulation model is next used to evaluate the quality of this initial solution. The SA algorithm searches for a better solution using the information provided by the simulation model and the initial solution. The search procedure uses the simulator every time that it needs to evaluate the performance of a new solution. An optimal or close to optimal solution is obtained by iteratively running this search procedure. After the search procedure ends, the best solution is animated to show the states of the activities and resources as time progresses. Figure 1 shows a block diagram of the proposed approach.

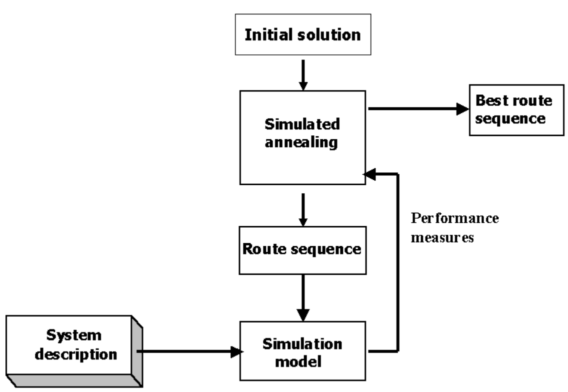


Figure 1. Optimization model

Forest Project Description

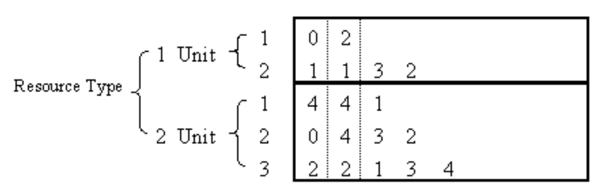
The optimization model assumes that the forest project consists of N spatially dispersed worksites. The quantity d_{ij} gives the distance between worksites i and j. At each worksite i (i=0,...,N-1), a set of M_i tasks need to be performed. The set of tasks to be performed at worksite i is denoted by $\{t_{1i}, t_{2i},\ldots\}$. The task precedence relationships, resource requirements, and execution times of the tasks are all part of the project description. Table 1 shows an example of the data needed to fully describe a worksite. The initial positions of each of the resources and the initial status of the tasks are also part of the project description. This feature allows for the resolving of the optimization model when the location of a resource and/or the status of a task needs to be adjusted.

Table 1. Description of a worksite

WORK CENTER 1				
Activity Instance	Activity Type	Duration	Preceding Act.	Type of Resource(quantity)
0	-	0	-	-
1	104	4	0	5(1)
2	106	7	0	2(1)
3	117	4	2	2(1)
4	104	8	1,3	5(1)
5	101	14	4	3(1)
6	117	4	5	2(1)
7	106	8	6	2(1)
8	-	0	7	-

Transport Schedule Representation

A solution to the optimization problem consists of a set of routes for each of the resources. A route specifies the sequence in which the resource will visit the worksites. For example, for a forest project consisting of four worksites and three resources, a feasible solution could be given by the set of routes S= {(1, 4, 3, 2, 3), (2,1,4), (4,2,1)}. In this solution, resource 1 is scheduled to start at worksite 1, then to travel to worksite 4, and so on. In our formulation, we assume R different types of resources and that each type k (k=1,..,R) has r_k identical units available. Figure 2 shows an example of a transport schedule (a solution) for a forest project with 5 worksites, 2 identical units of resource type 1 and 3 identical units of resource type 2. Here, worksite 0 is assumed to be the hub center. The first entry at each row denotes the initial location (worksite) of a unit of that particular resource. The other entries denote the worksite in which a task requires a resource of that type. Figure 2 shows a case in which each unit resource type 2 has been scheduled to visit worksite 4. In this example, there are three tasks that require a unit of resource type 2.



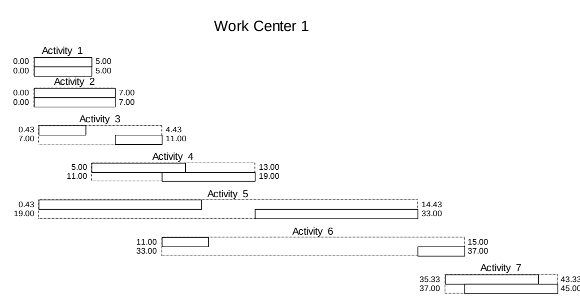


Figure 2. A solution for a forest project with five worksites and two types of resources.

Simulation Model

We have developed a simulation model using Microsoft Visual C++. The objective of this simulation model is to evaluate the performance of a given solution. The inputs to the simulation model are the data corresponding to the project description and a transport schedule (a feasible solution). The simulation model outputs performance measures such as completion times for the tasks and distances traveled by the resources. The simulation model also gives the source code for the animation.

Figure 3. A Gannt chart of the simulation ouput for worksite 1.

Simulated Annealing Algorithm

We use a SA algorithm to find an optimum or near optimal solutions to the optimization problem. The SA algorithm is a meta-heuristic optimization technique for solving combinatorial optimization problems. It uses an iterative improvement approach, which is also known as neighborhood search. A SA algorithm avoids the entrapment in a local optimum by allowing "uphill" moves based on a model of the annealing process in the physical world. At the start, the simulated annealing algorithm requires an initial solution, which becomes the current solution. Next, the heuristic perturbs the current solution to obtain a new solution, called a neighbor solution, which may become (by a random selection process) the current solution in the next iteration of the algorithm. The procedure continues until the annealing process cools off. We have implemented three neighbor operators to perturb the current solution. We use a random selection process to choose the operator to be applied at each neighborhood search.

Neighbor Operator A

Operator A generates a new solution by switching two worksites (randomly selected) of the current solution within a route of a specific unit. Figure 4 shows an example where a new route for unit 3 of resource type 2 has been generated by switching the worksites 3 and 4.

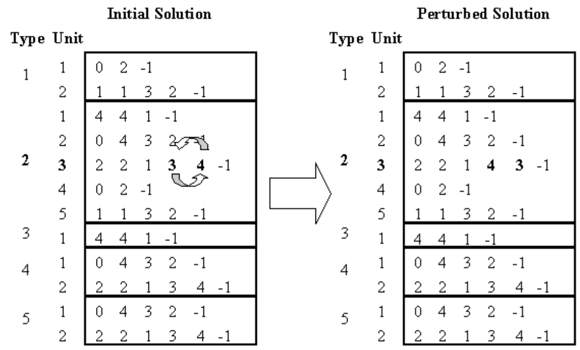


Figure 4: Example of applying neighbor operator A

Neighbor Operator B

Operator B generates a new solution by switching two worksites between two different units of a same type. The units and the worksites are randomly selected. Figure 5 shows an example where new routes for units 1 and 2 of resource type 1 have been generated by switching the worksites 2 and 3.

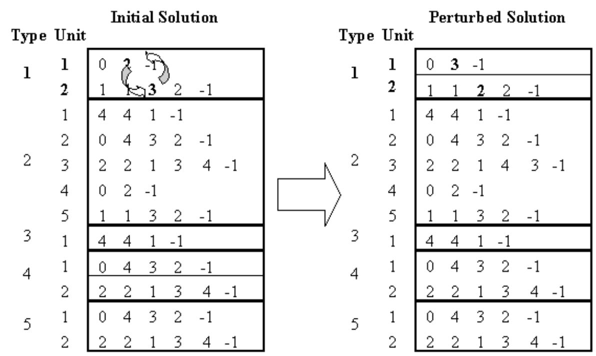


Figure 5: Example of applying neighbor operator B

Neighbor Operator C

Operator C generates a new solution by moving one worksite from a unit to another unit of the same resource type. Figure 6 shows an example where new routes for units 1 and 2 of resource type 4 have been generated by removing worksite 3 from the route of unit 1 and scheduling unit 2 to worksite 3 twice.

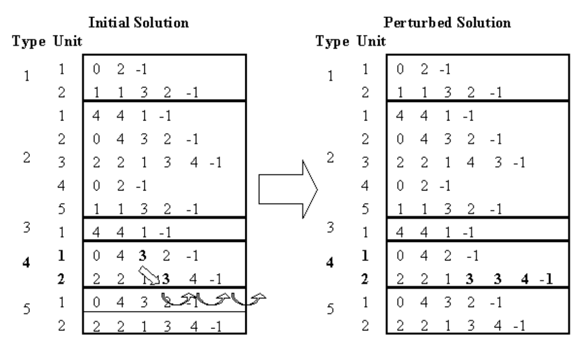


Figure 6: Example of applying neighbor operator C

EXPERIMENTAL RESULTS

Using data from a forest service company located in South Alabama, we have created a test problem to verify our optimization model. The problem consists of four worksites and one central hub. Table 1 gives the distances between each of the worksite.

Table 1. Distance between worksites (in miles)

Worksites	0	1	2	3	4
0	-	21.5	44	66	16.5
1		-	22.5	87.5	28.5
2			-	110	49
3				-	64.5
4					-

We assume that five types of transport resources are critical and need to be scheduled. Table 2 gives the number of identical units and their initial locations for each resource type. We assume that the resources will move at the average speed of 50 mph.

Table 2. Resource units and their initial positions

Resource type	Unit	Worksite
1	1	0
1	2	3
2	1	0
2	2	1
2	3	0
2	4	2
2	5	0
3	1	0
4	1	2
4	2	0
5	1	1
5	2	2

The set of tasks performed at each of the worksites are given in Table 3. This table describes location (worksite), duration, precedence, and resources of each task.

Table 3: Task Description

Worksite	Task	Duration	Preceding Task	Resource type (quantity)
1	1	4	-	5(1)
1	2	7	-	2(1)
1	3	4	2	2(1)
1	4	8	1,3	5(1)
1	5	14	4	3(1)
1	6	4	5	2(1)
1	7	8	6	2(1)
1	8	0	7	-
2	1	4	-	5(1)
2	2	5	1	-
2	3	8	-	1(1)
2	4	6	3	4(1)
2	5	8	2,4	-
2	6	12	2,4	2(1)
2	7	8	6	2(1)
2	8	0	5,7	-
3	1	3	-	1(1)
3	2	8	1	4(1)
3	3	8	-	-
3	4	14	3	5(1)
3	5	10	2,4	-
3	6	4	5	2(1)
3	7	0	6	-
4	1	4	-	2(1)
4	2	9	-	2(1)
4	3	4	2	2(1)
4	4	3	1,3	-
4	5	8	4	2(1)
4	6	10	5	1(1)
4	7	8	4	4(1)
4	8	4	7	2(1)
4	9	3	6,8	-
4	10	0	9	-

To test our model, we first set the objective of the optimization to minimize the makespan (completion time of the last task) of the entire project. Minimizing the makespan is equivalent to maximize the utilization of the resources. We set up the initial and cooling temperature of the SA algorithm to be 150 and 40 F°, respectively. The temperature of the SA algorithm is decreased at the rate of 5%. At each temperature step, the neighborn of the current solution is searched one hundred times. To evaluate the sensitivity of the SA algorithm to the initial solution, we run the algorithm ten times. At each run the initial solution is randomly generated. The results – best, average, and worst – of the ten replications are 45.00, 46.20, and 50.75 hours, respectively. The best solution, which for this particular case is also the optimal solution (checked by complete enumeration), is illustrated in Table 4. For this solution the total distance traveled by the resources is 685 miles.

Table 4: Best routes that minimize the makespan

Resource type	Unit	Optimal Route Worksite(task)	Total distance (miles)
1	1	0→2 (3)	44.0
1	2	3→3 (1)→4 (6)	64.5
2	1	0	0.0
2	2	1→1(2)→4→(2) →4(3)→1(3)	57.0
2	3	0→4(1)→2(7) →4(8)→1(6)	143.0
2	4	2→2(6)	0.0
2	5	0→1(3)→4 (5) →3(6)	114.5
3	1	0→1(5)	21.5
4	1	2→2 (4)	0.0
4	2	0→3 (2)→4(7)	130.5
5	1	1→1(1)→1(4)	0.0

5	2	2→2 (5)→3(4)	110.0

Next, we change the objective function to minimize the total traveled distance. The results – best, average, and worst – of the computational experiment are 409.5, 477.5, and 543.5 miles, respectively. The best solution is illustrated in Table 5. For this solution the makespan of the project is 73.31 hours.

Table 5: Best routes that minimize the total traveled distance

Resource type	Unit	Optimal Route Worksite(task)	Total distance (Miles)
1	1	0→4(6)→2(3)	65.5
1	2	3→3(1)	0.0
2	1	0	0.0
2	2	1→1(2)→1(3)→1(5)→3(6)	87.5
2	3	0→4 (1)→4(2)→4(3)→4 (5)	16.5
2	4	2→2(6)→2(7)	0.0
2	5	0→1(4)→4(8)	50.0
3	1	0→1(5)	21.5
4	1	2→2(4)	0.0
4	2	0→4(7)→3(2)	81.0
5	1	1→1(1)→1(4)→3(4)	87.5
5	2	2→2(1)	0.0

It is clear that the final decision will require making an explicit trade-off between the objective of minimizing the makespan and minimizing the total traveled miles. Figure 7 depicts this trade-off by displaying a set of feasible solutions. Each point identifies the makespan and traveled miles of a particular solution. Notice that the three points joined by the line dominate all the other solutions. A final decision that explicitly considers the trade-off between the makespan and the traveled miles should lie on or near this curve. Notice also that the range of the solutions is quite large. For example, there are many solutions that have the minimal makespan of 45 hours, but have different total traveled miles ranging from 482 to 680 miles. Here, there is a potential for an improvement of 198 fewer miles. Furthermore, without an optimization procedure, the company could be operating on any of the dominated solutions, namely traveled total distance equal to 550 miles and makespan equal to 65 hours. By using one of the solutions that lies on the curve, say traveled total distance equal to 460 miles and makespan equal to 52, the company can reduce by 13 hours (20%) the completion time, and by 90 miles (16%) the total traveled distance.

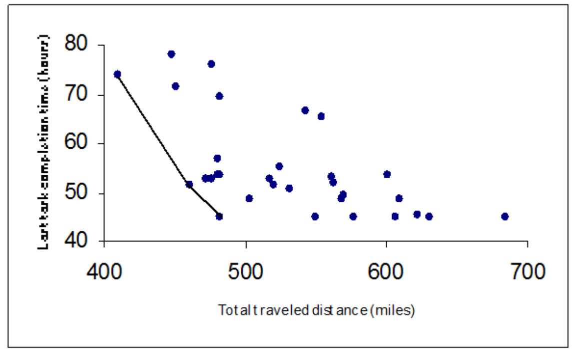


Figure 7: Trade-off between makespan and traveled miles

DISCUSSION

A heuristic procedure for scheduling transport resources to tasks at remote locations has been described. The use of a simulation model makes the proposed approach very attractive because detailed features of a company's operation can be easily included. The results obtained solving one instance of a medium size problem showed that the best solution could be found in less than two minutes. A silvicultural services company could achieve significant savings by using this approach to schedule its operations. It is well known that transportation costs represent a significant portion of the total operating cost of a forest products company. Additionally, transportation cost reduction has positive environmental effects as fuel use is minimized. Future plans are to incorporate into the simulation model random components such as breakdowns of machines or trucks and weather uncertainties. The performance of the optimization model also will be evaluated with larger problem instances.

ACKNOWLEDGEMENT

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Hardwood Log Damage and Degrade Occurring During Harvesting Operations in Central Appalachia

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ABSTRACT - Damage is often seen as an important consideration when conducting partial harvests in hardwood stands, as excessive damage to residual trees will significantly reduce the potential value of the residual stand. Potentially, damage to harvested logs, especially hardwood saw and veneer logs can be an even more important concern relative to value loss associated with log degrade. This study focuses on log damage and degrade caused by two commonly used ground-based harvesting systems in the central Appalachian region - chainsaw felling/cable skidder vs. feller-buncher/grapple skidder on moderately sloped sites. Observations were made of all grade logs during the felling, skidding, decking/sorting, and loading phases of the harvesting operations. All logs were recorded with species, diameter, and length information. The number of saw or veneer logs sustaining damage to the bark or cambium was recorded with additional information obtained for damage location, damage volume, damage type, and possible cause of the damage. Data were analyzed to determine and rank the phases of the harvesting process relative to potential damage and degrade to hardwood logs. Operator experience was also evaluated for differences in damage potential. Overall results showed large differences in mean damage volume between the two different harvesting systems, with the chainsaw felling/cable skidder system having a larger impact. Other conclusions included a large difference in the felling procedure between the two systems, with the chainsaw felling/cable skidding system again having the greatest impact.

INTRODUCTION

The value of forest products from the Appalachian hardwood region continues to grow as the demand for quality hardwood lumber increases. Damage to harvested hardwood logs is becoming a major concern to wood producers in the region, where much of the hardwood timber harvested will find itself being turned into veneer, veneer based composites, and sawn into grade hardwood lumber. These trees can give the high quality sawlogs and veneer that industry needs for fine furniture, flooring, cabinetry and other wood products (Seymour et al. 1986). The condition of the outer area of the log is important to the potential future grade of the log and the potential value recovered from the log in the form of veneer or lumber.

Damage to logs was observed during the felling, skidding, decking, and loading stages of the timber harvesting process. Damage was considered to be physical wounds that detracted value from the harvested log. Past studies have suggested that significant gains can be achieved through a log quality control system. Craig (1982) estimated that implementing a quality control program could increase returns by as much as 50 percent of the harvest value. Murphy and Twaddle (1985) indicated that nearly 40 percent of the standing value of a tree can be lost through degradation during the harvesting process. Williston (1979) also found that breakage and skidding/yarding damage associated with harvest operations destroyed almost six percent of the total value of harvested logs.

The previous studies have suggested that some damage can be expected, particularly where quality control programs are not emphasized. In addition, most of the studies considered harvest operations where only one or two species of timber were harvested. McNeel and Copithorne (1996) indicated that species was a factor in defining the extent of breakage expected during harvest. They found that more brittle species, in this case western red cedar *(Thuja plicata)*, exhibited significantly more damage than less brittle species in the same harvest.

In Central Appalachia, we can see dozens of species, each with different manufacturing criteria, being harvested off one site. There is no definitive set of criteria for what species are most affected during harvest operations. Nor are there any studies in Appalachian forests that have addressed the question of how harvest operations damage harvested logs. The objective of this project is to examine and analyze the extent of harvested log degrade by harvesting system, function, and species in central Appalachian hardwood sites.

RESEARCH METHODS

Partial cuts were performed on two sites (Table 1). Two harvesting systems were compared in this study to determine the effects of them on log damage. The mechanized operation consists of a tracked Timbco feller-buncher equipped with a bar and chain felling head and a Timberjack 660C grapple skidder. This operation also utilized a Caterpillar 517, which was used to pre-bunch the trees for the skidder. The knuckle-boom loader was a Prentice 310E. The manual operation consists of a Husqvarna 385XP chainsaw and a Timberjack 380C cable skidder. The loader was a Timberjack 330.

Each log was considered to be an observation, with each harvesting function receiving equal observations. The four harvesting functions were felling, skidding, decking/sorting, and loading. The variables measured for each observation include: small end diameter, large end diameter, length, species, damage type, damage location, damage dimensions, and damage severity. Log volume and damage volume were derived based on the above variables. Logs were placed in 100 board foot volume classes ranging from 100 to >1300 BF.

DATA ANALYSIS

A total of 2000 observations were recorded for both sites. Data was analyzed using the Statistical Analysis System (SAS). The analysis of variance (ANOVA) was applied to determine the means and significant levels of statistics among harvest methods. The goal here was to determine the effect the following variables had on the volume of damage occurring to the logs: harvest method, operation, species, damage type, log length, and log volume class.

RESULTS

Damage volume between both harvesting systems was significantly different. The mean damage volume for the manual system was 123.9 in^3, which contrasted sharply with the mechanized system, which had a mean of 18.5 in^3. The manual system showed a large difference in the felling operation when compared to the mechanized felling operation. The manual system seemed to be affected by the species being cut. For example, white ash *(Fraxinus Americana)* and white oak *(Quercus alba)* being cut by the manual system have much higher average damage volume than the same species being cut by the mechanized method. The manual system also showed a very large difference in damage type. Splits caused by manual felling, were found to have an average damage volume 60 times higher than mechanized harvesting functions.

Mean damage volume of 248.0 in^3 for the felling process between harvesting systems was much higher than skidding, decking, and loading processes. There were significant differences in damage volume among all four of the mechanized harvesting functions (Table 2). The manual felling harvesting showed a significant difference in the damage volume means resulting from the felling function when compared to the other harvesting functions.

Of the species sampled, white ash showed a distinct difference between harvesting systems in mean damage volume with an average of 901.1 in^3. Analysis of variance of the mechanized harvesting showed no significant differences among species, although the greatest mean volume damage occurred to white oak. Mean damage volume for species were also not found to be significantly different on the manual site, although white ash showed by far the greatest amount with a mean damage volume of 922 in^3. White oak showed the second greatest amount of damage volume with a mean of 317 in^3.

Among the damage types recorded, splits showed a significant difference between harvesting systems with a mean damage volume of 4213.0

in^3. Significant differences among mean damage volumes of all damage types were presented by the mechanized system, showing the greatest volume damage occurring due to slabs. For the manual felling site, the analysis of variance results indicated that splits caused the most mean damage volume. The remainder of the damage volume caused by gouges, scrapes, and chokers were comparable.

Between harvesting systems, the log length and the log volume class did not have a significant impact on the mean volume of damage that occurred to logs. The mechanized harvesting did show that the damage volume averages differed significantly among log lengths. More damage volume occurred to the longer logs. Differences in average damage volume were also found among log volume, with more damage occurring to logs of greater volume. It is worthy of note that the mechanized site had no logs with a volume greater than 900 board feet. The manual felling harvesting system showed no significant differences in mean damage volume pertaining to log length or log volume class. Shorter logs of 8 and 10 feet did show a greater mean damage volume than the longer logs, and logs with 200 to 300 board foot volume (BFV) showed more mean damage volume than the other volume classes.

Table 1. Research Conditions.

	Site 1	Site 2
Harvest Site		
Harvest Method	Mechanized Felling/ Grapple Skidding	Manual Felling/ Cable Skidding
Harvest Type	Partial Cut	Partial Cut
Stand Density (tpa)	115	105
Harvest Intensity (tpa)	40	60
Terrain Slope (%)	5-10%	5-15%
Aspect	N-NW	N-NE
Tract Size (acres)	100	75
Time of harvest	Fall	Fall
Species Composition	Mixed Hardwoods	Mixed Hardwoods
Total logs sampled	1000	1000
Operator Experience		
Faller (yrs)	4	12
Skidder (yrs)	23	39
Loader (yrs)	25	1

Table 2. Means and Significance Levels of Statistics by Harvest System[1].

Function	Damage Volume (in^3)	Function	Damage Volume (in^3)	Function	Damage Volume (in^3)
Operation		Damage Type		Species	
Mechanized		**Mechanized**		**Mechanized**	
Felling	31.2a	Gouge	45.8a	Cherry	17.6a
Skidding	23.4b	Slab	189.8b	Red Oak	18.8a
Decking	13.3c	Split	94.1c	Sugar Maple	14.9a
Loading	6.2d	Shatter	18.0d	White Ash	9.0a
Manual		**Manual**		White Oak	27.9a
Felling	464.9a	Gouge	53.6a	Yellow-Poplar	17.4a
Skidding	17.9b	Split	6501.3b	**Manual**	
Decking	10.6b	Scrape	114.0a	Cherry	83.2a
Loading	2.41b	Choker	42.4a	Red Oak	120.0a
				Sugar Maple	14.5a
				White Ash	921.8a
				White Oak	317.3a
				Yellow-Poplar	23.3a

[1]Means with the same letter within harvest system and function are not significantly different at the 5 percent level using Duncan's New Multiple Range Test.

DISCUSSION

Results have shown that damage to harvested logs does occur during the felling, skidding, decking/sorting, and loading stages of the timber harvesting process (Table2). Mean damage volume caused by the mechanized felling/grapple skidder and manual felling/ cable skidder harvesting systems differ under similar research conditions.

The manual (chainsaw) felling/cable skidder system is the most common harvesting system found in the Appalachian hardwood forest region (Egan 1999). This system caused approximately 6 times more damage than the mechanized felling harvesting system. The mean damage volume difference between the two systems could be attributed to the large difference in the manual felling operation, which was 15 times greater when compared to the mechanized felling operation.

As reported earlier, the manual system also seemed to be affected by the species being cut. For example, white ash being cut by the manual system has average damage volume close to 100 times greater than the white ash being cut by the mechanized method. Also, white oak being cut by the manual system has average damage volume 10 times greater than the white oak being cut. This difference could be attributed to the felling operation. White ash is a species that splits very easily. The mechanized felling system is very efficient in the directional felling and bunching of trees after they are cut.

Not unexpectedly, the manual system also showed a very large difference in damage type. Splits in the manual system, usually caused by felling, were found to have an average damage volume around 60 times greater than the splits caused by the mechanized system.

The results also indicated that felling has the most impact on log damage. This is especially true in manual felling. The loading process showed the least damage to the logs. Skidding and decking showed moderate amounts of log damage. Based on these results, log damage decreases as the distance away from the stand increases.

Both skidder drivers showed similar experience, and the mean log damage volumes for both systems are very comparable. The loader operators across the two systems vary greatly in experience, although the means for both systems were very similar. The mechanized felling system operator has 4 years experience to the manual felling system operator's 12 years experience, and the manual felling harvesting system showed a significant difference in mean damage volume.

The bucking process of a harvesting operation is an important function that usually causes the greatest damage and value loss. Improper bucking may not damage the log in a physical sense, but it can damage the potential value gained from bucking to the correct dimensions (Zavala 1995, Pickens et al. 1992, Sessions 1988). The bucking process is not included along with the felling, skidding, decking, and loading functions in this project because it is attributed mostly to improper decision making (Pickens et al. 1992) and does not contribute any real physical damage to harvested logs.

Value loss will be associated with the study in the future. Log damage should be viewed in terms of log degrade. A system will be devised based on answers to questionnaires received from the hardwood lumber industry, and current market prices. Pre-damage grades will be given to all logs based on their superficial condition, and a monetary value will be associated with the log based on scale and species. This system will then assign a grade and monetary value to each log based on the amount of damage the log has received. Each log will then have a pre-damage and a post-damage monetary value associated with it. Value loss will be determined by calculating the difference between the pre-damage value and the post-damage value. Statistical analysis will be performed to determine the effect harvesting damage has on the potential value of hardwood logs.

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Evaluation of Site Preparation Plow Energy Requirements

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ABSTRACT

In this field study, data were collected to determine energy requirements of trailing site preparation plows and the magnitudes of dynamic forces experienced by a plow during normal operation and during impact with stumps or other obstructions. Drawbar pull data were collected from five different tillage treatments on a recently harvested loblolly pine site in central Alabama. The five treatments were: 1) a coulter, ripping shank, and four bedding disks; 2) a coulter, ripping shank, and two bedding disks; 3) a coulter and ripping shank; 4) a coulter alone; and 5) a ripping shank alone. A 334 kN [75 000 lbs] capacity tension load cell was used to measure the drawbar load, a GPS receiver recorded tractor speed, four direct current displacement transducers (DCDT's) monitored the depth of the disks, and two optical tachometers measured the speed of the tractor's front and rear drive shafts. Each treatment produced significantly different drawbar loads (to alpha levels less than 0.001). The resulting mean loads were 45.95 kN [10 330 lbs], 33.47 kN [7525 lbs], 31.50 kN [7081 lbs], 15.84 kN [3561 lbs], and 43.42 kN [9761 lbs] for treatments one through five, respectively. The maximum drawbar load recorded during a collision with a stump was 338.9 kN [76 188 lbs].

INTRODUCTION

Mechanical and chemical site preparation operations in the Southeastern United States have been scaled back in recent years in an effort to reduce costs of regeneration. Many of the recent reductions in site preparation activities have focused on tillage operations while forest landowners struggle to determine how tillage fits into their silvicultural prescription. Tillage appears to benefit tree survivability and growth, however little information is available on the extent of tillage needed to produce the desired benefit.

Revitalization of tillage operations could occur if tillage systems were developed that increased productivity, reduced costs, and produced favorable soil conditions that were beneficial to the production of woody fiber. A tillage tool must create the optimal soil conditions for tree growth and withstand the rigors of forestry site preparation. The first step towards development of new tillage systems is focused on gathering numerical data, such as energy requirements for existing tillage implements. The numerical data could be used to make decisions about proper tractor-plow combinations, to improve the design of current plows, and to determine the feasibility of creating multiple-row plows.

As a site preparation tillage implement is pulled through soil, stumps, rocks, and logging debris, forces are created that must be overcome by the site preparation tractor. The drawbar force is the reaction force that the tractor generates in order to move the plow through a forest soil. Drawbar power is the energy requirement that the tractor must generate to pull a forestry plow. Previous studies that measured the drawbar force for towed mechanical site preparation equipment have suggested that a tractor or prime mover would need to generate 60.9 kW [93 hp] to pull a three-row Bräcke patch scarifier [1]. In a similar study, the average drawbar power of a 10 660 kg [23 501 lbs] three-row scarifier, consisting of six barrels, was quantified as 79.9 kW [107 hp] [2]. Results from this study indicated that the weight of the implement appeared to affect the drawbar force more than the soil texture and amount of surface debris. Typically, a scarifier disturbs only the top of the soil surface, whereas a plow equipped with a subsoiling shank may be disturbing soil down to a depth of 609.6 mm [24 in]. Also, these studies [1, 2] only measured average drawbar loads on a single silvicultural treatment. They did not take into account how interaction between cultivation implements can affect drawbar load. No research is available in a forestry setting that has documented drawbar force requirements of typical combinations of subsoiling shanks and disks as used in the southern United States.

Agricultural research has determined that the energy consumption of a single subsoiling shank set at a depth of 406 mm [16 in] is in a range from 29.83 kW to 37.28 kW [40 to 50 hp] [3]. When compared to forestry implements, the tillage tools used in agriculture are smaller and generally work in fields with lesser amounts of debris. Therefore, it may be assumed that forestry tillage tools consume greater amounts of energy than similar agricultural implements. In agricultural research on the energy consumption of disks [4], researchers generally conclude that drawbar force is a function of implement weight.

OBJECTIVES

The objectives of this research are to: 1) determine energy requirements for pulling various tillage implements through recently harvested forest sites, and 2) determine the magnitudes of dynamic forces experienced by a plow during normal operation and during impact with obstructions.

EXPERIMENTAL METHODS

Equipment Description

The forestry site preparation plow used in this study was a Savannah Model 310 trailing subsoil plow. The layout of the Savannah Model 310 plow is as follows: a 1219-mm-diameter [48 in.] vertical coulter, a 76-mm-thick [3 in.] adjustable-depth vertical ripping shank, and four 914-mm-diameter [36 in.] "stump-jump" disks on the rear of the plow. The "stump-jump" feature allows the disks to rise out of the ground when an obstacle is encountered and re-enter after the obstacle is cleared. Two hydraulic cylinders attached to the wheels allow the entire plow to be raised to facilitate transportation, avoid large obstacles, and establish plow depth. The plow used in this study weighed approximately 5443 kg [12 000 lbs].

The prime mover used to pull the plow during this study was a SuperTrac SK-300 Forester rubber-tired site prep tractor. The SK-300 is equipped with a Caterpillar 3606 diesel engine. This engine provides the site prep tractor with 198 kW [265 hp] flywheel power. The operating weight of the SK-300 is approximately 18 144 kg [40 000 lbs]. The site prep tractor was outfitted with 35.5 x 32 tires, giving the tractor a wheelbase of 3607 mm [142 in.] and a width of 3454 mm [136 in].

Study Site

The study site selected for this experiment was located in southwestern Butler County, Alabama (Latitude 31^{o} 36' 10.81" N, Longitude 86^{o} 47' 23.79" W). The site was planted with loblolly pine (*Pinus taeda*) in the late 1960's and was clearcut in the summer of 2000. An initial site preparation operation was completed in the fall of 2000; the site was raked leaving little logging debris on the site. The study was conducted on 1.42 ha [3.5 ac] located between a windrow created during the raking operation and a recently planted loblolly pine plantation. There was little slope (less than 1%) on the site and the average stump diameter was 495 mm [19.5 in]. The soil on the site was classified as a Luverne Sandy Loam, 1 to 5 percent slope. This soil is characterized by a brown sandy loam surface layer to a depth of 200 mm [8 in.] and a yellowish-red clay subsoil.

Experimental Setup

Five treatments were established in the testing program, each utilizing different combinations of plow implements on the Savannah 310 trailing subsoil plow. The first treatment had the coulter, ripping shank, and all four disks contacting the ground (Figure 1). The second treatment had the coulter, ripping shank, and two disks contacting the ground. The third treatment had the coulter and the ripping shank contacting the ground. The fourth treatment had only the coulter contacting the ground. Finally, the fifth treatment had only the ripping shank contacting the ground.

Figure 1. Supertrac SK-300 pulling a Savannah 310 trailing subsoil plow with coulter, ripping shank, and four disks

The 1.42 ha [3.5 acre] site was divided into four blocks, 61 m [200 ft] long with a 38 m [125 ft] long buffer area between each block. Within each block the treatments were applied on rows spaced 3.6 m [12 ft] apart. Each of the five treatments were randomly assigned to a row within each block. The tractor operated in second gear for the all treatments. This gear selection corresponded to an average ground speed of 8.3 kph [5.15 mph]. The ripping shank was set to a depth of 380 mm [15 in.].

A 334 kN [75,000 lbs] capacity tension load cell was placed in a linkage between the site prep tractor drawbar and the hitch on the Savannah plow. The linkage was fabricated to prevent shear loading and torsion on the load cell during operation. The voltage output from the load cell corresponded to the drawbar pull exerted by the site prep tractor. An example plot of drawbar force versus time for Treatment 1 (i.e. the treatment with the coulter, ripping shank, and four disks) in Block 2 can be seen in Figure 2.

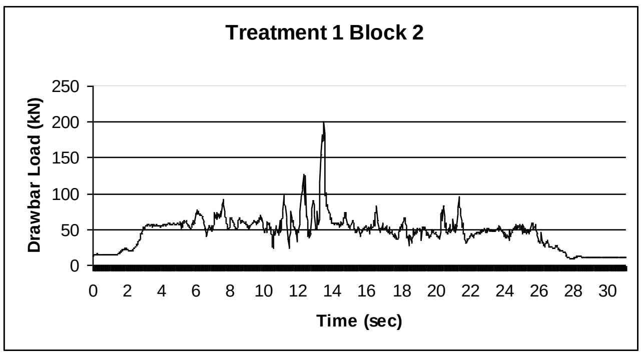

Figure 2: Drawbar Force versus Time for the Coulter, Ripping Shank, Four Disks Treatment Operating in Block 2.

Direct-current displacement transducers (DCDT's) were attached to the four jump arms controlling the depth of the disks at the rear of the plow. The DCDT's monitored the position of the disks and indicated when the jump arms allowed the disks to withdraw from the ground during a collision with an obstacle. Two optical tachometers were used to monitor the revolutions of the drive shafts leading to the front and rear axles. A GPS unit was placed on the roof of the site prep tractor cab to measure the ground speed of the machine. A Somat 2100 field computer was used to run a sampling routine and store data collected by the external sensors. The Somat field computer was set to sample at a rate of 25 Hz.

Data Analysis

To determine the drawbar load on the tractor, the data produced by the load cell were filtered to remove values that did not accurately reflect the treatment being tested. The types of values filtered out include extreme load spikes, negative values, values at the beginning and end of the data set, and values associated with raised disks. Load spikes were associated with stump-plow collisions. Negative values were removed because they represented invalid drawbar force values. Values at the start and stop of each run were removed because the tractor was not up to operating speed or the plow was not fully in the ground. Finally, the values recorded from the DCDT's were used to filter out data logged when a disk was raised.

RESULTS AND DISCUSSION

Drawbar Force

A summary of the drawbar forces recorded by the load cell can be seen in Table 2. As the combination of tillage implements was changed, there were corresponding changes in drawbar forces. A maximum average drawbar force of 51.15 kN [11 500 lbs] was achieved by the coulter, ripping shank and four disk implement combination. At the test velocity of 8.29 km/s [5.15 mph], this loading corresponds to an energy requirement of 106 kW [142 hp]. Table 2 also illustrates the importance of a coulter. There is a 39% reduction in energy consumption when a coulter is used in conjunction with a ripping shank [72 kW] versus the use of a ripping shank alone [100 kW]. Also, this table appears to show that the first set of disks behind the ripping shank were not significant consumers of energy. There was only a 6% drop in drawbar force when coulter and ripping shank were used without the first set of disks [72 kW] versus when these disks were utilized [77 kW]. The increase in coefficient of variation seen as one progresses down the treatment rows may be attributed to the destabilization of the plow as implements were removed from the ground.

Table 2. Summary of Drawbar Force Data

Treatment	Mode Force Value (kN)	Mean Force Value (kN)	Coefficient of Variation (%)	Mean Power Requirement (kW) [hp]
Treatment 1	51.15	49.95	30.0	106 [142]
Treatment 2	33.36	33.47	35.1	77 [103]
Treatment 3	28.91	31.49	52.2	72 [97]
Treatment 4	11.12	15.84	65.9	37 [50]
Treatment 5	37.81	43.42	79.9	100 [134]

An analysis of variance conducted on the data showed significant differences in the drawbar forces generated by the various treatments. The effect of treatment on drawbar force was significant to alpha levels less that 0.0001. The test blocks did not significantly affect the drawbar forces measured. In conjunction with the ANOVA, both Fischer's LSD and Duncan's Multiple-Comparison Tests were conducted on the drawbar force data to determine which treatments were significantly different from a given treatment. The Multiple-Comparison test results are shown in Table 3.

Table 3. Multiple-Comparison Results Table

Treatment	Count	Mean Force Value (kN)	Duncan's Test Different From Treatments	Fisher's LSD Test Different From Treatments
Treatment 1	4	49.95	4, 3, 2	4, 3, 2
Treatment 2	4	33.47	4, 5, 1	4, 5, 1
Treatment 3	4	31.49	4, 5, 1	4, 5, 1
Treatment 4	4	15.84	3, 2, 5, 1	3, 2, 5, 1
Treatment 5	4	43.42	4, 3, 2	4, 3, 2

From the ANOVA results, the effect of the treatments on the drawbar force value was highly significant. Also, the effect of the test blocks and the interaction between test blocks and drawbar force was not significant. Therefore, it appears that the difference in drawbar forces was a function of the tillage implement combination used during site preparation activities. This statement is strengthened by the results of the multiple-comparison tests, which show there were only two treatment pairings that were similar. The treatments that appear to be similar are 1 and 5, and 2 and 3.

The reason for the similarity between the first and fifth treatment was most likely due to the use of the ripping shank without a coulter in the fifth treatment. Without a coulter to cut through surface debris and the upper layers of soil, the force generated by the ripping shank dramatically increased. There was nearly a 39% increase in force between the coulter and ripping shank treatment to the treatment involving only the ripping shank. As the plow traveled through the ground, debris would accumulate around the ripping shank and engulf the frame of the plow. Because the plow was pulling the ripping shank through the soil along with the weight of a substantial amount of debris, the force generated by the ripping shank only treatment was similar to the force generated by the treatment that utilized the coulter, ripping shank, and four disks.

The second and third treatments also appeared to be similar in their forces. The only difference between these two treatments was that the second treatment used a set of disks that mix the soil and surface organic matter. The first treatment utilized an additional set of bedding disks located at the rear of the plow. The bedding disks created considerable soil disturbance as a bed 1.5 m [5 ft] wide and 0.5 m [18 in] high was produced. It appears that the force produced by the two mixing disks was relatively low when compared with the force generated by the rear set of bedding disks. When the bedding disks were raised so that they did not contact the soil, there was a 27% decrease in force compared with a 6% decrease in force when the mixing disks were raised. This result seems reasonable because visual appraisal of the tests noted that the soil disturbance was dramatically increased when the bedding disks were utilized.

Stump Collision

As stated earlier, an objective to this study was to investigate the magnitudes of the dynamic forces generated by a collision between a tree stump and the plow. Returning to the original, unfiltered data set, drawbar force values in excess of 111 kN [25 000 lbs] were selected for further examination. In general, values of this magnitude occurred over a short period of time, were associated with a sudden decrease in velocity, and were followed by a sharp drop in drawbar force (this indicated the plow was removed from the ground to clear an obstacle). Stump events were recorded in 2.85% of the data collected and for a total of 17 individual events. The highest load recorded was 338.9 kN [76 188 lbs].

CONCLUSIONS

Based on the results of this study, the following conclusions can be made:

1. There were clear trends in the drawbar power required for each of the five treatments. These trends are supported by analysis of variance tests and multiple-comparison tests.
2. Field tests indicate there is a 28% decrease in energy consumption when using a coulter along with a ripping shank compared to using a ripping shank alone.
3. The front set of mixing disks appears to consume a relatively low amount of energy when compared to the ripping shank, bedding disks, and coulter.
4. The maximum average drawbar power recorded for a block was 124 kW [166 hp]. This drawbar power occurred while applying the coulter, ripping shank, four disk treatment at a speed of 8.30 kph [5.15 mph].
5. Stump events (forces over 111 kN [25 000 lbs] appeared in 2.85% of the load data collected. The highest drawbar load recorded was 388 kN [76 188 lbs].

The drawbar forces reported in this research indicated that seemingly small changes in the configuration of a site preparation plow could greatly influence the energy consumption of the plow. The drawbar force required by other tillage implement configurations not tested in this study needs to be quantified. Also, the effects on drawbar force requirements of soil conditions, rigidly mounting plows on prime movers, and tillage implement spacing are yet to be determined. In order to produce a site preparation plow capable of competing in the today's economic environment, solutions to these problems must be found.

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RISK MANAGEMENT OF STEEP TERRAIN HARVESTING

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ABSTRACT

Harvesting systems, ranging from a simple ground-based cable winch skidder through to cable yarders or helicopters, can extract timber on steep forested slopes. Depending on soil and terrain factors, not all are environmentally acceptable. Concerns include continued erosion problems; risk of debris slides and increased peak flood flow. After a significant storm event in June 2001, a Forest Service cable harvest area in south-western Virginia was evaluated regarding debris flows on site. This evaluation led to a more comprehensive research project regarding risk management of steep slopes. This paper presents a review of the common slope failure causal methods associated with cable logging operations. A decision matrix was developed to determine debris flow risk using readily available GIS parameters including geology, slope gradient and slope shape. The GIS platform can be used to analyzing a specific area and provides the harvest planner with the harvest system that is physically feasible and environmentally acceptable.

INTRODUCTION

Large areas of forest lands in Virginia are on steep terrain. Active forest management, including harvesting, can be beneficial in terms of stand improvement, long term stand health, as well as providing possible resources for local industries and revenue for other improvement programs. Driven by the federal Clean Water Act, sedimentation of waterways is currently the primary environmental concern associated with forest harvesting activities.

Terrain slope is the primary driver in dictating erosion levels, as it both concentrates water and increases water velocity. Harvesting on steep slopes has always carried the risk of excessive erosion and in more extreme cases debris flows; hence the focus on improved management practices over the last 40 years. Best Management Practices (BMPs) have been established (i.e. Virginia Department of Forestry BMP manual) to ensure a minimum possible environmental impact. While BMPs document how an impact can be minimized, it does not evaluate the risk of steep terrain harvesting alternatives.

This paper focuses on an evaluation of debris flows after a storm event on a cable logged site. A GIS planning tool is then developed to determine debris flow risks and help with strategic and tactical level planning of harvest system selection.

CABLE YARDING AND LANDSLIPS

The primary way that a steep terrain harvesting operation might cause or contribute to a landslip is through concentrating surface runoff, essentially on the skid or haul roads. Poor road location (lack of planning), excessive road gradient, in-sloped roads without adequate drainage structures, poor re-vegetation and excessive cut and fill are all factors that can lead to significant failures. Cut bank failures can occur through inappropriate road location, including cutting into the slope with a resulting angle greater than that of the natural repose. Such banks can collapse or continue to erode into the slope until stabilized with vegetation or reaching a natural angle of repose.

Yarding corridors, which is the path along which the trees are extracted by the cables, can also intercept cross-slope surface runoff if the suspension of the stems was inadequate during extraction. Problems can also occur if sections of the slope are compacted, thereby lowering infiltration rates and increasing the volume of surface flow. If debris is left on site in such a way as to form small dams in gully or even small depressions then their sediment trapping ability and subsequent collapse can release small surges of water.

FOREST SERVICE SITE

The site where the landslips occurred during the storm event of 29th June, 2001 was part of the Forest Service National Forest Mahogany sale in the Clinch Watershed. The harvested slope faces west and is approximately 550 to 750ft in elevation, and typically has between 55 and 65% slopes. The soil is described as a Dekalb Channery sandy loam, well drained and interbedded with shale and greywacke, overlying hard fractured sandstone (National Cooperative Soil Survey).

It was harvested in 1996 using a running skyline cable yarder system. A skid road was constructed across the face of the slope, with two wider areas that were used for the yarder landings. The area was harvested uphill, with a large streamside management zone left along Stony Creek

Although no site-specific rainfall data is available for this small area, the concentration of slips in this small watershed would indicate that it received above the regional rainfall for that particular torrential storm, over 8 inches in the two-day period. Landslips are evident on the cable-logged site, on both the neighboring segments of the same slope that have not been harvested, as well as the opposing slopes on both Forest Service land and private land (Figure 1). The forest stands on these slopes include uncut stands, recent helicopter salvage cuts and the clear-cut cable logged site in question.

Figure 1: Debris flows on the opposite (east-facing) slope, covering both private and Forest Service lands.

Such debris flows have occurred on similar sites around Virginia after torrential rainfall events. This includes the landslips studied by Wieczorek *et al.* (2000) in Madison County based on events that occurred in June 1995, and August 1969 storm in Nelson County (Morgan *et al.*, 1999). The debris flows observed on this site are also similar to those described in the literature. The comprehensive reports on previous torrential rainfall events link the location of debris flows to rainfall intensity at the site, slope and soil type and structure. No direct information on the influence of land use type was published, such as the likelihood of occurrence on cleared land versus forested land.

Additionally, Wieczorek *et al.* (2000) suggests that on a site-specific basis the return period for such an event is possibly as high as 2000 years. However on a larger watershed frequency of occurrence is much higher, and four such significant events in Virginia with a larger number of debris slides following torrential rains have been well documented in the last 50 years.

MAIN FINDINGS

There were 5 significant landslips, as well as a few minor slips on the clear-cut cable harvested site. The significant slips were approximately 10 to 30 feet across and 200 to 500 feet long. The size and shape of these landslips are very similar to those seen on both the adjacent forest areas as well as on the other side of Stony Creek.

On site it was observed that a typical soil structure was approximately 5ft depth of sandy-loam / colluvium overlying the fractured sandstone, whereby the lower 12 inches were mottled and suggest significant underground water flow over longer periods of time. Increased water flow (and water pressure) through this lower soil zone would have been the primary trigger for the debris flows. The saturation of the overlying soil would have added weight, and once the failure had occurred the concentrated flow would have scoured out and taken a lot of the finer material downslope (Figure 2).

Figure 2: Main landslip just before main yarder landing.

The head of one of the landslips was some 250 ft above the skid trail and the colluvium from this slip came to rest on the skid road, with 3 to 4ft depth (Figure 3).

Figure 3: Debris from the slip that originated above the skid road.

RISK MANAGEMENT

The concept of making maps for landslide hazard evaluation and reduction in Virginia is not new (Wieczorek, 1984). Based on published knowledge, both with regard to terrain and soil, it should be possible to identify areas at risk of debris slides and manage for them accordingly. Studies in Europe are now also well underway that integrate expected environmental standards and terrain and stand parameters using GIS as computer modeling tool, and based on given performance characteristics of a variety of harvest system alternatives, will map out the most environmentally and economically appropriate system for any given area. Such a tool would be very beneficial for the decision making process in this region, although this tool is still in its infancy (Stampfer, 2000).

GIS MODEL

A GIS model was created using readily available GIS parameters. Three steps are involved. The first is to import all the necessary parameter layers. The second is to generate a debris flow risk model using slope gradient, geology and slope shape.

Slope gradient uses three broad categories with increasing risk associated with them. The geological description also has risk associated to it, whereby areas with shallow overlaying material on hard bedrock poses the greatest risk. The slope shape parameter identifies shallow depressions on the landscape.

The final step is to use the overall assigned debris flow risk category, slope gradient and soil strength to determine the most appropriate harvesting system for the area.

MODEL VALIDATION

A preliminary model validation was possible for the assignment of debris flow risk using the actual landslips mapped in the Little Stoney Creek area. Figure 4 shows an excellent correlation between those areas automatically identified as high risk and the actual slides.

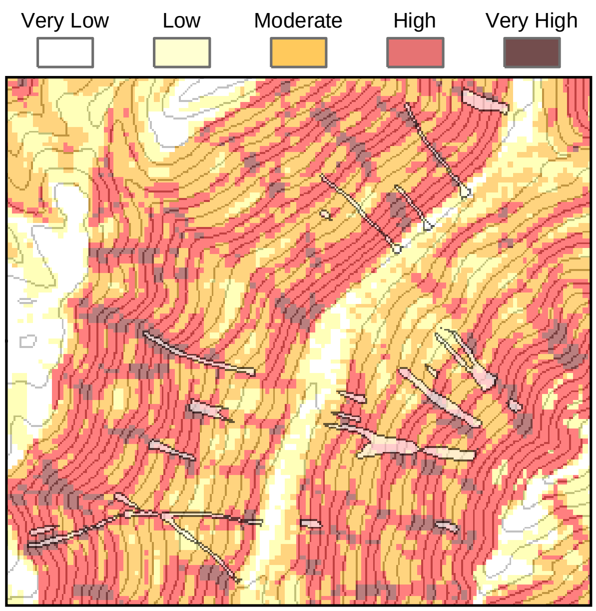
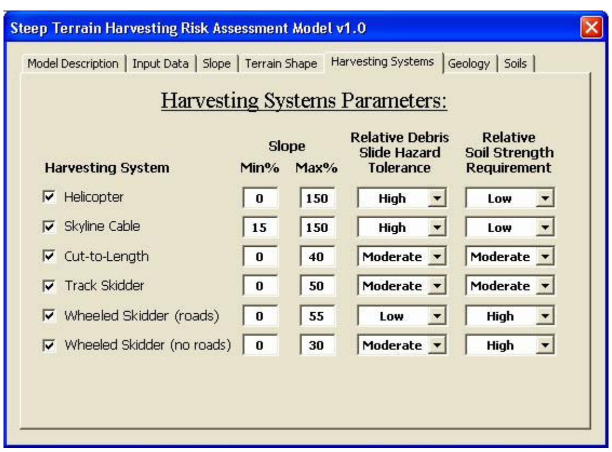


Figure 4: GIS based map showing risk categories and actual debris flows that occurred during the June 2001 storm event.

HARVEST SYSTEMS

The following generic harvest systems were chosen. A matrix format is used to present minimum standards regarding the three key factors that are used to determine the acceptability of the harvest system (Figure 5). At the time of writing this paper, this part of the model has not been validated.



Steep Terrain Harvesting Risk Assessment Model v1.0

Model Description | Input Data | Slope | Terrain Shape | Harvesting Systems | Geology | Soils

Harvesting Systems Parameters:

Harvesting System	Slope Min%	Slope Max%	Relative Debris Slide Hazard Tolerance	Relative Soil Strength Requirement
Helicopter	0	150	High	Low
Skyline Cable	15	150	High	Low
Cut-to-Length	0	40	Moderate	Moderate
Track Skidder	0	50	Moderate	Moderate
Wheeled Skidder (roads)	0	55	Low	High
Wheeled Skidder (no roads)	0	30	Moderate	High

Figure 5: Decision matrix for steep terrain harvest system selection.

CONCLUSION

Harvesting on steep terrain has always carried a risk of excessive erosion and or debris flows during major storm events. An evaluation of a cable logging operation showed that careful planning and implementation of BMPs can avoid most environmental impacts. A GIS tool was developed, based on readily available parameters, to identify areas prone to debris slides and help allocate the correct harvesting system.

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Commercial Forestry Operations at the Urban Interface – Forest Harvesting in the Australian Capital Territory (ACT)

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Abstract: The Australian Capital Territory (ACT) is a self-governed region associated with Australia's capital city, Canberra (similar to the United States' Washington D.C.). The Territory comprises an area of approximately 236,540 hectares (ha) of which 26,000 ha is managed as forestry land by ACT Forests, a government owned business. 16,000 ha is exotic pine plantation (predominantly ***Pinus radiata***) with the remaining 10,000 ha being native forest and grasslands which are managed for non-timber values.

Forest plantation establishment commenced in the late 1920's and continued at a steady rate into the early 1980's. Urban growth rates have now exceeded plantation expansion rates, especially over the last decade. The consequence of this is that forest operations in the ACT are increasingly being conducted adjacent to or, in some circumstances, completely within Urban Areas. This adds another level of complexity to harvest planning and harvest management processes.

This paper describes three harvesting operations that ACT Forests has undertaken at the urban interface and highlights successful outcomes as well as areas that require improvement. It also provides an overview of forest harvesting systems used in the ACT.

1. Introduction

Canberra, the capital of Australia (Fig 1) is a planned city that features tree lined streets, parks and open spaces and promotes a clean, orderly image that draws admiration from visitors worldwide. A prominent feature of the surrounding landscape of Canberra is a pine plantation that was originally established during the city's inception to ensure that the national capital has a suitable timber supply. This plantation estate is managed by ACT Forests on a fully commercial basis and supplies a local timber industry that competes at national and international scales.

Figure 1. Map of Australia showing location of Canberra

Being on the doorstep of the nation's capital, ACT Forests' estate receives more than one million visitors each year. These visitors undertake a diverse range of recreational activities including:

- Walking / Jogging
- Mountain Bike Riding
- Horse Riding
- Dog Sled Racing
- Motor Rallying
- Trail biking
- Archery
- Orienteering

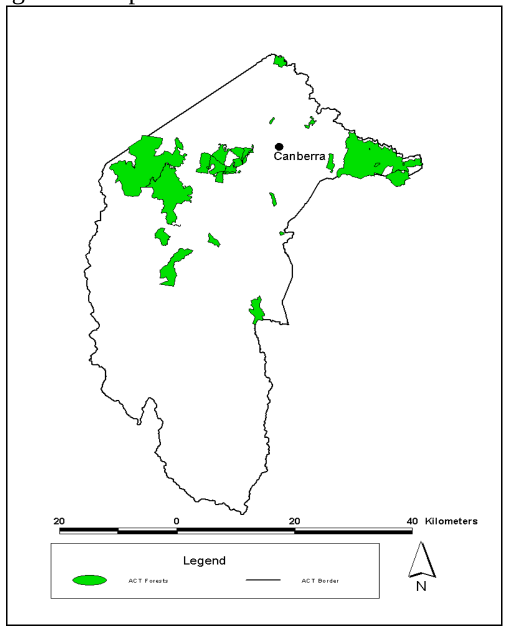
ACT Forests also manages sites of historic significance with both indigenous and non-indigenous cultural values and provides areas that are available for bomb disposal and military training

With high visitation rates and a highly visible estate, management of forest operations can be problematic. The ACT has a relatively highly educated population and heightening awareness of environmental issues means that forest operations are increasingly being subjected to public scrutiny

Increasing focus is being placed on ensuring that forest operations have a minimal impact on water produced from forested catchments. This is imperative due to the need for a high level of environmental compliance as well as approximately one quarter of the plantation estate occurring in the catchment of Canberra's water supply.

Forest harvesting in the ACT is generally undertaken using conventional equipment. Single grip harvesters which fell and process tree lengths produce much of the volume, whilst stroke delimbers working behind feller-bunchers also produce significant amounts. Extraction is mainly conducted using forwarders with skidders being utilized in steeper areas. A proportion of ACT Forests plantations (Fig 2) also occur on terrain that can only be harvested successfully using cable logging.

Figure 2: Map of Plantations in ACT



As the urban area of Canberra continues to expand, it is becoming more common for ACT Forests to have to plan for forest operations occurring at the urban interface.

2. Impact of Urban Interface on Forest Harvesting

Example 1. Orana School

Urban encroachment into the pine plantation resource over the years has resulted in 'remnant' islands of pine plantation that are partially or, in some cases, completely surrounded by built-up areas. Typically, problems with harvesting such areas include:

- Difficulty of keeping people out of the harvest area
- High visibility attracting a large number of complaints or inquiries from the general public and the cost of dealing with these
- Provision of suitable stockpiling and log loading areas is difficult
- The use of logging trucks on narrow built up roads
- The difficulty of trucking harvest equipment into these areas due to low-hanging power lines and narrow, bitumen paved streets
- Harvesting trees without damaging adjacent light poles, telephone wires, fences etc.
- Increased instances of vandalism of harvest machinery

One such example of harvesting an 'island' of pine plantation in a 'sea' of urban infill was a small area (8 ha) of pine plantation which was harvested in January 2002. This area was surrounded by a school, a center of worship, the Federal Police headquarters and a busy road.

The stand to be harvested had been poorly managed, being unthinned and exhibiting extremely poor form. In the opinion of the ACT's bushfire authority, the stand represented an unacceptable fire risk and the decision was made to remove it via a commercial harvesting operation (Fig 3).

The complexity of the harvest planning process was increased by the fact that the school had actually been built amongst the pine trees and extensive consultation with the school was required to determine which trees were to be retained. It was explained that removal of the majority of the trees would increase the exposure of the retained trees to prevailing winds. It was then explained that the retained trees, having grown in the middle of an unthinned stand, had an increased susceptibility to toppling in the next strong wind event. The school management took this suggestion on board but decided that the trees were such an important part of the environment and intrinsic nature of the school that they be retained.

Careful planning involving the school, surrounding businesses, residences and the local community group plus timing of the operation in early January to coincide with a major holiday period (so the school was vacant) resulted in a successful outcome with virtually no complaints from the public or reports of accidents or near misses as a result of the harvesting activity.

Figure 3. View of harvesting operation adjacent to Orana school, showing stockpiling of logs at the end of an urban street

This success is attributed to the extent of the planning process. This process was underpinned by educating the various interest groups as to the need for the operation to occur and what the end result would be. Concerns raised during this process were factored in to the operation. For example, logging crews had to limit their hours of work in order to minimize disturbance to surrounding residents during early morning and evening periods.

In March 2002, the concerns relating to the chance of the retained trees in this area suffering windthrow turned out to be justified and the school has now reversed it's previous decision to keep these trees. At time of writing, consultation has recommenced between ACT Forests and the school as to the best way of harvesting them,

Example 2. Fire Salvage, Christmas 2001

On Christmas Eve 2001, three fires were ignited simultaneously in the Stromlo Forest area immediately to the west of Canberra. Two of these fires linked up and burnt in an easterly direction, destroying large areas of plantation forest (Fig 4). During an easterly run, fanned by strong westerly winds, the fire jumped a 4-lane express way before burning another stand of pine plantation located between the expressway and the lake which forms a central feature of Australia's capital. This stand was planted in the late 1940's that was awaiting clearfall when it was burnt.

A road and a heavily used bicycle path passed through the stand, both of which were closed prior to the fire reaching the area and remained closed due to the risk of burnt or burning trees falling. Salvage harvesting was rapidly organized and commenced whilst many trees were still smoldering (Fig 5).

Figure 4. View of fire burning in the Stromlo Plantation showing its proximity to Canberra City

It quickly became apparent, during the first week of operations, that the major problem in managing the harvesting would be in keeping members of the general public away from tree-falling activities. Despite prolific warning signage, assistance from various emergency services including the Police Force and regular coverage in both visual and print media. This proved a serious and ongoing problem with many people climbing over barriers and breaking through warning tape. In some cases, warning signage was removed completely.

The road remained closed for several days whilst trees in danger of falling on the road were harvested. The bicycle path, however, remained closed for around two months due to the vulnerability of cyclists to tree falling. Harvesting continued after the road was reopened in order to remove all risk presented by the dead and dying trees as well as to salvage some commercial product from the burnt stand.

From an operational perspective, the harvesting progressed in a satisfactory manner. However, due to its high visibility and the

Figure 5. Harvesting Machinery commencing roadside salvage following Stromlo fire, 2001

swiftness with which it commenced following the passing of the fire, the operation also attracted public criticism. People questioned the need to remove the burnt pine trees, cycling groups criticized the need to keep the cycle path closed for many weeks when the road was opened within days of the fire. Many members of the public also expressed dissatisfaction with the state the harvested area was left in despite the fact that it didn't differ from any conventional clearfall operation.

Case 3 – Harvesting of Narrabundah Hill

In 2000, harvesting was undertaken at area known as Narrabundah Hill. As can be seen from Figure 6, the plantation adjoins a suburban area and, over the 30 years since its establishment, the residents of the suburb came to think of the plantation as an important recreational facility for activities such as jogging, dog-walking, horse riding and cycling. A local community group lobbied the government to prevent the harvesting occurring. However, extensive community consultation resulted in a compromise which involved leaving a visual buffer parallel to the suburb boundary. It was agreed with the community that the buffer would only be harvested once the new pine had grown to a height of around 6 metres.

Figure 6. Aerial photograph of Narrabundah Hill plantation showing proximity to urban area

Early into the harvesting operation poor communication of the harvest plan resulted in the logging crew commencing work in the buffer area. This immediately drew severe criticism from the residents of the neighboring suburb that required further urgent consultation to resolve. After this incident, harvesting continued in this area as originally planned.

3. Lessons to be Learnt

The above examples provided a chance to ascertain the understanding and acceptance of forest harvesting by the general public. The post fire salvage operation in particular attracted a large amount of media interest and public comment. Key observations are summarized below:

- Many members of the general public did not appear to appreciate that the plantations that dominate the city's surroundings were established with any commercial intent. Indeed many people were unaware that a timber industry (the Territory's largest primary industry) existed in the ACT.
- People in general failed to comprehend the danger associated with being in the vicinity of working harvesting machines, despite installation of safety barriers, articles in local newspapers and television news stories.
- A lack of understanding of the end condition of the harvested stand was evident.

Two of the harvesting operations described both achieved their objectives but one involved a significant planning period (not available for the other operation) and, consequently, from a public relations perspective, was more successful. The third example described demonstrates the imperative to clearly communicate any special conditions to forestry workers when operating at the urban interface prior to work commencing.

These three examples highlight the need for forest managers in the ACT to place emphasis on managing the public relations aspect of forest operations. Public acceptance of high impact forest operations such as harvesting, aerial spraying and prescribed burning will only occur through persistent educational efforts focusing on the need for such operations and the importance of the timber industry in general.

Forestry Harvesting Mechanization in Mountainous Areas in Brazil. CENIBRA Experience

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Summary - CENIBRA is a eucaliptus fiber bleached cellulose producing company, with a 860,000 ton annual production capacity, equivalent to 3,728,000 m³. The wood used in its industrial facility located in Belo Oriente, Minas Gerais state, Brazil, is, in its entirety, originated from its own plantations and from forestry farmers. The present paper depicts the company profile, showing its operational characteristics and its forestry harvesting system evolution since the beginning of its operation, in 1977. As it works in differentiated topographical conditions as compared to the other Brazilian companies, the company developed a forestry harvesting system adapted to its conditions, obtaining a highly competitive operation cost.

Introduction:

CENIBRA is a Japanese capital company, located in Belo Oriente municipality, Minas Gerais state, Brazil. The company produces 860,000 tons of cellulose per year from its eucaliptus cultivated forests. Its production is basically sold in the international market, with 41% of the production being directed to Japan, 32% to the European market, 16% to the North American market, 8% to the Brazilian internal market and about 3% between Latin American and Asian markets. The annual consumption of wood at CENIBA industrial facility is 3,728,000 cubic meters. The company has 232,282 hectares of lands of which 111,718 are cultivated with eucaliptus. The cutting forestry cycle is of 7 years and the annual average increment is of 33 cubic meters of wood per hectare. The company plants about 11,000 hectares per year of forests, aiming at meeting its supply plan.

CENIBRA has a characteristic that makes it a unique company among the other big Brazilian companies in the industry, as its forestry base is located in a totally mountaineous region and with a low soils fertility. Furthermore, the difficulty to transport the wood, due to the fact that it works in a mountaineous area, represents an extra challenge to the company productive process.

The present paper has the purpose of showing an evaluation of the projected and implanted forestry harvesting system to meet the company needs and characteristics, as well as the developments that are being carried out in the forestry harvesting area.

History:

CENIBRA plant began its operation in the year of 1977 with wood originated from planted forests existing in the area of its influence. Traditionally, the harvest in that area was carried out with chain-saw, the wood was transfered with animals and winches adapted to tractors, and manually loaded on small trucks that transported the wood to the industrial facility.

This harvesting system underwent a series of analyses during the 1980s with the introduction of some internal solutions, such as: truck with crane operating in the planting field, winches with return cable, until the introduction of the first Forwarders made in Brazil, by the end of the decade. Other introductions were also the mechanized loading with small cranes adapted to agricultural tractors and trees delimbering devices also pulled by agricultural tractors. It is important to point out that the country was undergoing a series of restrictions to the equipments import, and this was an incentive to the Brazilian industry to carry out some developments in the forestry harvesting. During the first years of the 1990s, the use of Forwarders in the transference operation was incremented. The skidding winch system remained, however, with a great part of the wood transporting system. In that period, hydraulic excavators with grapples were also introduced in the wood loading process in the field.

The company made a series of technical analyses, from 1995 on, with the purpose to re-evaluate the totallity of its harvesting system due, mainly, to the high number of persons involved in the process and to the operation cost of the system then employed. The year of 1995 established a new step in CENIBRA production process as it was the year when the production activities of the second line of the plant began, doubling its production capacity. It also occurred, at that time, an opening to equipments import, providing to the Brazilian forestry industry access to state-of-the-art equipments. Only in 1999, however, the mechanization process took place in CENIBRA harvesting system, with the introduction of international level updated technology.

Project Description and Steps of its Implantation:

The evaluation of the new forestry harvesting project in CENIBRA underwent a characterization of the end product type to be obtained, of its topographical characteristics and of its real, present and future, forest conditions, considering the silviculture development program to be implanted in the company.

It was previously established that the company would receive trees with cortex, cut in 2.20 meter long logs, already delimbered. Its topographycal condition was evaluated according to the distribution of its forestry projects, where we notice the following:

43% of the area ⇨ up to 15 degrees of declivity

42% of the area ⇨ between 16 and 26 degrees

15% of the area ⇨ above 26 degrees

Most of CENIBRA dense forests were originated from seeds plantations, and would be reformed with the use of clones. The impacts caused to the soil by the mechanized harvesting would be important factors on the final decision about the model to be adopted.

View of CENIBRA operational conditions

Two prospect systems were selected according to these criteria to meet the first phase of the project, which forecast the mechanization of the forestry harvesting until a 26 degrees descenting slope.

1. **Feller Buncher System**

•	Harvesting with Feller Buncher
•	Mannual Delimbering
•	Transference with Skidder
•	Evolution with Tracing Grapple

2. **Harvester System**

•	Harvesting with Harvester
•	Transference with Forwarder

In the first analysis, the Feller Buncher system was projected at US$ 2.67 per cubic meter, placed on the roadside; the Harvester system at US$ 4.51 per cubic meter whereas the conventional system was at U$ 3.93/ m³. The company decision was for the Feller Buncher system, but the impacts caused by this system should be evaluated. As the company had no previous experience with the most intense mechanization, the final decision was to have distinctive modules of both systems in operation, so that the proper field evaluations could be accomplished.

An important fact that had influence on the decision was the Brazilian currency inflation rate which, at that period, was very high, as the investments in mechanization were based on the American dollar, the impact on the final result of the process was very meaningful for the decision making. As a way to maintain the economical feasibility of the mechanization project, it was decided that a differentiated project, as compared to the other ones that had been implanted until then, should be designed. New operation standards should be reached so that the economical feasibility could be maintained. This way, challenging operational rates, as compared to CENIBRA operational conditions, were established:

• Feller Buncher - 70 m³/hour
• Skidder - 70 m³/hour
• Tracing grapple – 52 m³/hour
• Operation in 3 shifts per day, 7 hours per shift, 6 days/week, 12 months/year
• Goal of 4500 hours per machine/year
• Fleet replacement - 4 years

To accomplish the objetives of the project, a huge capacitation program was implanted, involving about 160 operators, 85 servicemen, besides all operational supervision personnel. In this program the following phases were developed:

- Selection of operators and servicemen by means of a psychological evaluation of the company operators as well as of candidates.
- Capacitation in internal courses of fundamentals in mechanics, hydraulics and electronics.
- Operational capacitation with training directed by the manufacturer.
- Operational capacitation with CENIBRA internal instructor.
- Follow-up and operational recycling with internal instructor.

As far as the mechanized system impacts evaluation is concerned, a joint work was developed with Brazilian Universities, with the purpose to evaluate the soil damages caused by the forestry harvesting systems. The Feller Buncher, Harvester and conventional systems were compared. The results showed that the mechanized process had more impact than the conventional harvesting process. The 4x4 skidder used in the transference operation was the most impacting machine in the process. The other track-type equipments (Feller Buncher and Tracing Grapple) were less impacting than the wheel-type Harvesters and the Forwarders used, even though they were equipped with "ecotrack" tracks.

After the first phase of the process (April/1999 to September/2000) meaningful changes in the mechanization process were introduced, with the purpose to increase the harvesting capacity of the system and to minimize the impacts caused by the transference machine. With the introduction of 8x8 Clambunck, the Feller Buncher system total harvesting capacity was completed, with areas of up to 26 degrees of declivity.

During this phase the evaluation of a new mechanized harvesting process also took place to meet the needs of those areas with a declivity superior to 26 degrees. The system was defined in 2000 and its first module was implanted in 2001, involving the following activities:

• Harvesting with Feller Buncher / Chain-saw
• Mannual Delimbering
• Transference with Track Skidder
• Tracing with Slasher

The characteristics of these areas with high declivity are the difficult access from the road to the forest planting field, as well as the lack of areas for the tracing operation. For this situation, the solution found was the use of the Track Skidder as a way to overcome the access difficulties to the area and the tracing operation with slasher accomplished on the road. The operation performances of this system are the following:

• Feller Buncher - 52 m³ per hour
• Track Skidder – 35 m³ per hour
• Slasher – 35 m³ per hour

The system developed to meet the needs of those areas with a topography higher than 26 degrees of declivity proved to be economically feasible as compared to the conventional system with the use of skidding winches, offering also an important contribution in reducing environmental impacts. The final cost of this activity carried out with the Track Skidder is of US$ 3.56 per cubic meter of wood, whereas the cost of the conventional system with winch was of US$ 4,64 per cubic meter.

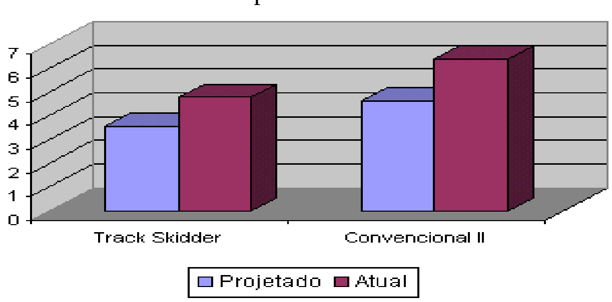
The first equipments of the forestry harvesting mechanization project were incorporated to CENIBRA fleet in April/1999, and two other important aquisitions were made in the following years. Presently, CENIBRA operates with the following equipments fleet:

- 9 track-type Fellers Bunchers
- 4 4x4 wheel-type Skidders
- 2 8x8 wheel-type Skidders
- 3 8x8 Clambuncks
- 13 Tracing Grapples
- 1 Track Skidder
- 1 Slasher
- 14 Log Loaders for Transference
- 3 wheel-type Log Loaders (storage yard)

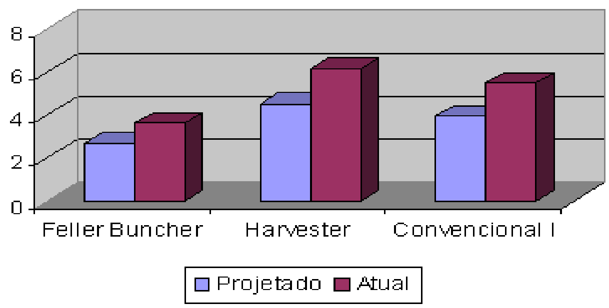
To provide support to the uninterrupted shifts regime operation, the company established its field maintenance support based on corrective and preventive maintenance teams, besides those teams in charge of supplying and lubricating the equipments. With the purpose to meet the parts supply in an efficient way, the partners manufacturers of CENIBRA project opened stores in the company operation areas.

During the project implantation, some equipments concept changes were introduced, mainly in the transference area. The beginning project was devised to operate in up to 20 degrees of declivity with the use of 4x4 skidders, evolving, during the second phase to the 8x8 clambunck and, later on, to the use of 8x8 skidders This enabled to extend the mechanization to the areas with 26 degrees of declivity. In the present CENIBRA operation model, due to the peculiarities of the wood tracing process, the operation should be carried out in part by 8x8 Skidders and 8x8 Clambucks.

Harvest in areas up to 26º.



To provide support to CENIBRA forestry activities, the company implanted the PTEA-Environmental Technical Planning, where all interfaces of the forestry process to the environment are evaluated, serving as a basis for subsequent harvesting and forestation operational actions. Specifically for those forestry harvesting activities where there is the interface of three distinctive systems (conventional, Feller Buncher and Track Skidder) a detailed planning model, known as microplanning, was developed, where all activities are previously planned and informed to the operators to be accomplished. The same work is done for the forestation area.



Harvest in areas above 26º.

Conclusion :

Three years after the beginning of the forestry harvesting mechanization project, CENIBRA is now in the phase of replacing the first equipments purchased in 1999. The Track Skidder system introduced in 2001 is in consolidation phase, and its implantation is being taken care of by the company.

The Brazilian currency devaluation factor, in this period, caused a strong impact on the mechanized activities final cost, but the initial figures calculated for the project were reached, and this has guaranteed the project economical sustainability.

Present situation of the operational cost (US$/m³)

Parallelly to the forestry harvesting project, a new project was accomplished and implanted to transport and to transfer the wood in CENIBRA facility storage yard, consolidating the changes in the company operational area.

As it was mentioned at the beginning of this paper, due to the fact that CENIBRA does not have forests in adverse conditions as compared to the other companies in the Brazilian forestry industry, the company needed to carry out extremely quick operational activities, and this was accomplished with the forestry harvesting mechanization project.

The big operational change in the forestry area, among others, was the important factor so that CENIBRA could be elected as the best Brazilian company in the paper and cellulose industry in 2000 (Best and Biggest Companies Award of Exame Magazine).

The Harvester system was discontinued in March 2002, as the evaluations initially proposed were accomplished. The impacts to the soil and to the forests were evaluated and, together with the obtained operational costs, they have validated the use of the Feller Buncher system as the best one for the company operation. In the analyses made, the Harvester system only showed its feasibility when operated with long wood (6 meters) and making the bucking operation.

As a challenge for the future of the company forestry harvest, CENIBRA is analysing the project of 4.40 meter long wood, with the evolution to 2.20 meter at the facility, by slasher, due to the operational limitation at the bucking line and in the chippers.

The company also analyses the use of field chippers as an alternative technology for the expansion project of its productive capacity.

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Tradução de Jusmar Gomes/Susie Fercik Staudt – 26/5/2002.

Nota do tradutor: Toru, os gráficos da página 4, do original em português, estão escaneados. Não consegui alterá-los. Segue abaixo a tradução dos gráficos.

1º Gráfico
Feller Buncher Harvester Conventional I
Projected Present
Harvest in areas of up to 26°

2º Gráfico
Track-type Skidder Conventional II
Projected Present
Harvest in areas above 26°

FOREST MANAGEMENT AND REDUCED IMPACT LOGGING TRAINING IN THE AMAZON: THE FUNDAÇÃO FLORESTA TROPICAL

by

Johan Zweede, Geoffrey Blate, Frank Merry, and Natalino Silva

Sustainable development implies a balance between conservation, social, and economic objectives through the rational use of renewable resources. The forests of the Amazon are such a resource and present such an opportunity. The sustainable use of the region's forests depends, however, on the application of appropriate systems and technologies by trained people Today, perhaps the greatest barrier facing the Amazon forest sector is the lack of trained and qualified people to implement FM-RIL. The sheer size and diversity of the area, the complex array of producers, and the need to target all levels and all stakeholders has made the spread of knowledge about FM-RIL a complicated task. Nevertheless, several successful programs have begun to tackle this problem. One of these is the FM-RIL program run by the Fundação Floresta Tropical (FFT).

INTRODUCTION

The Amazon Basin is the most diverse terrestrial region on earth. It is a storehouse of biodiversity and provides untold ecological services at local, regional, and global scales. This vast area, comprising 9 countries, is also home to millions of people, many of whom rely on the Amazon's forests and other natural resources for their livelihoods.

The Brazilian Amazon alone encompasses 5 million Km^2 and harbors 85 percent of Brazil's remaining natural forests. A recent study[1] concluded that 83 percent of the remaining upland area of the Brazilian Amazon is suitable for forestry, with a commercial timber stock of about 60 billion cubic meters[2]. The remaining Amazon Basin countries have smaller forest areas, but forestry plays an equally important role in land use throughout the region. Therefore, the scope of this proposal is international and includes the entire Basin area.

Considering its economic potential and the large area it affects, the forest sector –in conjunction with other land uses – should play an integral role in strategies to conserve the Amazon's environmental resources. This potential will only be realized, however, if producers[3] improve their practices. A growing number of producers have already begun to adopt better forest management practices. There are currently

[1] Schneider *et al.* 2000, *Amazônia Sustentável: limitantes e oportunidades para o desenvolvimento rural*, is available from the World Bank and IMAZON. According to this study, about 75 percent of the Brazilian Amazon remains forested and 15 percent has been cleared; an unknown proportion has been burned.

[2] The forest sector of the Brazilian Amazon employs more than half a million people and generates annual revenues of about 2.2 billion dollars. About 90 percent of Brazil's hardwood production comes from the Amazon and nearly all of that wood (~ 34 million m^3 annually) is consumed domestically.

[3] 'Producers' refers to people engaged in forest harvesting and milling activities.

278,000 ha of FSC certified[4] forests in Brazil and 467,000 ha under certification review. Two years ago there were no FSC certified forests in Brazil. The area certified by FSC in Bolivia is even greater – nearly 1 million hectares. Most forests across the Amazon, however, are still being logged poorly and without regard to their long-term productivity and diversity.

In recognition of this problem, several Amazon countries have recently instituted new national policies supporting the continued development of the forest sector. The Brazilian government, for example, wants to increase the area of well-managed forests and certified timber on world markets by 10 percent in the next few years. In addition, the government launched a new National Forest Program (PNF) in September 2000. The PNF aims to commit more than 200,000 Km^2 of Amazon forest to sustained timber production and to reforest 600 thousand ha per year. The PNF also calls for 500,000 Km^2 under concessions by the year 2010. If these targets are to be met, it will require trained personnel.

The new legislation and technical guidelines[5] are designed to promote sustainable use of the forest resource[6]. Coupled with a growing acceptance of the need for improved management by the forest industry these national programs have created a shortage of qualified forestry practitioners in all countries in the region. This shortfall exists across all levels of practitioners – from woodsmen to forest managers – and among all stakeholders and producers. This lack of trained people constitutes one of the greatest obstacles to the adoption of good forest management across the Amazon. Indeed, it leaves the forest sector with limited capacity to comply with government regulations.

ADDRESSING THE PROBLEM

Forest Management and Reduced Impact Logging

Forest management (FM) is a broad concept the meaning of which depends on the objectives of the forest owner. The term forest management is not reserved exclusively for timber harvesting. It includes a broad array of forest-related activities including wildlife management, extractive reserves, and recreation. Across much of the Amazon, however, the principal FM objective is the sustainable production of wood products. In this case, forest managers need to consider the silvicultural requirements that will yield sustained timber volumes without compromising forest quality or composition over time[7].

Although any harvest will alter the forest to some extent, it is clear that minimizing physical impacts is an important first step in the goal of sustainable production. Reduced-impact logging (RIL) provides standards for mitigating the silvicultural activity that causes the greatest ecological impact. As such, RIL is considered a necessary step toward achieving sustainable

[4] Forest certification refers to third party verification that a company's management practices are moving toward sustainability. The Forest Stewardship Council (FSC) accredits third party certifiers that use FSC criteria and indicators when they audit companies.

[5] IBAMA recently published general technical guidelines for the appropriate management of upland forests in the Brazilian Amazon.

[6] In 1995, EMBRAPA conducted a forest management survey in Paragominas, and found that no producers had effective management plans.

[7] Activities away from the forest can also affect profitability and should be considered in management plans. For example, wood processing, wood marketing, and business development.

forest management. RIL is an essential component of forest management where the principal objective is to provide a sustained yield of wood products while simultaneously maintaining native species diversity and key ecological processes and services.

Information about how to harvest trees with minimum damage exists. FM-RIL guidelines are available through ITTO, FAO, government agencies and NGOs. In addition, IMAZON, EMBRAPA[8], and the Fundação Floresta Tropical have field models in Brazil that demonstrate the improvements of FM-RIL practices over conventional logging. Specifically, FM-RIL methods reduce soil and canopy damage, protect future crop trees, and decrease waste by at least 50 percent. The Fundação Floresta Tropical has demonstrated how these ecological benefits can be obtained without an increase in costs[9].

Fundação Floresta Tropical – Catalyzing Interest in FM-RIL

In 1994, the Tropical Forest Foundation (TFF), a U.S. based non-profit organization dedicated to the achievement of sustainable forest management in the tropics, established its FM-RIL program in the Brazilian Amazon. Building on IMAZON's research that demonstrated the technical feasibility and financial viability of FM-RIL, TFF's objective was to accelerate the adoption of FM-RIL by producers across the Amazon. In 1995, TFF created a subsidiary, the Fundação Floresta Tropical (FFT), to implement this program. The FM-RIL program integrates practical training with demonstration models and research. It also involves a broad coalition of stakeholders including private landowners, industry, the conservation community, government agencies, and donors.

By 1997, FFT had established five FM-RIL model sites and trained a core crew of foresters, technicians, and operators. With funds from USAID and the World Bank, the FFT crew trained other forestry practitioners through on-site field courses. In 1998, FFT began a 2-year ITTO-funded project that eventually trained 138 foresters, trainers, and technicians from Brazil, Guyana, Suriname, Colombia, Ecuador, Peru, Venezuela, and Ghana. Currently, FFT is conducting more training courses with funds from ProManejo[10]. These courses are due to end in November 2001.

To date, funding to pay for the costs incurred by FFT has been through the generous assistance of international donors. TFF and FFT have raised over 5 million dollars from international donors in a combined effort to improve forest management in the Brazilian Amazon.

The practical training offered by FFT, along with many other related efforts, has catalyzed a strong interest in forest management and created a demand for skilled forestry personnel at all levels. In the past 5 years, FFT has received an increasing number of requests for qualified people from all sectors as well as from all types of producers (Figure 1).

[8] IMAZON is the Amazon Institute for People and the Environment; EMBRAPA is the Brazilian Corporation for Agricultural Research

[9] See Holmes et al, 2000. *Financial Costs and Benefits of Reduced-Impact Logging in the Eastern Amazon*, which is available in short and long versions at www.fft.org.br and www.fs.fed.us/global.

[10] PROMANEJO is a project of IBAMA that administers the promising initiatives project of the Pilot Program to Conserve the Brazilian Amazon, which receives its funding from G7 donors.

FFT's program expanded during this period to try to address the human resources dilemma of the forest sector. Between 1996 and 2000 the number of trainees graduating from the FFT program increased dramatically (Figure 2). Importantly, all of the trainees found forestry work immediately.

As Figures 1 and 2 suggest, FFT has just begun to fulfill the large demand for trained forestry personnel in Brazil let alone other countries in the region. Unfortunately, the FFT courses have so far been the only source of trained field personnel in Brazil and the increasing demand is rapidly overwhelming FFT's current training capacity.

Current Training Program

Both on- and off-site courses are practical with a focus on experiential learning, and, where appropriate, evaluation through performance based criteria. The specific activities and themes in each course differ according to the level and needs of the trainees; they last from 5 to 15 days depending on the theme and audience. All the courses, however, emphasize worker safety and include lessons and demonstrations on first aid. FFT trainers and staff spend an additional 1 to 5 days to prepare for each course. FFT trainers, complemented by consultants with wide experience in forest management from various governmental and non-governmental institutions, conduct the training courses.

FFT Courses (On- and Off-site)

TD -- Forest Management for Decision-Makers

GM – Reduced Impact Logging for Forest Managers

MF -- Forest Management for Practitioners

GE – Reduced Impact Logging for Supervisors

TC – Felling Techniques

TI -- Tree Identification

TP -- Forest Inventory and RIL Planning

TA -- FM-RIL Audit Techniques

TE -- Off-site – RIL Implementation

Course participants vary in education, skill level, and experience. They also represent a broad range of forest stakeholders across the Amazon.

The following sections describe the specific on-site courses, off-site courses, and other training services FFT offers.

On-site Courses

On-site courses areconducted at FFT's training center. Table 1 presents a detailed list of activities associated with each course and the hours allocated to each subject.

Although FFT courses are tailored for different parts of the target audience, participants will come from the full range of sectors during each course. This encourages the frank exchange of ideas and experience that each stakeholder brings to the courses. To ensure that course participants come from a range of sectors, FFT establishes criteria to screen applicants. These selection criteria help maintain a balance (including gender balance) during each year's courses.

Off-site Courses

Half of the people FFT trains each year receive training in off-site courses. These courses take place in a broad range of locations across the Brazilian Amazon. As

FFT builds its training capacity, it also explores opportunities to conduct off-site courses in other Amazon countries.

FFT trainers provides two kinds of off-site courses. The first type of course targets on sawyers and heavy machine operators. It has the same objectives and includes the same activities as the TC course listed above.

The second type of course (TE) is tailored to the specific needs of the client. It focuses, however, on the general principles of FM and the implementation of RIL practices. For example, FFT will send staff to train the entire logging crew of a particular company or community. Both types of courses last from 5-8 days including preparation time.

The principal clients for off-site courses are expected to be communities with grants and large private companies (especially those interested in FSC certification).

Course Descriptions

- TD -- Forest Management for Decision-Makers

Rationale: Most decision-makers are removed from reality of forest management and need to have insight into the theory and practice of FM-RIL. Participants: Policy makers from regulatory and monitoring agencies (at both State & Federal levels); community leaders, company executives, and landowners. Objectives: The course is designed to remove the misconceptions surrounding FM-RIL and to demystify the process. This will enable participants to make informed decisions. Five days of demonstration, observation, and discussion all aspects of FM-RIL. The course does not have a hands-on component.

- GM – Reduced Impact Logging for Forest Managers

Rationale: Teach a new technology to forest managers. Companies that plan to adopt FM-RIL, must have staff that understand why they are changing methods. It is difficult to manage something that you have never done, and most managers have never been involved in any of these activities. Participants: Supervising foresters at all levels and from all stakeholders (NGOs, government agencies, industry, communities). Also people who plan to disseminate this knowledge to others. Objectives: Observe and participation in all aspects of FM-RIL to understand how, and why, different activities are done. Contents: 13 days of hands-on participation and discussions.

- MF -- Forest Management for Practitioners

Rationale: Today's technical school graduates have little practical training and so are not sufficiently prepared for the work they are hired to do. Participants: Technical school students (seniors in final semester). Objectives: Translate theory to practice. Prepare students to be effective and capable of applying FM-RIL on the job. Content: 17-day practical hands on-training focused on allowing participants to conduct all aspects of FM-RIL upon completion. The course focuses on activities appropriate for technicians.

- TC – Felling Techniques (on- and off-site)

Rationale: Felling directly affects value of wood through its impact on waste and damage. Participants: Sawyers, sawyer supervisors in both industry and communities. Objectives: Improve capacity of sawyers to cut trees the right way. Content: 7 days of safety, chainsaw maintenance and operation, and directional felling techniques

- <u>TI -- Tree Identification</u>

Rationale: To unify the nomenclature of the trees, and to reduce waste by ensuring correct identification. Participants: Tree Identifiers. Objectives: Make forest inventories more uniform. Content: 7 days of dendrology, taxonomy for correct tree identification.

- <u>TP -- Forest Inventory and RIL Planning</u>

Rationale: 100% inventory is new practice and concept. It is a new requirement in legislation and newly accepted by companies, but few people know how to do it. Participants: Practical woodsmen - technicians and supervisors. Objectives: Teach people to do good inventories. Content: 7 days of practical, hands on inventory techniques.

- <u>TA -- FM-RIL Audit Techniques</u>

Rationale: To increase the number of people who can analyze the quality of forest management. Allows companies can get an idea of the quality of their operation. Participants: Government and monitoring agencies as well as forest supervisors. Objectives: Teach auditing criteria and indicators. Content: 6 days of observation, lectures and discussion

- <u>TE -- Off-site – RIL Implementation</u>

Rationale: This course can reach people who are unable to attend on-site courses. Participants: Company crews or community crews. Objectives: Use team of trainers to train or upgrade a whole crew at a company's site. First train one member of crew on-site then travel to the off-site and conduct training. Content: 6 days on all aspects of FM-RIL

Table 1. Course Activities and Subject Hours

	COURSE and SUBJECT HOURS[a]									
ACTIVITIES	**TD**	**GM**	**MF**	**GE**	**TC**	**TI**	**TP**	**TA**	**TC**	**TE**
Lectures in Belem		8								
Daytime field activities										
Worker safety for forestry activities		4	4	2		2	2	2		2
First-aid training for forestry activities		6	8	3	3	3	3	3	3	3
Block layout, definition and line cutting	1	5	10	2			15	2		2
100% Inventory and vine cutting	4	5	10	3		5	40	3		3
Introduction to data processing	2	4	4	2				2		
GIS for FM planning and map making	3	4	4	3				2		
Tree identification for para-botanics						50				
Continuous forest inventory	1	4	4					2		
Forest infrastructure planning (R&L)	2	5	5	5				3		5
Forest structures and stream protection	1	4	4	4				2		3
Forest infrastructure construction	3	5	5	5				5		5
Tree marking	1	1	2	2				1		1
Chainsaw safety		2	2	2	3				3	3
Chainsaw maintenance and use		3	3	3	5				5	5
Directional felling and cutting techniques	4	5	10	5	50			4	50	7
Skid trail planning, mapping, & layout	4	5	5	5				4		5
Heavy equipment operation		1	2							2
Log skidding	4	5	5	5				3		5
Log deck operations (grading and scaling)	4	5	5	5				3		5
Traditional harvesting methods	4	5	5	1				2		
Conventional-regional logging practices	5	5	5					3		
Post harvest silvicultural treatments	4	5	10					5		
Harvest damage evaluation	2	4	4	2				5		2
Harvest waste evaluation	2	4	4	2				5		2
Use of forestry equipment and instruments		4	4	2		5	8	2		2
Forest products utilization	4	5	5							
Evening lectures and discussions										
Forest protection	1	1	2	2	1			2	1	1
Forest management systems	1	1	1		1			1	1	1
Forest management plans and POAs	1	1	1			1	1	1		1
Forest management certification	1	1	1							1
Forest management costs and benefits	2	2	2	2	2	1	1	2	2	1
Forest management legislation	2	1	2	1						1
Forestry management and biodiversity	1	1	2			1	1	1		1
Demonstration / visual aids / presentations	1	0	2	2	2	2	2	2	2	
Perspective for Amazon forest products	1	1	1		1				1	1

[a] Numbers in the matrix indicate the number of hours students participate in the corresponding activities for each course.

Figure 1. Distribution of participants in FFT training courses:1996-2000

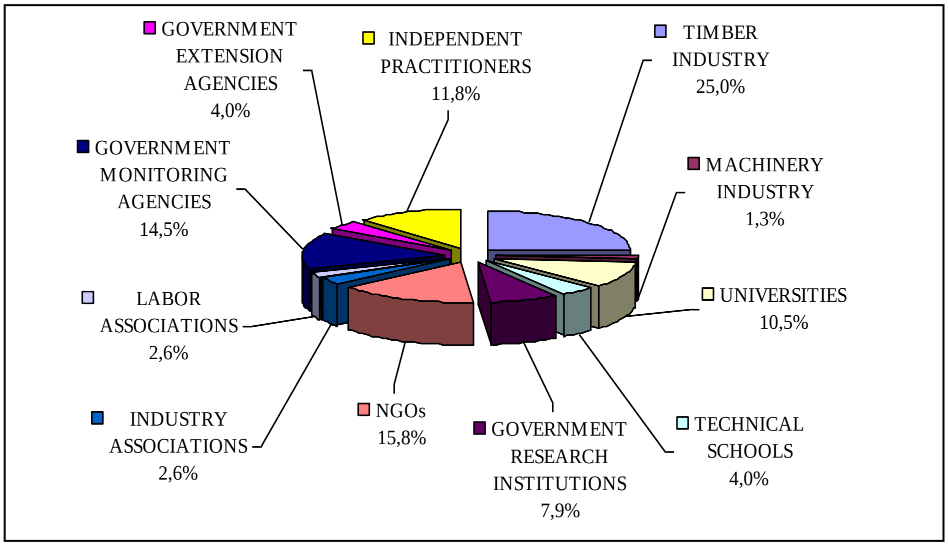
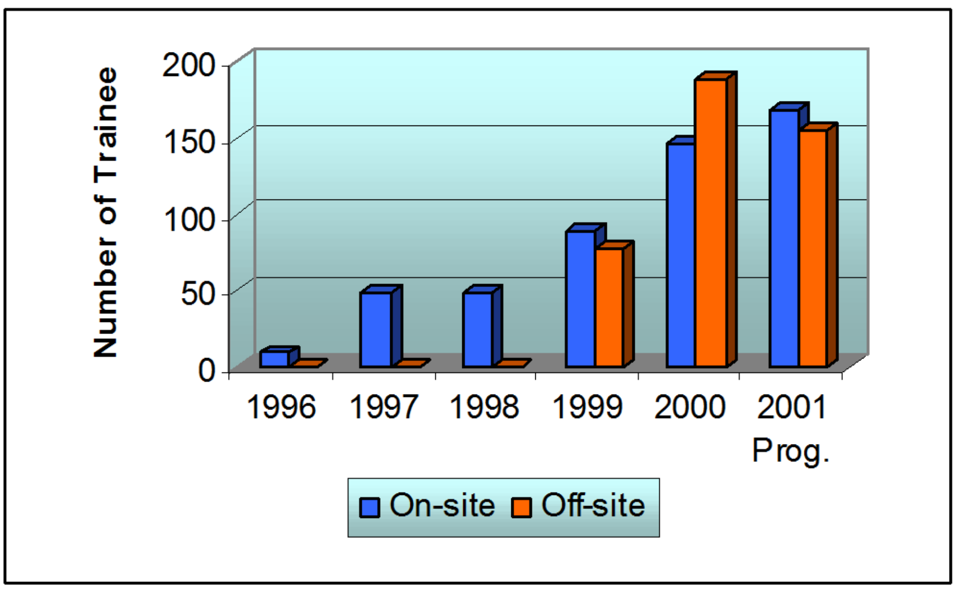


Figure 2. Participants in FFT's on- and off-site FM-RIL training courses and extension activities (1996-2000).



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