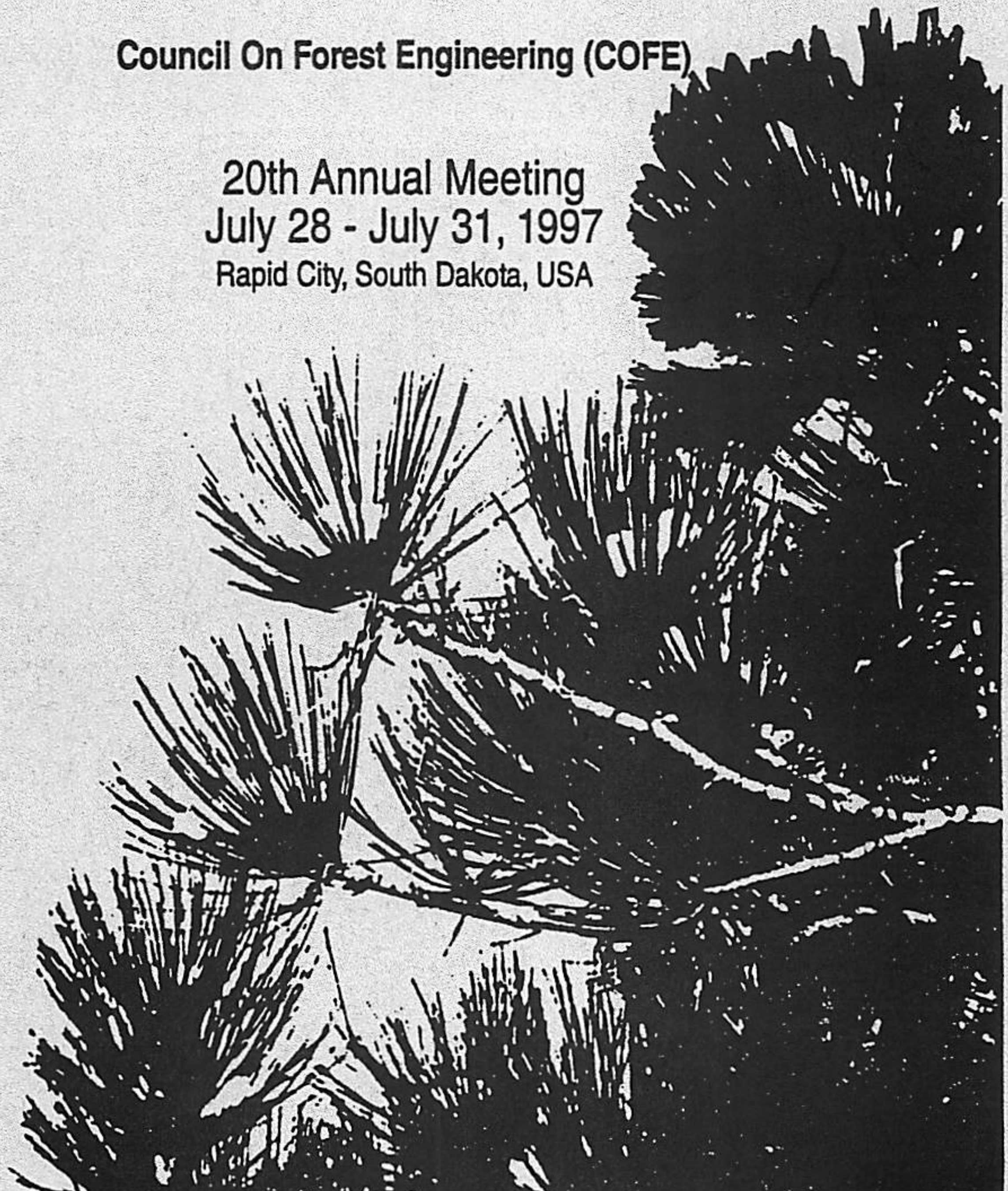
PROCEEDINGS

Forest Operations for Sustainable Forests and Healthy Economies

Council On Forest Engineering (COFE)

20th Annual Meeting
July 28 - July 31, 1997
Rapid City, South Dakota, USA



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Hosted by
USDA /Forest Service
South Dakota State University

Editors: John J. Ball and Lawson W. Starnes

FOREWORD

The Council of Forest Engineering (COFE) is a professional organization based in North America interested in matters related to forest engineering. Through an annual meeting with technical sessions, field sessions, and publication of a proceedings and through regional activities, COFE encourages the exchange of information and technologies relating to forest operations.

The theme for this year's meeting is "Forest Operations for Sustainable Forests and Healthy Economies." The meeting is composed of four technicial sessions that cover sustainable management, forest operations and the environment, efficiencies in forest operations, and mapping and visual assessment of forest operations. The all-day field tour highlights sustainable forest operations in the Black Hills.

We would like to thank the sponsors of this meeting: Danzco; Pope & Talbot, Inc.; Neiman Sawmill, DBA Devils Tower Forest Products; Timbco Hydraulics, Inc.; Stihl, Inc.; Wheeler Lumber; Black Hills Forest Resource Association; Rapid City Chamber of Commerce; Resource Roundup; South Dakota Department of Agriculture; Forestry & Natural Resource Management Division; South Dakota State University, Department of Horticulture, Forestry, Landscape & Parks; and USDA Forest Service. We would also like to thank Ms. Mary Brashier of the South Dakota State University Agricultural Communication Department for her assistance in the production of this proceedings.

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Contents

Session 1: Sustainable management

Session 2: Forest operations and the environment

Session 3: Efficiencies in forest operations

COFE regional reports

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Forestry Operations in the Next Century

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ABSTRACT: What will future forestry operations resemble? In what context will workers, technicians and forest engineers work? A recent analysis of the technical, social and economic factors the forest industry faces can help us predict how operations will have to change to adapt to future demands. In this context the presentation focuses on outlining what forestry operations may be like in the next century.

Key Words: forestry operations, predictions, driving forces, trends, advanced technologies

INTRODUCTION

We are living in an age when change is accelerating and the only thing that we can really predict is that tomorrow will be different from today. Even though the underlying natural rhythms of the forest's evolution are dictated by Mother Nature, and remain unchanged and largely invisible even to forestry experts, forestry activities are undergoing a revolution. In this light, what will future forestry operations resemble in the next century? In what context will workers, technicians and forestry managers work? It would be presumptuous to attempt to predict this with any certainty, but an analysis of the technical, social, and economic factors the forest industry currently faces can nonetheless help us to predict how operations will have to change to adapt to future demands. The beauty of predicting the future is that nobody today can prove that we're wrong; it will be interesting to reread this text in 5 or 10 years to compare our predictions with reality!

In this context, my presentation will focus on outlining what forestry operations will be like in the year 2000 and beyond, based on the factors that are driving change ("driving forces") that we can perceive today. I will start with a definition of those factors that are evident at local and international scales, from both a technical and an economical view and in a human context, after which I will discuss how forestry activities and equipment must adapt to these changes.

This presentation is based on a strategic "orientation" exercise that FERIC recently completed on behalf of Industry Canada with the assistance of our members. This exercise, entitled "Technology Road Map for Forest Operations in Canada," had the goal of formulating recommendations for governments, the forest industry, equipment manufacturers, research groups, and others involved in the forestry sector and was intended to focus action on the sector's future priorities. To do so, an exhaustive review of current trends was carried out through group discussions, a literature review, and interviews with key personnel in the sector. The most promising emerging technologies were identified, and the identification of technological or organisational gaps subsequently helped define the road or roads along which the "road map" would lead to prosperous forest operations in the next century.

DRIVING FORCES

We identified nine groups of factors that, together, affect and will continue to affect future forestry operations:

1. The delivered cost of fiber.
2. Environmental issues.
3. Resource availability.
4. The profile of the operations and operators.
5. Government involvement.
6. Public pressures.
7. Worker needs.
8. Market demands.
9. Technological innovations.

Most of these factors are interrelated and act together; for example, public pressures influence government involvement, and environmental issues have an impact on market demands.

Some of these factors act in concert whereas others conflict; for example, environmental issues can impose financial constraints that act against the need to reduce costs so as to remain competitive. No matter their relative importance and how they act, the following driving forces are generally recognized as primary elements of change and will significantly affect forestry operations of the future.

Cost of fiber delivered to mills

The delivered cost of fiber is often the main component of a product's total cost. Thus, costs must be maintained at the lowest possible level for the industry to retain or regain its competitiveness against international competition that will only increase in the future. Technological and operational changes in harvesting, silviculture, and transportation are thus often largely driven by the need to reduce costs.

Environmental issues

We are all aware of our collective responsibility to conduct forestry operations that respect the environment within the context of sustainable management. Whether from the point of view of water quality, wildlife preservation, biodiversity, or esthetics, future forestry operations must evolve in response to society's growing expectations. Planning, forestry practices, and equipment must be modified as a result.

Resource availability

Our forests are a renewable but not inexhaustible source of raw material. Healthy management practices and pressures from other users of the forest, specifically the general public, require that losses and wasteful practices be eliminated and that good use be made of all the available fiber. In some areas, we are already experiencing shortages of fiber in certain quality classes, and this has led to changes in our forestry practices toward techniques that further favor the recovery and use of species that were formerly considered noncommercial; in addition, increasing attention is being devoted toward making the processing phases contribute as much as possible to quality, and thus to the value of the endproduct.

Profile of operations

The structure of the forest industry itself greatly influences the nature of forestry operations. For example, a trend, that began a few years ago and is common today, toward contractor-based operations rather than company-owned equipment imposes certain practices adapted to the needs of contractors. The need for direct and constant communication and monitoring at all levels of operations also determines the appropriate equipment and organizational structures.

Government involvement

Governments play a major role in directing forestry practices, whether through forest practices standards and regulations, land tenure and harvesting policies, environmental laws, or other legislation (or lack thereof), and they will continue to play this role in the future. Whether they fulfill this role via incentives or coersion, the policies by which they act will have a decisive influence on the equipment and operational techniques used in the forest. Workers and forest managers must, more than ever, understand and apply these increasingly complicated laws.

Public pressures

The public comprises an increasingly important driving force. Not only does the public participate in public consultations in specific cases (as in the case of Clayoquot Sound), but there is also an increasing and unremitting role in daily decision-making and the planning of forestry operations. Whether in terms of questions such as clearcutting, monocultures, prescribed burning, roads, pesticides, or roadside debris, the public has the power to shape future practices.

Worker needs

There is already an anticipated scarcity of qualified forest workers, and this trend cannot be reversed unless forestry jobs of the future offer attractive working conditions; moreover, some form of modified education must be provided to train operators to deal with the demands of increasingly complex machinery and operating conditions. Even though operators have some ability to adapt to technological changes, technology itself must also be adapted to meet the needs of the available workers.

Market demands

Globalization of markets and fierce competition for raw materials have motivated the industry to seek markets for new, more specialized products. Just as markets dictate the nature of the products that the industry manufactures, so too do the products dictate the nature and the quality of the raw material that is required. Market demands thus determine the nature of operations in the forest to some extent.

Technological innovations

The arrival of new, innovative technologies is another source of change. If it is true that the factors I've previously cited are the engines of technological evolution, it is also true that the availability of the technology itself will lead to changes in forestry operations. For example, global positioning systems (GPS) were not invented to address a specific forestry need, but they have revolutionized some of our operating techniques. It is certain that other technological innovations outside the forestry sector will change our way of working in the future.

TRENDS IN VARIOUS SYSTEMS

Harvesting systems

Gingras (1992) studied the evolution in eastern Canada of the three main harvesting systems, namely full-tree harvesting with roadside delimbing, tree-length harvesting with delimbing at the stump, and shortwood harvesting using cut-to-length machines with multifunctional heads. The current trend suggests that machines with multifunctional heads will continue to replace full-tree systems over the next 5 years. Many of the previously discussed factors that are driving changes, such as fiber recovery and quality, reduced environmental impacts, and increased operational flexibility, explain this trend.

Another trend is becoming apparent in the form of increased harvest volumes from partial cutting. A recent survey indicated that 25% of FERIC's member companies are already performing commercial thinning, at least in the form of operational trials, and an additional 34% expect to do so over the next 5 years. There is no doubt that partial-cutting techniques will be refined in the Canadian context and applied on a wider scale in the next century.

Silvicultural systems

A growing trend towards protecting and promoting advance regeneration will dominate in the next century. In general, silvicultural systems will tend to encourage the natural evolution of the forest rather than impose an artificial approach. The areas to be planted will continue to decrease.

Herbicides and pesticides will become increasingly unacceptable means of intervention, even where they are not actually prohibited. Other means of intervention will be developed.

The demand for fiber and the need to protect investments will allow companies to justify stand-tending operations, especially for stands near mills. Precommercial thinning operations will increase in popularity.

Transportation systems

It may be a lack of vision, but it is hard to imagine that transportation from the forest to the mill will be performed by any means other than trucking over the next decade. One can imagine an increased use of rail transportation, aerial systems (balloons), pipelines for chips, or a modernized form of water transportation, but these are relatively improbable solutions. In contrast, the semi-trailer system will continue to evolve to increase its efficiency and safety. Important gains can result from increasing payload while respecting regulations on total or axle weights, as well as from using more efficient motors that provide substantial fuel savings.

It is perhaps at the level of forest road construction and maintenance that the evolution has been most striking. In effect, we are approaching a situation in which the road network is already fairly well developed and the priorities will change to focus on maintenance and management of the established network rather than on its establishment. It is also obvious that the design and construction of roads must be integrated with reliable systems of preventing erosion and the consequent sedimentation of streams.

ADVANCED TECHNOLOGIES

Now let us move on to examine various technologies that could increasingly be applied in forest operations or equipment. FERIC has identified ten technologies that, in our opinion, will be a significant part of the life of a forestry worker in the next century:

1. Machine-control systems.
2. Operator aids/robotics.
3. Lightweight components.
4. Positioning systems.
5. Computerized decision-support systems.
6. Training simulators.
7. Machine vision.
8. Environmentally friendly fluids.
9. Environmental technologies for soil protection.
10. Communications.

Machine-control systems

The machines of the future will be equipped with "intelligent" control systems that let them adapt to the environment in which they are working; by using various sensors, the machine will "know" when it is on a slope, when it is on wet ground, or when its wheels are slipping. It can thus adapt to these conditions in a way that optimizes its performance and reduces its impact on its environment; for example, controlling wheel slip will reduce soil damage, cabs can automatically adjust themselves to account for slopes, an understanding of ground firmness would let a planting machine adjust planting depth for seedlings, and a machine could even provide its operator with diagnostics on its operating condition, thus reducing downtime for repairs.

Operator aids/robotics

As a result of automating a machine's functions, operators could concentrate their energy and resources on making strategic decisions rather than on routine operating tasks. After an initial learning phase, the machine would manage systematic and repetitive actions by itself; these could include placing logs in piles, grabbing a tree for delimbing, or moving in a straight line. Current efforts in this area focus largely on the development of a boom-control system based on coordinated motion control; this system lets the operator control the implement (e.g., a felling head) by using a mini-joystick without having to worry about the operation of the hydraulic cylinders. In such a system, the operator simply points the control lever in the desired direction and the onboard computer controls the necessary hydraulic valves. Moving from this point to a fully autonomous robot in the forest represents an unlikely step; even if certain activities will be highly automated, the operator will retain an important role for the foreseeable future.

Lightweight components

There are two main reasons to reduce the weight of the components of forestry machines: to increase their payload or capacity and to reduce ground pressure as much as possible, thus reducing impact on the soil. The systems used in forestry operations have traditionally made little use of lightweight materials developed in other sectors such as the aerospace industry. Aluminum, Kevlar, carbon fiber, and other materials permit the construction of very strong, light components, and will be widely used in forestry equipment in the next century. Several examples are currently under development.

In sensitive areas such as riparian zones, where travel by forestry machinery must be avoided, operators of cable skidders can use synthetic-fiber cables rather than steel. These cables are as strong as steel, but weigh much less, which lets operators haul out the cables much farther from the machine and thus reduce the need for on-site travel.

To maximize the protection of regeneration and soils, harvesting equipment will need to have the greatest possible boom reach to let operators maximize the spacing between skid trails. Telescoping or unusually long booms are beginning to appear, and the use of composite materials may permit even greater lengths.

Positioning systems

Global positioning systems (GPS) technology now lets users rapidly update maps and other forestry data and efficiently perform on-site surveys, which formerly required considerable time and resources.

The machines of the year 2000 and beyond may be equipped with navigation systems based on GPS technology to facilitate the conduct and monitoring of harvesting and stand-tending operations. The operator can navigate using a map displayed on a screen in the cab. Navigation systems will eliminate several costs related to the demarcation of blocks, reserves, streams, and roads.

However, this assumes that our basemaps have the required degree of precision and thus that the computerized spatial reference information will be reliable, which is not currently the case. In this context, better survey data and remote sensing will play a key role.

Computerized decision-support systems

Taking increasingly strict standards and alternative values into account, the industry faces an increasingly complex planning process for its forest interventions. In addition, a considerable quantity of biophysical, ecological, and social data will have to be available for integration into the planning process.

This data is ruled by complex interrelations that will be better understood and better integrated within more precise, but not yet perfect, models. Geographic information systems (GIS) are already operational tools that greatly facilitate the management of large quantities of information. In contrast, managers have relatively few decision-support tools available to help them select an optimum harvesting and silviculture scenario. FERIC is currently working to develop a computerized model called "Interface" that will let managers simulate various harvesting and regeneration scenarios and calculate their total cost.

Similar decision-support tools will be available in the future for optimizing forestry operations in terms of environmental, ecological, social, wildlife, and other parameters. Forestry managers will still make the final decisions, but formulating the elements of a solution will be greatly simplified by the use of such computerized tools.

Training simulators

The need for training machine operators will only increase with increasing constraints and operational demands in the forest and with increasing complexity of forestry equipment. Because of the high cost of such equipment, the risks involved in using an inexperienced operator in the field, and the complexity of the concepts to be taught, training will rely more and more on simulators. FERIC, along with our partners in the ATREF (application of robotics technologies to forestry machines) project, is already working on the development of a simulator that will help operators learn to use a harvester's boom.

Machine vision

Most future equipment will incorporate some form of machine vision that will let it evaluate the objects it must handle (trees, logs, chips, etc.) and respond appropriately. For example, FERIC foresees the development of a camera system for measuring logs on delimbers or processors. Analyzing an object, as in determining tree diameter, will help to optimize slashing. The same technology will be developed for measuring logs (while accounting for various deductions for rot, etc.), and the analysis and sorting of pulp chips. Finally, if we hope to automate certain forestry operations (e.g., through robotics), the machine must "visualize" its environment, for example, to be capable of "seeing" a tree before it can grab it. Such machine vision systems are already well implemented in facilities such as sawmills, but will have to be adapted to the constraints of the forest environment.

Environmentally friendly fluids

Forestry equipment should never be a source of contamination of the water table or the atmosphere. Hydraulic, cooling, and combustion systems should be very "tight" and should incorporate some mechanism for handling spills. Exhaust gases must meet strict standards, and fluids (oils, liquid coolants, fuels) will need to be biodegradable.

We are already seeing the emergence of some of these products on the market. For example, vegetable oils can now replace mineral oils for lubricating the chain saws of multifunctional heads (Makkonen 1994). Soon, this type of oil will also be able to replace the hydraulic oils in forest machines.

Environmental technologies for protecting soils

Over the next decade, we will see the introduction of many innovations in existing or new traction systems intended to reduce the impact of machinery on soils. One technology that is currently well developed—oversized tires and tracks—contributes to reducing soil compaction and rutting and improves the flotation of forestry machines. We will also see wider use of central tire inflation (CTI) on most forestry equipment. This technology is already well developed in the trucking sector. The technology involved in "walking machines" is still at an embryonic stage, but may one day replace wheels and tracks, which are responsible for most soil disturbance.

The development of each of these systems relies on a better understanding of the terramechanics of forest soils (i.e., the interaction between wheels and the soil), a science that is still largely unknown today.

Communications

In the year 2000 and beyond, our current means of communication will appear archaic to us; for example, the Internet is only beginning to show its potential. Oral communication and the transfer of large amounts of data and images between the forestry worker, the site foreman, and the mill and its clients will be easy and free from obstacles. The efficiency of an operation will rest, to a large degree, on good communication between the various parties involved in the forest. For example, it is highly likely that a client in Copenhagen will be able to send an order for sawlogs to a mill in Thunder Bay, which will relay the species and size specifications to an operator in the forest, who can program his onboard computer to accommodate the order.

The foreman could also check the status of distant equipment and know, for example, the position of a truck, the fuel level in a harvester, or the area treated by a scarifier.

Some foresters from the British Columbia government already use a portable office that gives them access from their trucks, via modem, to information such as digitized maps of a region, databases, and the text of applicable forestry practices codes.

Modernization of our means of communication will surely rely on the development and use of a network of satellites such as MSAT and the development of standard data-exchange protocols.

CONCLUSIONS

The important pressures and trends that will shape forestry operations in the next century are already in place. The challenges that they represent will be partially solved by the use of modern technologies applied to our tools and our management and communication methods. But these technologies will provide only a support on which the worker and the forest manager can lean to accomplish their work according to the "rules of the art." The forest manager of the next century will have to be capable of making decisions that extend beyond a strictly forestry context.

Significant changes are thus expected in forestry operations, and these changes will to a large extent be imposed by necessity. It is, however, urgent that the forest sector readies itself to recognize this need to evolve and ensures that the necessary research and development efforts are undertaken.

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Wetland Harvesting Systems—
Developing Alternatives for Sustainable Operation

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ABSTRACT: Wetland forests represent some of the most productive forest lands in the southeast. They are also an environmentallysensitive ecotype which presents unique problems for forest operations. Sustaining active management in these areas will require systems which can operate on weak soil conditions without adversely affecting soil properties or stand regeneration. The systems must also operate economically. This paper reviews current investigations of alternative systems including large-capacity forwarders, clambunk skidders, and the skidder/shovel logger system in the southeastern U.S. The systems are compared in terms of production, cost, and potential site impacts.

Key Words: wetland harvesting, forwarders, site impacts

INTRODUCTION

Forested wetlands are an important natural resource in the southern United States. McWilliams and Faulkner (1991) estimate that bottomland hardwood forests cover 10 million hectares of the southern coastal plain. These forested sites provide significant ecological values in modifying hydrology, improving water quality, and life support. The unique hydrology and soils of wetland forests also make them highly productive in terms of wildlife, aquatic habitat, and plant communities. McWilliams and Faulkner (1991) note that bottomlands contain over half the hardwood timber resource in the south-central United States.

The ecological value and productive potential of bottomland hardwood forests reveal two constraints. First, the economic incentive to maintain these areas in forest cover depends on cost-effective forest operations. Secondly, however, productive use must not compromise the ecological functions of these sites.

The soft soils of typical wetland sites make it difficult to achieve either objective. Low-bearing-capacity soils impede access and extraction and increase harvesting costs. Soft soils are also more sensitive to disruption, magnifying the impacts of ground operations.

In 1986, an industry task force conducted a survey of southeastern wetland loggers (Stokes 1988). The most common system configuration averaged six workers and had one tracked feller-buncher and two rubber-tired skidders. Production averaged 350 cords per week. A survey of Mississippi Delta loggers (Jackson 1990) found 98% using rubber-tired skidders for extraction. Wide tires and dual tires were commonly applied to enhance trafficability.

While rubber-tired skidders are common, many of the problems in wetland logging are tied to this extraction function. Rubber-tired skidders can cause rutting and puddling of soils. Aust *et al.* (1993) also found changes in subsurface hydrology associated with the impacts of skid trails on wet pine flats. Skidders operating in these conditions typically have lower productivity and higher operating costs than similar machines working on dry sites. The combination of reduced productivity and the limited load capacity of the skidding function establishes the economical skid distance. This in turn determines road and landing spacing.

Several papers (Jackson and Stokes 1990, Reisinger and Aust 1990) briefly reviewed alternative technologies for wetland operations. They described a range of equipment including tracked skidders, large-capacity forwarders, cable systems, and helicopters. However, their report did not address system configurations.

The contractor working on wet sites faces the challenge of developing an integrated system of equipment and methods that will (1) operate effectively on wet soils, (2) minimize ecological impacts which include rutting, soil disturbance, and hydrologic alterations, and (3) provide a reasonable economic return. With increasing market demands in the South for hardwood fiber, forest operations are extending into more adverse sites. Under today's social pressures to protect sites and ensure sustainability, it is more difficult to harvest such areas cost effectively. It is also apparent that conventional harvesting systems do not adequately address the needs of the wetland logger.

This paper is a review of some currently operating and evolving hardwood, wet site harvesting systems: (1) conventional grapple skidding, (2) clambunk skidding, (3) high-capacity forwarding, and (4) shovel logging. Helicopter and cable systems are briefly described.

WETLAND LOGGING EQUIPMENT

A wetland logging system has to perform the functions of felling, limbing and topping, primary transport, and loading. Such equipment is often conventional forest machinery with special adaptations to enhance operability in wet terrain.

Feller-bunchers

Felling trees on wet sites requires moving a felling machine to the tree, making the cut, and directing the placement of the fallen tree. These tasks are complicated in wetlands by soft soils and large trees with extreme butt swell. Within the last few years, many operators have replaced chainsaws or rubber-tired, drive-to-tree feller-bunchers with tracked, swing-to-tree feller-bunchers. Swing feller-bunchers may reduce site disturbance by limiting travel and by the use of wide flotation tracks. On extremely wet sites, swing feller-bunchers may even use felled trees or constructed mats for support. By bunching felled trees, swing machines help increase extraction productivity and reduce the amount of traffic on the site.

Swing feller-bunchers have higher initial and operating costs than rubber-tired equipment. Historically, this option was the least preferred because of these high costs. However, increasing emphasis on reducing site disturbance and the cost of workman's compensation are offsetting the additional capital costs of swing machines.

Grapple Skidders

Rubber-tired skidding has been and continues to be the most widely used and cost-effective wood extraction method in most situations. By eliminating choking, the grapple skidder has higher productivity than a cable skidder. In wetlands, however, this advantage is reduced if the machine cannot drive to each turn. Wider tires or dual tires increase payload and improve flotation. The dual-tire combination has proven to be a cost-effective alternative to single, wide tires (Table 1).

Table 1. Skidder tire costs for wetland logging.

Tire size	*Ground pressure (psi)* [1]	*Total cost*
Singles		
23.1x26	7.1	$8,600
28Lx26	5.9	$9,800
30.5x32	5.3	$12,400
66/43.00-26	4.1	$14,800
72x68-28	2.6	$39,400
Duals		
23.1 (2)	4.0	$17,200
28L (2)	3.4	$19,600
34.00 (2)	3.2	$28,000
24.5 + 30.5	3.4	$23,000
28L + 43.00	2.8	$24,600

[1] based on a John Deere 548G

An alternative approach to improving skidder trafficability is the recent innovation of a hydrostatic grapple skidder. By powering the wheels independently, the machine can better control torque and slip to match the ground conditions. Reduced wheel slip can result in less site disturbance by reducing rutting from wheels spinning and displacing soil.

High-Capacity Forwarders

High-capacity (over 11 t) forwarders are also being used to extract wood on wet sites. Tree-length forwarders can move payloads of up to 23 t. Large loads reduce the total number of trips into the stand. The forwarders may be self-loading, but to reduce weight and increase payload, they are usually loaded and unloaded by knuckle-boom loaders. Roads are not necessary, but forwarder trails are generally wider and straighter than skid trails to improve travel speed and accommodate the long loads. Self-loading forwarders require pre-bunched wood along the main trail. Forwarders without loaders require an in-woods knuckleboom loader and a roadside loader.

The large capacity may also extend the economic skid distance compared to skidders. This is a critical part of the evaluation of these machines. Longer extraction distance reduces roadbuilding costs. Fewer roads also reduce the overall site disturbance. Systems using tree-length forwarders may also be less sensitive to wet weather since highway haul trucks are not operating on unimproved woods roads. High capacity forwarders can work at very long distances; one study observed extraction at 8 km.

Clambunk Skidders

Clambunk skidders are another alternative to conventional skidders. Like tree-length forwarders, clambunks extend extraction distance and reduce travel by having a larger payload. Six- and eight-wheel drive clambunks have been manufactured by various companies for a long time but have not been widely accepted due to their overall large size and high price. The large size makes them difficult to move over the road to different locations. A smaller, less expensive four-wheel-drive clambunk capable of skidding 15-ton loads was introduced in 1993 (Schilling 1993).

Clambunks generally are self-loading. However, with limited maneuverability as the load accumulates, clambunks need to work from pre-bunched material along a main trail. Effective extraction distance lies between conventional skidders and tree-length forwarders.

Shovel Loaders

Shovel loaders are hydraulic knuckleboom loaders adapted to heavy swing applications. Shovel loaders have been used in the Pacific Northwest (Andersson and Jukes 1995, McNeel and Andersson 1993) to extract wood short distances to roadside. Typically, the tree-length stems or logs are picked up, swung 180 degrees toward the deck or roadside, perpendicular to the direction of travel of the shovel. In effect, the wood is moved two lengths of the boom; this distance is increased by grappling longer stems near the end.

On wet sites in the southern U.S., the procedure is significantly different. Shovel loaders are used to pile felled trees in a "road" of stems. The trees are laid down end-to-end which provides a continuous mat to support skidders. The shovel machine builds the mat, pre-bunches stems to load skidders, and loads out the "road" as it works from the back of the corridor out of the stand. With long reach and wide tracks, shovel loaders minimize site disturbance. Corridor spacing can be two to three times the boom reach.

Aerial

Cable systems and helicopters have also been used in wetlands on a limited basis. The primary advantage of these systems is a reduction in site disturbance and the ability to extract wood in areas which will not support ground systems. Such systems are also employed to provide woodflow during wet winter months.

Murray (1996) describes a cable system operating in Georgia which uses mobile intermediate supports for a multi-span standing skyline. A tracked feller-buncher cuts the timber which is forwarded 100 m to the skyline corridor by a shovel loader. The Christy yarder carries enough skyline to reach 760 m.

Helicopters are used more frequently on wet sites but require larger tree sizes and short distances to be economical. This system causes the least disturbance except for the building of decks and roads.

Both cable and helicopter systems require large capital investments and well-trained, skilled crews. These systems must also maintain high production to achieve profitability. For these reasons, aerial systems tend to be associated with large contractors closely associated with major wood consumers.

Equipment Costs

While initial cost is only one component of a machine rate, it is directly related to hourly operating costs and capitalization requirements for the operation. Table 2 summarizes some current price data (Brinker 1997).

SYSTEM CONFIGURATIONS

A comprehensive evaluation of wetland logging alternatives must look at a range of combinations of equipment. To compare among alternatives, system production rates were estimated using the Auburn Harvesting Analyzer, a spreadsheet template that combines stand information, production equations, and cost information. Four systems were modeled: (1) swing feller-buncher with grapple skidder; (2) swing feller-buncher, grapple skidder, clambunk; (3) swing feller-buncher, grapple skidder, tree-length forwarder; and (4) swing feller-buncher, shovel loader, grapple skidder. All systems included manual topping with chainsaws.

Production functions were developed for a clambunk skidder, shovel loader, and swing-to-tree feller-bunchers using standard production and time study methods. Regression analysis related productivity to various stand parameters. Previous studies of tree-length forwarders, grapple skidders were used as estimators for those functions. Machine costs were estimated using the machine rate approach and current price data. A

Table 2. Costs of representative wetland logging equipment.

Machine	*Make/Model*	*Tires*	*Purchase Price*
Cable skidder	Franklin 405	23.1x26 duals	$95,600
Grapple skidder	Timberjack 450C	28Lx26 duals	$138,915
Grapple skidder	Timberjack 480C	28Lx26 duals	$181,218
Clambunk skidder	Franklin 170	24.5x32 duals	$162,500
Clambunk skidder	Timberjack 933C	20.5x25	$417,502
Clambunk skidder	Ardco "N" 6x6	66/43.00-25	$460,000
Swing feller-buncher	Timbco T425-B	tracks	$238,641
Swing feller-buncher	Timberjack 608	tracks	$248,623
Swing feller-buncher	Tigercat 860	tracks	$319,000
Drive-to-tree feller-buncher	John Deere 643D	28Lx26	$153,975
Drive-to-tree feller-buncher	Franklin C5000	28Lx26	$173,500
Tree-length forwarder	Ardco "K" 6x6	66/43.00-25	$233,933
Shovel loader	Timberjack 735	tracks	$255,000

stand table was constructed from cruise plot data of an actual bottomland stand (Table 3). The stand had 344 trees per ha with a quadratic mean DBH of 28 cm. Stand volume averaged 292 t per ha.

Table 3. Bottomland hardwood stand for analyses.

DBH (cm)	*Trees/ha*	*Tons/ha*
15	86	9.7
20	69	18.6
25	42	21.1
30	37	29.9
35	35	40.0
40	27	42.7
45	20	41.6
50	10	27.4
55	10	31.9
60	5	21.1
65	0.5	2.0
70	1.2	7.2

Using the common stand table and production functions, each system was modeled at the actual observed extraction distances.

The summary data in Table 4 is based on very different extraction distances and tract configurations. The lateral distance refers to the average distance from the stump to the main trail (pre-bunch distance). The external distance is the one-way distance of primary extraction transport. The extraction distances are considered representative for each specific system.

SUMMARY

The wetland forest resource challenges forest operations from both an environmental and an operational perspective. The operating conditions in these stands push the limits of equipment capabilities. Variability in operating conditions also means that there is no single best operational approach for working in wetlands. Wet pine flats in Louisiana are very different from alluvial Delta islands and Carolina pocosins.

Resource managers and logging contractors need the capability to analyze system performance for varying conditions to minimize production costs. The approach

Table 4. Wetland logging system estimated production summary.

System	*Lateral distance (m)*	*External distance (m)*	*System Rate (t/SMH)*	*System Cost ($/SMH)*	*Unit Cost ($/t)*
Feller-buncher, grapple skidder	0	213	29.7	$171.77	$5.78
Feller-buncher, grapple skidder, clambunk	107	366	32.1	$219.98	$6.85
Feller-buncher, grapple skidder, forwarder	107	1676	29.4	$213.93	$7.28
Feller-buncher, shovel, grapple skidder	10	274	40.8	$237.38	$5.82

demonstrated in this report is a simple technique for addressing such questions. For example, the system spreadsheets can be iterated over distances to determine breakeven extraction distances which separate systems. Changes in stand volumes or diameter distribution can also be studied to estimate the impact of selective harvesting strategies on unit cost.

Increasing fiber demands in the South mean there will be a continuing search for better ways to work in wetlands. New equipment developments, new system combinations, and better methods of analyzing and understanding system performance will be the key to finding solutions.

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Logging Technology for Managing Northern Hardwoods

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ABSTRACT: Logging is a key activity in the rural communities of the Northeast. For these communities to remain viable in a global wood market, forestland owners need to integrate new forest harvesting technology with the concept of sustainable forestry. Major issues affecting the selection of new logging technology are costs, production goals, silvicultural treatments, environmental impacts, and sustainable forest goals. Addressing these issues in the treatment of northern hardwood stands requires the use of alternative logging technology. Forest planners, managers, and loggers need to know what type of logging technologies are available and their limitations for treating these hardwood stands. We compared three logging technologies that are applicable in hardwood stands: a small cable yarder, a conventional ground-based tractor, and a cut-to-length (CTL) and forwarding system. The results suggest that the impact of piece size on the cost for the cable yarder is a major factor. However, it is not quite so pronounced for the ground-based and CTL systems.

Key Words: cable logging, ground-base skidding, cut-to-length harvesting, thinning, cost, production, break-even comparison.

INTRODUCTION

Increasing concern with the impact of logging systems on the forest site has led managers to consider alternative harvesting technologies. Although rubber-tired skidders have long been the standard for extracting timber from hardwood sites, loggers are beginning to use other harvesting systems to minimize adverse impacts on the harvest site.

A way of life in many of the rural communities in the Northeast, logging is not only the economic base but also a major part of the social structure within these communities. Logging represents the starting point for much of the market activity in the forest products sector and is the focal point for multiple use and the different values placed on the forest. Woodland owners and forest managers are trying to understand ecosystem management objectives and the practices that will meet those objectives.

For these and other reasons related to multiple use, the silvicultural practices and logging technology available for harvesting are important factors in achieving cost-effective yet environmentally sensitive operations.

A series of time and motion studies has documented production rates and costs of small tractors, a small cable yarder (Huyler and LeDoux 1997), and a small cut-to-length (CTL) and forwarding system (Huyler and LeDoux 1996). Field studies of small tractors (Huyler and LeDoux 1989) have shown that these machines are well suited for removing timber from hardwood sites. The time studies were conducted on commercial timber sales in the Northeast. In this paper we used these time-study data, a stump-to-mill costing model (LeDoux 1985), and ECOST version 3.0 (LeDoux 1997) to compare production rates and costs of a small tractor, small cable yarder, and small CTL forwarding system.

METHODS

The stand prescription for all systems studied was primarily thinning to reduce the stand basal area.

Typically, the long-range plans for these stands were to grow high-quality hardwoods while providing for other forest uses. The harvesting technologies were classed as small systems and selected on the basis of two criteria: that they be less than 60 hp, and that ground-based systems have 4-wheel-drive capability.

The conventional ground-based system used in the analysis was an A60F Holder tractor. An articulated 48-hp diesel tractor manufactured in West Germany, it was equipped with an Igland-Jones 3000 double-drum winch with a rated pulling capacity of 6,600 lb. The cable yarding system was a Koller K-300 yarder. This is a trailer- or tractor-mounted uphill yarder used mostly for commercial thinning and small-wood harvesting. Manufactured in Austria, it has a minimum power source of 40 hp, a 23-ft (7-m) tower, and a payload capacity of 3,500 lb. The CTL harvester/processor was a single-grip Peninsula design roller processing saw-head model RP1600. The maximum cutting diameter is 14.0 inches; the minimum-maximum limb diameter is 1/2 to 9 inches, respectively. The single-grip head was mounted on a modified 988 John Deere, 70-tracked excavator platform. The 55-hp machine has a 48-gal/min hydraulic pump system. Included in the CTL system was a Valmet model 524 forwarder. This bidirectional 4-wheel-drive machine was equipped with a small clam loader and an 8-ft log bunk.

RESULTS

Figure 1 shows stump-to-landing cost curves by average piece size for the Koller K-300, CTL and forwarding system, and Holder tractor. The impact of piece size on cost is more pronounced for the cable yarder. For example, yarding pieces that average 3.88 ft^3 cost $0.9382/$ft^3$, while pieces that average 4.94 ft^3 cost $0.5470/$ft^3$, or a reduction in cost of about 42%. The interactive effect of piece size and logging system used also affects stump-to-landing cost. For example, cable-yarding pieces that average 3.88 ft^3 cost $0.9382/$ft^3$. Using a CTL and forwarding system to remove the same 3.88-ft^3 piece cost $0.3963/$ft^3$, a decrease in cost of about 58%. In contrast, using CTL and forwarding to harvest 3.88-ft^3 pieces cost $0.3963/$ft^3$, while using the Holder tractor to harvest the same piece cost 13.07% less, or about $0.3445/$ft^3$. Figure 1 illustrates the impact of piece size on cost/ft^3 by logging system used.

Figure 1 also shows the break-even point (BEP) average piece sizes for each logging system compared. At a fixed stump-to-landing logging cost of about $0.30/$ft^3$, the BEP piece sizes are 4.54 ft^3, 5.66 ft^3, and 9.11 ft^3 for the Holder tractor, CTL and forwarding system, and the Koller K-300, respectively. Loggers could operate in stands of these tree sizes and still break even. Loggers operating in stands with tree sizes that are above the BEP would see a profit. In contrast, in stands where the average piece size is less than the BEP, they would operate at a loss. Piece size is a critical factor in stands where tree size is less than 4.54 ft^3. Looking at the cost-curve segment in Figure 1 by logging system (piece size of 6.00 ft^3 to 10.24 ft^3), we see that costs decrease at decreasing rates (flatter slopes). This suggests that loggers generally will see a profit in stands where the average piece size exceeds the BEP.

LOGGING TECHNOLOGY APPLICATIONS

Small, ground-based skidders such as the Holder A60F, the single-grip CTL processor, and small cable yarders used for thinning and general stand improvement cuttings are feasible. Timing of entry, type of machine, and careful site selection and layout are critical factors for ensuring a profitable operation while minimizing adverse environmental impacts. The significant advantages of the logging technology presented are less soil compaction, ease of movement to and from logging jobs, and minimal damage to the residual stand.

The Holder tractor has good maneuverability over most terrain and in dense, small-diameter stands. It is most efficient in stands with medium to large stems and short skid distances (up to 500 ft). Average volume per turn is about 50 ft^3, and the average daily production is 1,108.0 ft^3 (Table 1). This tractor is a good choice in pole and sawtimber stands on small parcels where large equipment would not be cost effective and would pose a high risk of residual damage.

The CTL single-grip harvester/processor can operate in both the rural woodlot and suburban private and municipal woodlots while meeting environmental and aesthetic objectives and values. It has the advantage of increased tree utilization due to less log-end splitting and well-delimbed logs. A significant advantage of the CTL system, especially in the Northeast, is that it can lay a mat of limbs and debris in front of the machine to travel on; this reduces soil disturbance and compaction, an important attribute in wet and muddy areas. In such conditions, the window of time for logging activity can be increased with no loss in water quality standards and/or Best Management Practices. Also, on-site observations and study data indicate there is less residual stand damage during thinning operations because of the short-wood and forwarder component of the CTL system. Trees can be felled directionally with the machine and whole trees or stems are not pulled through the stand as is usually the case with ground-

Table 1. Estimated mean production for each logging system studied.

Production	*Holder A60F*	*Koller K-300*	*Cut to length*
		ft^3	
Mean daily	1,108.8	3,360.8	1,825.0
Mean annual	277,200	840,200	456,250

based, rubber-tired skidders. Also, the CTL harvester/processor is highly efficient in softwood stands. In a study in which a young hardwood sawtimber stand on a small municipal woodlot was thinned (Huyler and LeDoux 1996), the productivity was about 1,825 ft^3 per scheduled 8-hr day (Table 1).

The CTL system's greatest disadvantages are high initial investment and operating costs. Steep terrain also can slow productivity significantly, and harvesting large hardwood trees can be hazardous because of the possibility of machine rollover from the excessive weight of the tree. Large hardwood trees also cause excessive wear and strain on the processing head of the machine. In a recent test, we found a high incidence of hydraulic line failure during extremely cold weather and deep snow. The hydraulic hoselines became brittle in the extreme temperatures. However, the machine has a high degree of harvesting flexibility: 1) it can be used as a feller-buncher where whole trees are felled and bunched for grapple skidding to the landing; 2) it can process the tree by delimbing in the woods and then using a rubber-tired skidder to move stems to a landing, and 3) it can be programmed to process trees into specific log lengths that will meet specific factory-grade log requirements or pulpwood lengths.

The Koller K-300 is suitable for uphill yarding in steep terrain in precommercial thinnings of small, roundwood products such as firewood and for commercial thinning and selection cuts in young, high-quality sawlog stands. This cable yarder seems to be a good alternative to ground-based skidding in steep terrain (side slope > 30%). It can minimize roading requirements and environmental impacts on excessive slopes compared to conventional ground-based skidding systems. Average daily production for the Koller yarder is about 3,360.8 ft^3 (Table 1). In a study by Huyler and LeDoux (1995) comparing the cost of applying specific water-quality Applied Management Practices on steep slopes, the cost advantage of conventional ground-based skidding over cable yarding was reduced from 30 to 15%. This cost differential will become less important as stumpage prices escalate and more pressure is placed on conventional ground-based technology through regulatory compliance, and in wet soil and other environmentally sensitive areas where restrictions on ground-based technology are required to protect water quality. The greatest disadvantage of cable yarding is that it is more costly than ground-based systems, therefore requiring a multi-product market and/or a site with a large volume of high-quality timber

CONCLUSIONS

The results of this study should be of value to forest planners, loggers, and managers who need to compare and evaluate alternative logging technologies and their limitations for managing and treating northern hardwood stands.

We found that the cable yarder cannot operate profitably within stands with an average piece size smaller than 9.11 ft^3, but this system can be considered for side slopes greater than 30% and where minimal environmental impact is a factor.

The CTL system can operate at a profit in stands with an average piece size of 5.66 ft^3 and larger. It should be considered for wet areas and where soil erosion and compaction is a concern and water quality is an important requirement. This is especially true in some small suburban woodlots.

The Holder tractor can operate in stands with an average piece size of 4.54 ft^3 and larger. This system would be a good choice for thinning small farm woodlots and where there is a strong local market for firewood or wood chips. A word of caution: although the cost per unit or piece is comparable with larger profitable commercial forest operations, the Holder cannot produce sufficient volumes over time to be a sole source of income to the owner. However, combining it with other forestry activities such as prebunching and forwarding to main skid trails or with other farm activities can produce an acceptable level of income. It is sometimes difficult to locate replacement parts for this and similar tractors.

All three logging technologies studied have a light impact on the forest environment—minimal residual stand damage and less soil disturbance and compaction than other systems. Recommended application/conditions for each of these technologies is in Table 2.

Although we only summarized costs and productivity for operations in the Northeast, research is progressing to incorporate the concept of sustainable forests and current environmental regulations in the use of these technologies.

Table 2. Recommended application/conditions for each logging system studied.

Application/Conditions	*System*
A60F Holder tractor	Sideslope < 30%; no production quota, small tract size; average piece size ≥ 4.54 ft^3; short to medium skid distance; low erosion/soil disturbance required; use of low-standard skid trails; low production and profit goals; rated pulling capacity of 6,600 lb.; low residual stand damage required; frequent moves required.
CTL/Forwarding	Sideslope < 30%, high production and profit goals; small or large tracts; average piece size ≥ 5.66 ft^3; medium to long forwarding distance; low erosion/soil disturbance required; use of low-standard skid trails; uniform log lengths and sizes; maximum cutting diameter of 14.0 inches; increased tree utilization required; use in wet soils with mat of limbs to walk on.
Koller K-300 yarder	Sideslope > 30%; moderate to high production and profit goals; medium to large tracts; medium to long yarding distances; very low erosion/soil disturbance required; no skid roads or trails required; use in wet areas with shallow, compactable soils; average piece size ≥ 9.11 ft^3; payload capacity of 3,500 lb.; low residual stand damage required, frequent moves not required.

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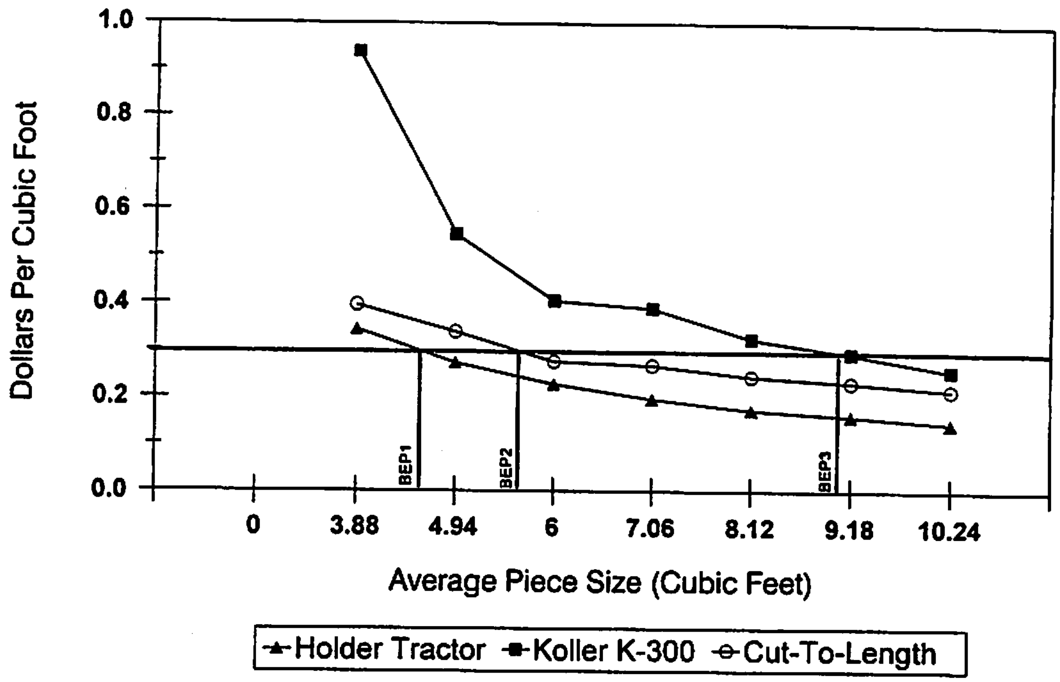

Figure 1.-- Stump-to-landing costs curves for the Holder Tractor, Koller K-300 yarder, and CTL and forwarding system by average piece size. Delay free conditions: for Koller K-300, average slope yarding distance of 400 ft, hourly machine rate is $65.92; for Holder Tractor, slope yarding distance of 1,000 ft, hourly machine rate of $21.75; for CTL system, hourly machine rate is $115; for forwarder, hourly machine rate is $30.

Stand, Harvest, and Equipment Interactions Caused by Harvesting Prescriptions

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ABSTRACT: Partial cutting is increasingly used as a harvesting method to address public concerns about timber harvesting. Such operations, however, increase the difficulty of felling and harvesting trees since less volume is removed and the residual stand must be protected. The interactions of stand types, harvesting methods, and different equipment were evaluated in an experiment using interactive simulation. Three felling methods (chainsaw, feller-buncher, harvester) and two extraction methods (grapple skidder and forwarder) were examined performing clearcuts, shelterwood cuts, and single-tree selection cuts in a natural stand and a planted stand. Elemental times, distances traveled, travel intensity, and productivity estimates were obtained for each combination of stand, harvest, and equipment. Results indicate the relative efficiency and feasibility of using partial cutting instead of clearcutting.

Key Words: partial cutting, timber harvesting, interactive simulation

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INTRODUCTION

Partial cuts increase the difficulty of harvesting and potentially have greater negative environmental impacts. Studying the interactions of stand, harvest, and machine factors and selecting an effective harvesting system are becoming prime concerns to forest managers. Several factors affect the operation of a harvesting system. Tree size, stand density, harvesting prescription, and machine each affect the production and cost (Greene *et al.* 1987a).

The productivity and profitability of individual harvesting machines have been addressed by many researchers (Lanford and Sirois 1983, Tufts *et al.* 1988, Greene and Stokes 1988, Greene and McNeel 1991, Tufts and Brinker 1993a and 1993b). Many of these previous studies examined a single harvest method. A few, however, reported on comparisons and interactions of harvesting systems (Kluender and Stokes 1994, Lanford and Stokes 1995 and 1996, Kluender *et al.* 1996). These side-by-side field comparisons identified differences in harvesting systems.

Field studies, however, are handicapped by the cost of replicating experiments over a variety of conditions. In addition, some influencing factors such as bunch size are not easy to control in the woods. Interactive computer simulation combined with a limited amount of field data overcomes many of these shortcomings.

Many harvesting simulation programs have been developed during last three decades. Goulet *et al.* (1979, 1980a, 1980b) summarized the models available through 1980. Most of the models were deterministic, numerical simulation programs (Martin 1975, Webster 1975, Bare *et al.* 1976, Bradley *et al.* 1976). The activities of a machine in partial cuts were not simulated well by these models since machine restrictions due to stand density, spatial patterns, and harvest prescriptions were not modeled.

Since 1980, more harvesting simulation studies have been reported. Garbini *et al.* (1984) used numerical simulation with graphical animation to illustrate material movement and machine activities in continuous simulation of a log merchandiser. In another decision simulator application, graphical animation and numerical data were used to make log bucking decisions (Lembersky and Chi, 1984). Fridley *et al.* (1982, 1985) and Fridley and Jorgensen (1983) reported the use of graphical interactive simulation for studying the design of swing-to-tree feller-bunchers used for thinning. The program was used to identify the effect of various design parameters on feller-buncher performance during thinning (Fridley *et al.* 1988). An interactive simulation program for modeling feller-bunchers was developed by Greene and Lanford (1984, 1986). Working with this simulation program, Greene *et al.* (1987a) examined the effects of stand and operating factors on the productivity of a small feller-buncher in second thinning operations and concluded that variability between simulation operators existed but did not appear to affect the usefulness of interactive simulation (Greene *et al.* 1987b). Block and Fridley (1990) described a three-dimensional, color, interactive, real-time, computer graphics simulation of a feller-buncher. The program allowed the user to vary physical parameters of the feller-buncher that would affect its performance in the woods. Baumgras *et al.* (1993) presented a simulation model to estimate stump-to-truck production rates and multiproduct yields for conventional ground-based timber harvesting systems in Appalachian hardwood stands. A method of estimating tree damage was also addressed in conjunction with an interactive machine simulation program that could model harvesting performance in a variety of silvicultural operations (Bragg *et al.* 1994). Some of the models since 1980 adopted interactive graphics-based simulation techniques which offer a better method to model the activities of harvesting machines. These programs mainly modeled and simulated the feller-bunchers.

OBJECTIVES

This study used interactive computer simulation to identify and evaluate the interactions of stand conditions, harvest prescriptions, and harvesting machines with a designed experiment. More specifically, the study examined:

1. distance traveled per harvested tree, time per tree, and felling productivity as affected by mean DBH removed, volume per hectare removed, harvest method, and felling machine type;
2. mean extraction distance, mean turn size, cycle time, and extraction productivity as affected by bunch size, volume per hectare extracted, harvest method, and felling and skidding machine; and
3. travel intensity on a logging site as affected by stand, harvest, and machine.

METHODS AND MATERIALS

Data from an intensive experiment using interactive simulation were used to examine the above questions. The simulation program was developed by Wang and Greene (in press). Three harvesting systems (chainsaw felling and grapple skidder, feller-buncher and grapple skidder, and harvester and forwarder) were simulated while performing felling and extracting activities in clearcut, single-tree selection, and shelterwood prescriptions (Figure 1). Felling was simulated on a 0.16-ha (0.4-acre) (40 m by 40 m or 132 feet by 132 feet) square plot. Skidding or forwarding simulations were performed on a larger area (7.84 ha or 19.6 acres) created by replicating the felling plot 49 times. A simulation was performed using a mouse to move the machine image in the stand map for felling or in a logging site for extraction. The activities of machines were recorded and stored for later analysis. Data from the simulation experiments were analyzed statistically to examine the quantitative and qualitative differences among the interactions of stand, harvest prescription, and harvesting system. Differences in mean values of the variables examined were detected by Duncan's multiple-range test.

Four travel intensity categories of extraction travel were used to record the travel intensity within each felling grid and the proportion of each category on a harvested site (Carruth and Brown 1996):

- TI1 Trees on the plot have been felled.
- TI2 Trees which stood on the plot have been removed and no other traffic has passed through the plot.
- TI3 Trees which stood on the plot have been removed and trees outside the plot have been skidded through the plot. Passes with a loaded machine are between three and ten.
- TI4 More than ten loaded machine passes have been made through the plot.

A planted and a natural stand of southern pine were used in experiments with the interactive simulation program. The conditions used to generate these two stands were as follows:

Planted stand
- loblolly pine
- stand density 1000 trees/ha (400 trees/acre)
- stand age 25 years
- dominant height 18 m (60 feet)
- uniform spatial pattern

Natural stand
- loblolly pine
- stand density 625 trees/ha (250 trees/acre)
- q-ratio 1.3
- maximum height in maximum DBH class 18 m (60 feet)
- random spatial pattern

A Weibull distribution was used as the form of DBH distribution of planted stands (Borders *et al.* 1990). The exponential function has been used to characterize the reverse J-shape DBH distributions for natural stands (Moser 1976, Davis and Johnson 1986). Applicable volume equations were used to determine individual stem volume (Clark and Saucier 1990). The stand and stock tables and spatial distributions of trees for two generated stands are presented to show their structures (Figure 2 and 3).

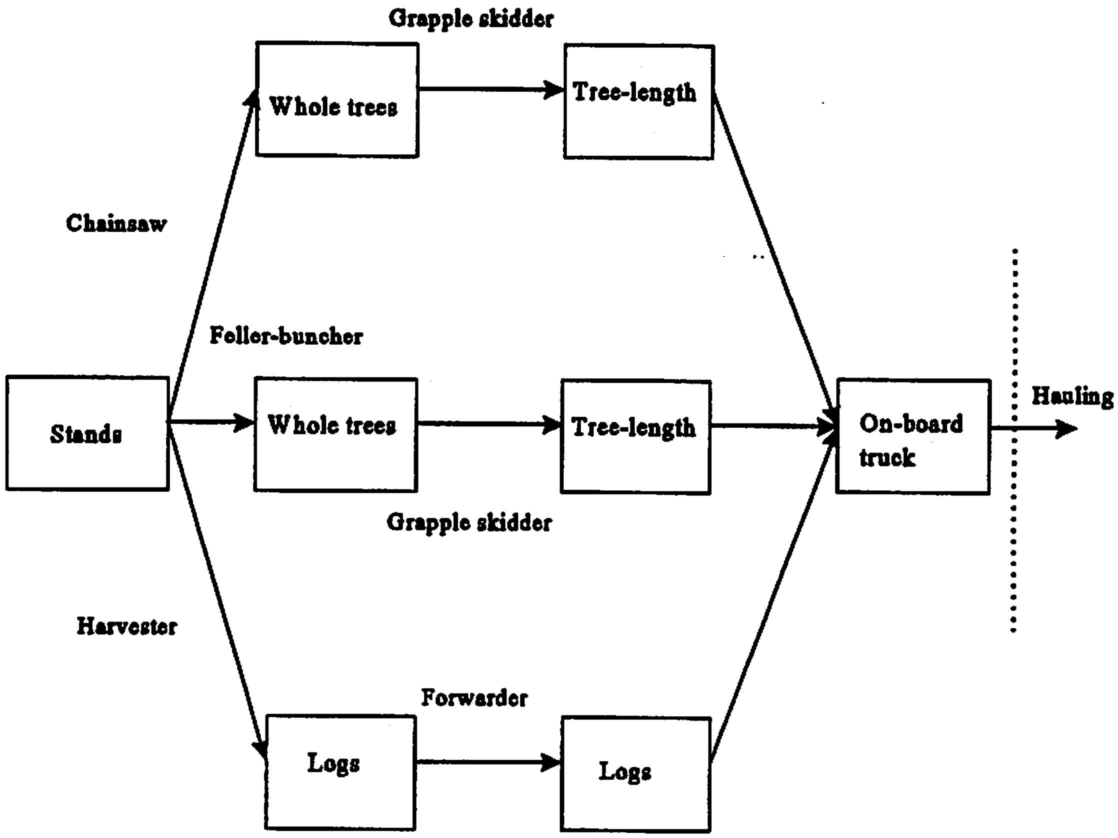


Figure 1. Harvesting systems examined in the experiment.

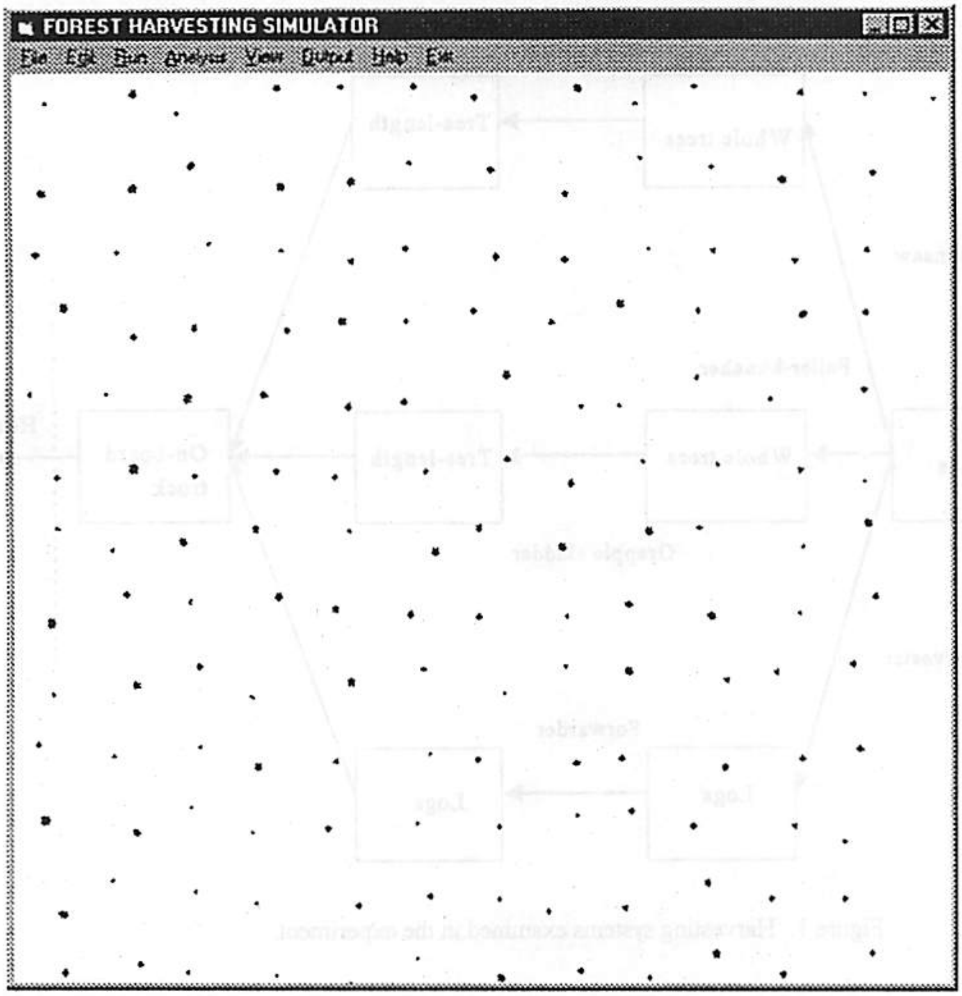
EXPERIMENTAL FACTORS

A controlled experiment was designed. To reduce the learning effects of operator, the experimental order of a simulation run was randomly arranged. The experiments were made by one operator who had significant practice before the experiment.

Factors in the experiment consisted of stand conditions, harvest methods, and harvesting machines (Table 1). There were 18 independent felling simulation combinations of equipment, stand, and harvest prescription. Three repeats of each felling combination were performed, resulting in a total of 54 felling simulation runs. Since the extraction site was a larger area [7.84 ha (19.6 acres)] that represented 49 replications of the felling plot, no repeats of each extraction simulation run were made. However, a two-stage random design was used to choose 18 independent skidding or forwarding simulations from the 54 felling simulation runs so that the extraction simulations could be performed for each of the 18 independent felling simulations.

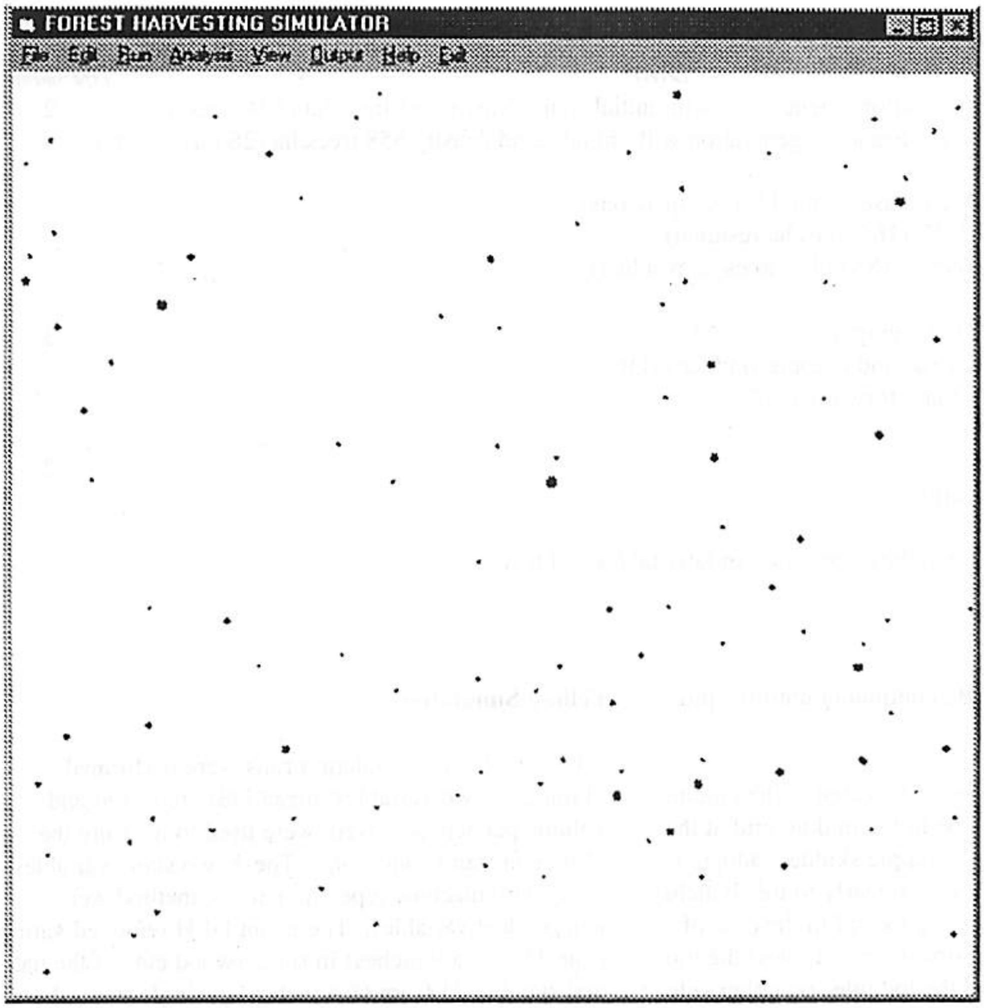
The three harvest prescriptions represented a wide range of harvest strategies. Clearcut and single-tree selection each symbolized an extreme harvesting intensity and shelterwood the intermediate method. The single-tree selection method left 413 trees per hectare (165 trees per acre) in the residual stand. Shelterwood cutting retained 188 trees per hectare (75 trees per acre). These were larger trees that would provide seed for a new, even-aged crop. The clearcut harvest removed all standing trees.

The felling machine was first located at one end of the plot and then moved parallel to a swath of trees. The feller-buncher worked in a strip 5 - 7 m (15-20 feet) wide. A narrower swath (about 3 m wide) of trees was used with manual chainsaw felling as the operator walked along the swath. The cut-to-length harvester moved in a relatively straight trail working in a strip 12 - 16 m (40-50 feet) wide. Trees on either side of the machine and within boom reach could be removed based on the operator's choice. When the machine reached the end of the swath, it turned around and cut



DBH (cm)	Trees/Ha	Total Height (m)	BA/Ha (m^2/Ha)	Volume/Ha (m^3)
10	33	13	0.25	1.82
12.5	87	15	1.08	7.89
15	138	16	2.43	18.23
17.5	175	17	4.23	33.41
20	175	18	5.49	44.35
22.5	150	19	5.96	49.21
25	112	19	5.51	46.17
27.5	63	20	3.71	31.59
30	32	20	2.21	18.83
32.5	13	20	1.04	9.11
35	8	21	0.61	4.86
Total	985		32.51	265

Figure 2. Spatial distribution of trees and stand/stock table for planted stand. (40*40 m, 985 trees/ha)



DBH (cm)	Trees/Ha	Total Height (m)	BA/Ha (m^2/Ha)	Volume/Ha (m^3)
10	163	9	1.28	4.86
12.5	125	11	1.53	6.68
15	95	12	1.67	8.51
17.5	75	13	1.82	9.72
20	57	14	1.78	10.33
22.5	38	14	1.49	9.72
25	32	15	1.53	10.33
27.5	25	16	1.49	10.33
30	20	16	1.33	9.72
32.5	13	17	1.04	7.90
35	8	17	0.61	4.25
37.5	7	17	0.70	5.47
Total	658		16.25	97.81

Figure 3. Spatial distribution of trees and stand/stock table for natural stand. (40*40 m, 658 trees/ha)

Table 1. Variables included in the simulation experiment.

Factor	*Levels**	*Number of experiments*
Stands	plantation (P) of uniform generation with initial stand density 985 trees/ha (394 trees/acre) natural stand (N) of random generation with initial stand density 658 trees/ha (263 trees/acre)	2
Harvests	clearcutting (CC) (base method for comparisons) shelterwood (SW) (188 trees/ha residual) single-tree selection (SS) (413 trees/ha residual)	3
Systems	chainsaw (CS) and grapple skidder (SD) feller-buncher (FB) and grapple skidder (SD) harvester (HV) and forwarder (FW)	3
Operations	felling skidding/forwarding	2

* Abbreviations defined in paratheses are used in later tables and texts.

other trees in the next swath, continuing until the plot was finished.

The extraction machine was first located at the landing. Landings were assumed to be in the middle grid at the bottom of the logging site. Grapple skidders adopted free-style extraction and moved linearly to tree bunches and directly back to the landing except in the case of protecting residual trees. Forwarders followed the trail of the harvester and loaded the log piles on either side of the machine by using their booms.

RESULTS

Stand conditions were the same for the different combinations of harvest prescriptions and machines. Before harvesting, planted stands averaged 21 cm (8.2 inches) DBH and 265 m^3 per hectare (43.6 cords per acre). Natural stands averaged 18 cm (7.1 inches) DBH and 98 m^3 per hectare (16.1 cords per acre). Diameter distributions for planted and natural stands were approximately normal and reverse-J shape before harvests (Figures 4 and 5).

Diameter distributions retained their original shapes after single-tree selection cuts. However, these curves were skewed somewhat after such cuts since the larger trees were removed from the stands. Because the smaller trees were removed in shelterwood cuts, the diameter distribution was shifted forward for planted stands and presented a flat-bell shape for natural stands after such partial cuts.

Felling Simulation

Fifty-four felling simulation runs were performed (Table 2). Two variables, mean DBH removed and volume per acre removed, were used to measure the change in stand conditions. These two stand variables along with machine type and harvest method were independent variables. The mean DBH removed varied from 15 cm (5.9 inches) in shelterwood cuts of the natural stand to 21.6 cm (8.5 inches) in single-tree selection of the planted stand. Volume removed ranged from 41 m^3 per hectare (6.8 cords per acre) in shelterwood cuts to 265 m^3 per hectare (43.6 cords per acre) in clearcuts.

Means and significance levels of some variables by stand, machine, and harvest factors were also compared (Table 2). Stand, machine, and harvest all affected these variables significantly at the 5% confidence level. Due to the higher density, larger DBH, and greater volume per acre removed in planted stands, distance traveled per tree was shorter, time per tree was greater, and volume per productive machine hour (PMH) was greater than in natural stands during felling operations. The distances traveled per tree were not significantly different in chainsaw and feller-buncher felling but both were greater than in harvester felling. Felling a tree with manual chainsaw took more time than felling with a feller-buncher or a harvester. Correspondingly, the feller-buncher was more productive than the harvester or the chainsaw.

Since only two stands were considered in the study, the effects of stands on these variables were shown clearly

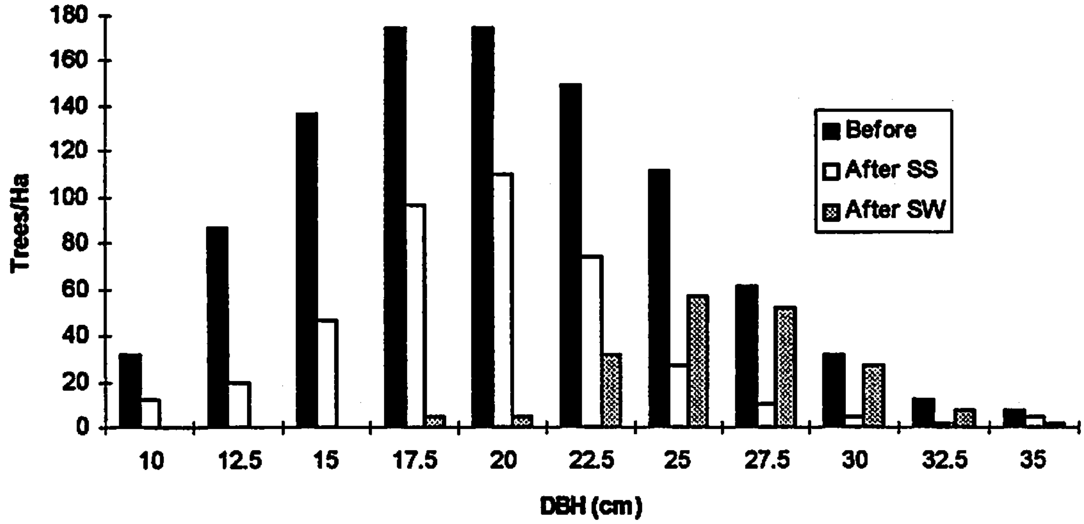


Figure 4. DBH distributions for planted stand before harvest and after single-tree selection (SS) and shelterwood(SW) cuts.

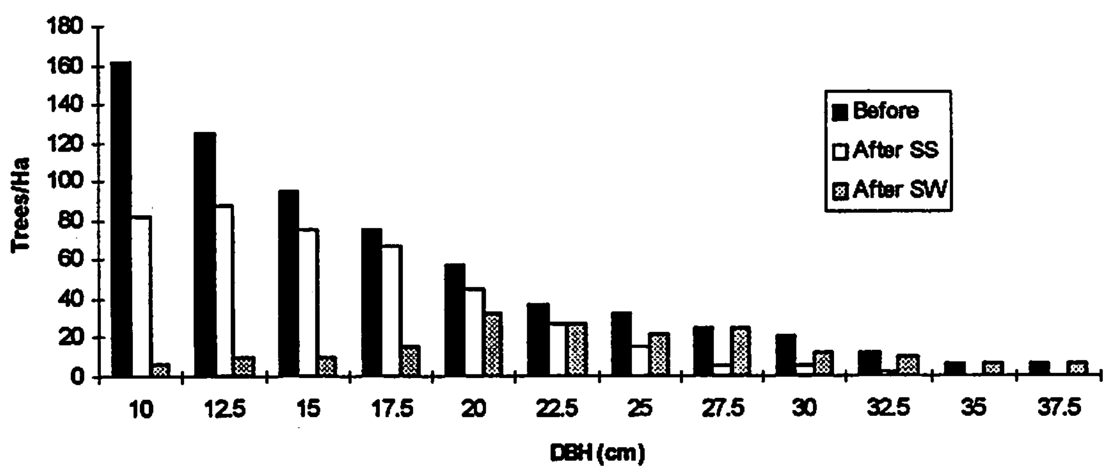


Figure 5. DBH distributions for natural stand before harvest and after single-tree selection (SS) and shelterwood (SW) cuts.

Table 2. Means and significance level of stand and operating variables in felling simulation.

	Stand		*Machine*			*Harvest*		
	Natural	*Planted*	*Chain saw*	*Feller-buncher*	*Harvester*	*Clear cuts*	*Shelter-wood*	*Single-tree*
DBH removed, cm	18	21	19.1	19.1	19.3	20	17.3	20.8
	A	B	C	C	C	D	E	F
Volume/ha removed, m^3	62.0	200.5	130.6	132.4	130.6	179.2	109.4	105.7
	A	B	C	C	C	D	E	E
Distance traveled per harvested tree, m	3.9	3.03	4.0	4.1	2.3	2.9	3.3	4.2
	A	B	C	C	D	E	F	G
Time per tree, min.	0.65	0.75	1.22	0.29	0.60	0.70	0.63	0.77
	A	B	C	D	E	F	G	H
Trees/min.	2.2	1.8	0.8	3.5	1.7	2.0	2.3	1.8
	A	B	C	D	E	F	G	H
Volume/PMH, m^3	18.2	27.9	9.7	39.4	20.4	24.1	19.9	25.3
	A	B	C	D	E	F	G	H

*Means with the same letter in a row are not significantly different.

(Table 2). Three variables, distance traveled per harvested tree, time per tree, and volume per productive machine hour (PMH), were used to illustrate interactions of stand, machine, and harvest factors (Table 3). These three variables were comparable among stands, machines, and harvests.

Distance Traveled per Harvested Tree: The distance traveled per harvested tree mainly depended on stand density, harvest intensity, and harvesting machine (Table 3). It increased as stand density or harvest intensity decreased. The harvesting methods here also represented different level of harvest intensity. Distance per harvested tree increased as the harvest varied from the clearcut to single-tree selection. The travel distance per tree of the drive-to-tree feller-buncher was longer than that of other two machines. This was because a chainsaw operator could walk

Table 3. Operating variables affected by machine and harvest in felling simulations.

Harvest	*Chainsaw*	*Machine* *Feller-buncher*	*Harvester*
		Ground travel distance per harvested tree, m	
Clearcuts	3.42	3.78	1.62
Shelterwood	3.81	3.87	2.25
Single-tree	4.71	4.71	3.00
		Time per tree, minute	
Clearcuts	1.22	0.29	0.58
Shelterwood	1.09	0.26	0.57
Single-tree	1.35	0.33	0.64
		Volume per PMH, m^3	
Clearcuts	10.11	40.68	21.17
Shelterwood	8.60	34.55	16.96
Single-tree	10.42	42.84	22.79

directly from one tree to another tree to be felled and the harvester could select and cut a tree by swinging the boom. Distance traveled per tree with chainsaw felling varied from 3.42 to 4.7 m (11.4 to 15.7 feet). Harvester felling gave the least ground travel distance per harvested tree, ranging from 1.6 to 3.0 m (5.4 to 10.0 feet).

Time per Tree: Stand, machine, and harvest factors all affected the time per tree significantly (Table 3). Time per tree was directly related to the mean DBH of the tree removed and inversely related to the harvest intensity. Since the quadratic mean DBH removed in the single-tree selection method was larger than that in the clearcut, time per tree was correspondingly greater than that with clearcutting. Similarly, time per tree in the shelterwood was less than in clearcuts since smaller trees were removed.

Chainsaw felling needed much more time (1.09 to 1.35 minutes) to cut one tree compared to the two harvesting machines. The feller-buncher took between 0.26 and 0.33 minutes to fell a tree. Because the harvester performed both felling and processing, its time per tree was nearly double that of the feller-buncher and ranged from 0.58 to 0.64 minutes per tree.

If considered as trees per minute (the reciprocal of time per tree), the same factors were important but gave inverse trends. Obviously, the smaller the tree, the more trees per minute could be cut. Due to this effect, trees per minute in the shelterwood method was higher than in clearcutting or single-tree selection. Trees per minute in single-tree selection was the lowest. Trees per minute of chainsaw felling ranged from 0.75 in single-tree selection to 0.94 in the shelterwood method. The feller-buncher produced 2.99 to 3.48 trees per minute, and the harvester 1.55 to 1.79 trees per minute, depending on harvesting methods and stand characteristics.

Volume per Productive Machine Hour: Volume per PMH was affected by stand, machine, and harvest at the 5% significance level (Table 3). In addition, volume per PMH was also directly related to tree size to be harvested, bunch size, and harvesting intensity. The productivity of chainsaw felling was the lowest and varied from 8.4 m^3 (3.45 cords) per PMH in shelterwood cuts to 11.2 m^3 (4.29 cords) per PMH in single-tree selection. Again, since the cut-to-length harvester also processed trees, its productivity of 17.0 to 22.8 m^3 (6.98 to 9.38 cords) per PMH was lower than the feller-buncher. The feller-buncher presented the highest productivity among these three felling machines, ranging from 34.6 to 42.8 m^3 (14.22 to 17.63 cords) per PMH. Productivity was very sensitive to the tree size harvested. Therefore, single-tree selection was the more productive method among the three cutting methods because of larger trees removed. The productivity of clearcut method was very close to that in single-tree selection, and the shelterwood method presented the lowest productivity.

Skidding/Forwarding Simulation

The same volume felled and bunched during felling was extracted to the landing during skidding or forwarding operations. For the sake of operational feasibility and efficiency of simulation, the number of trees in a bunch size for extraction following chainsaw or harvester felling was six, while for extraction following the feller-buncher it was three piles. Bunch size for extracting ranged from 0.51 m^3 (0.21 cords) in the shelterwood method of natural stand to 1.75 m^3 (0.72 cords) in single-tree selection of planted stands (Table 4).

Volume per acre removed and bunch volume were used as additional independent variables for comparisons among interactions. No significant difference in volume per acre extracted existed among the three harvesting systems. This value, however, did vary by the harvest method and stand. Bunch size was not significantly different among the three harvesting systems.

Volume per turn is another control variable in extraction. Stand and harvest could affect the volume per turn of the machine. Volume per turn, however, mainly depended on the machine's capacity. Due to residual stands and the bunch location, the skidder or forwarder might be driven back to landing without reaching its full capacity. The volume per turn of grapple skidder was controlled between 1.58 and 1.77 m^3 (0.65 and 0.73 cords) per turn. The loads of forwarder per turn were 9.43 to 9.94 m^3 (3.88 to 4.09 cords). The large payload of the forwarder meant that it needed fewer passes over the logging site to move logs to the roadside deck.

Volume per PMH in clearcuts and single-tree selection were also not significantly different due to the similar bunch size. Similarly, the effects of stands on these variables were clearly expressed. Average skidding distance, loads per turn, cycle time, volume per PMH, and proportion of skidder or forwarder travel intensity category by machine and harvest were analyzed further to illustrate the skidding or forwarding operations and their interactions.

Average Skidding Distance: Average skidding distance was affected by stand, machine, and harvest, especially, by machine holding capacity (Table 5).

Table 4. Means and significance level of operating variables in extraction simulation.

	Stand		Felling machine			Harvest			Extraction machine	
	Natural	*Planted*	*Chain-saw*	*Feller-buncher*	*Harvester*	*Clearcut*	*Shelter-wood*	*Single-tree*	*Grapple skidder*	*Forwarder*
Volume/acre removed, cords	25.71	76.86	51.0	51.61	51.39	70.54	42.28	41.04	51.22	51.39
	A	B	C	C	C	D	E	E	F	F
Bunch size, m^3	0.97	1.51	1.31	1.14	1.26	1.26	0.97	1.46	1.24	1.26
	A	B	C	C	C	D	E	D	F	F
Volume/turn, m^3	4.16	4.50	1.68	1.68	9.60	4.28	4.25	4.47	1.68	9.60
	A	B	C	D	E	F	G	H	I	J
Average skidding distance, m	206	176	145	151	278	182	203	188	148	278
	A	B	C	D	E	F	G	H	I	J
Cycle time, min.	13.97	11.47	7.63	7.18	23.35	12.12	14.11	11.92	7.40	23.35
	A	B	C	D	E	F	G	H	I	J
Volume/PMH, m^3	15.28	20.46	13.66	15.02	24.98	18.49	15.84	19.29	14.34	24.98
	A	B	C	D	E	F	G	F	H	I
Travel intensity 2, %	33	23	32	31	21	25	33	26	31	21
	A	B	C	C	D	E	F	E	G	H
Travel intensity 3, %	29	17	8	13	47	20	21	27	11	47
	A	B	C	D	E	F	G	H	I	J
Travel intensity 4, %	38	60	60	56	32	55	46	47	58	32
	A	B	C	D	E	F	G	H	I	J

*Means with the same letter in a row are not significantly different.

Within the specified logging site in the study, the average skidding distance under chainsaw felling was 138 to 148 m (459 to 487 feet). In the feller-buncher felling plot, the average skidding distance was a little bit longer than that with chainsaw, from 149 to 157 m (498 to 524 feet). This was mainly due to the different bunch size in such felling plots. Since the forwarding pattern and payload were very different from the skidding used in the simulation, the average forwarding distance varied from 253 to 303 m (843 to 1009 feet) and was longer than the average skidding distances in the logging sites with chainsaw and feller-buncher felling. The average skidding distance was also very sensitive to harvest methods and harvest intensity.

The shelterwood method removed relatively smaller trees and resulted in smaller bunch size. Consequently, the skidder or forwarder needed to move forward and pick up more smaller bunches to meet its capacity and resulted in a longer skidding/forwarding distance. The single-tree selection method with lower harvest intensity could have longer distances between bunches and sometimes resulted in a longer skidding distance than that in clearcuts.

Cycle Time: The cycle time of skidding or forwarding was summarized by machine and harvest (Table 5). The skidding cycle time in the chainsaw felling plot was 6.95 to 8.53 minutes. The cycle time of skidding

Table 5. Operating variables affected by machine and harvest in extraction.

Harvest	*Chainsaw Grapple skidder*	*Machine Feller-buncher Grapple skidder*	*Harvester Forwarder*
		Volume per turn, m^3	
Clearcuts	1.70	1.70	9.43
Shelterwood	1.58	1.73	9.45
Single-tree	1.77	1.70	9.91
		Average extraction distance, m	
Clearcuts	146	147	153
Shelterwood	150	157	303
Single-tree	138	149	278
		Cycle time, minute	
Clearcuts	7.42	6.68	22.28
Shelterwood	8.53	8.39	25.42
Single-tree	6.95	6.47	22.35
		Volume per PMH, m^3	
Clearcuts	14.12	15.82	25.54
Shelterwood	11.52	13.24	22.77
Single-tree	15.31	16.00	26.63

with feller-buncher felling ranged from 6.47 to 8.39 minutes and was slightly lower than that with chainsaw felling due to its smaller bunch sizes. The cycle time of the forwarder ranged from 22.28 to 25.42 minutes and was higher than skidder's, due to higher holding capacity of the forwarder, which took longer time for loading and unloading. Harvest methods with different bunch sizes and harvest intensity required different time to complete a work cycle. The lower the bunch size and harvest intensity, the more the cycle time of skidding or forwarding would be.

Volume per Productive Machine Hour: Volume per PMH was associated closely with stand, machine, and harvest factors (Table 5). This variable was also very sensitive to bunch size and harvest intensity or number of bunches in a skidding site. The productivity of skidding with chainsaw felling was 11.52 to 15.31 m^3 (4.74 to 6.30 cords) per PMH and with feller-buncher felling 13.24 to 15.92 m^3 (5.45 to 6.55 cords) per PMH, higher than with chainsaw felling due to its lower piling time while grabbing loads. Productivity of the forwarder with harvester felling varied from 22.77 to 26.63 m^3 (9.37 to 10.96 cords) per PMH.

Harvest methods did affect the extraction productivity. Extraction in a single-tree selection cutting area showed higher productivity because this method removed larger trees. Extraction in the shelterwood cutting area gave lower productivity. However, skidding or forwarding productivity in the clearcut area also presented the competitive productivity due to relatively larger bunch size and shorter distances between bunches.

Proportion of Skidder Travel Intensity Category: The proportion of travel intensity category was defined as the number of felling grids (0.16-ha) in each travel intensity category over the total number of grids (7*7 felling grids, 7.84 hectares) in a logging area. It was used to evaluate how machine and harvest methods affect the travel intensity (Table 6). The travel intensity category 4 (TI4) was the level of most concern since it caused the most damage to the soil.

No difference in travel intensity existed between skidding in chainsaw and feller-buncher felling areas. About 50% of the logging site was in TI4 after skidding and 30% after forwarding. The proportion of TI4 of forwarder was lower than that of skidder since the forwarder's higher holding capacity resulted in fewer passes to extract logs. The areas of TI4 after forwarding were also smaller than that after skidding.

Harvesting methods also affected the travel intensity. Since clearcut produced more bunches with higher cords per acre, the proportion of TI4 in the clearcutting area was higher than in single-tree selection and shel-

Table 6. Proportion of felling grids in each travel intensity category by machine and harvest after felling and extraction.

Harvest	*Travel intensity*	*Chainsaw Grapple skidder*	*Machine Feller-buncher Grapple skidder*	*Harvester Forwarder*
		(%)		
Clearcuts	TI1	0	0	0
	TI2	27	27	22
	TI3	6	10	43
	TI4	67	63	35
Shelterwood	TI1	0	0	0
	TI2	35	35	29
	TI3	7	11	45
	TI4	58	54	26
Single-tree selection	TI1	0	0	0
	TI2	35	30	14
	TI3	11	18	53
	TI4	54	52	33

terwood cutting areas. Due to smaller bunch size in the shelterwood cutting area with lower cords per acre, the proportion of TI4 was lower in this logging site. If a smaller grid size is used, the accuracy of travel intensity in each grid will be improved in the extraction plot. The proportion of TI4 will be decreased because the number of loaded machine passes in a larger grid is divided into several smaller numbers in smaller grids.

SUMMARY AND CONCLUSIONS

The most important factors affecting felling productivity were mean DBH removed, harvesting intensity, and harvest method.

Chainsaw felling required 1.09 minutes per tree in shelterwood harvests compared to 1.35 minutes per tree in single-tree selection. These figures were about 0.3 minutes lower than the 1.36 to 1.61 minutes per tree reported by Kluender and Stokes (1994) since the mean DBH removed in this simulation [15 to 22 cm (5.9 to 8.5 inches)] was much smaller than in their study [29 to 30 cm (11.4 to 11.7 inches)]. The feller-buncher produced 2.99 trees per minute in single-tree selection versus 3.48 trees per minute in shelterwoods. These rates compare favorably to those reported by Lanford and Stokes (1996). Volume per PMH was closely related to the tree size harvested, bunch size, harvest intensity or method, and felling machine. The feller-buncher produced more volume per hour in all harvest settings than the other alternatives. However, the harvester not only felled but also processed trees. Thus its productivity of 16.96 to 22.79 m^3 (6.98 to 9.38 cords) per PMH was lower than feller-buncher's but was within the range of 16.86 to 30.33 m^3 (6.94 to 12.48 cords) per PMH reported by Tufts and Brinker (1993).

Skidding or forwarding operations were significantly influenced by volume per hectare extracted, bunch size, harvest, and machine type. Average skidding or forwarding distance was also determined by the extraction pattern, size of logging site, and deck location. In this 7.84-ha (19.6-acre) logging site, average skidding distance ranged 138 to 157 m (459 to 524 feet) and forwarding 253 to 303 m (843 to 1009 feet) depending on harvest method. Loads per turn were determined by machine capacity and in turn determined machine productivity. Grapple skidder loads ranged from 1.58 to 1.77 m^3 (0.65 to 0.73 cords) and forwarder loads from 9.43 to 9.94 m^3 (3.88 to 4.09 cords). The type of felling machine used and the harvest method each affected extracting productivity. Skidding production rates following chainsaw felling varied from 11.52 m^3 (4.74 cords) per PMH in shelterwood to 15.31 m^3 (6.30 cords) per PMH in single-tree selection. Skidding production following feller-buncher felling ranged from 13.24 to 15.92 m^3 (5.45 to 6.51 cords) per PMH. Forwarder productivity following harvester felling presented higher productivity of 22.77 to 26.63 m^3 (9.37 to 10.96 cords) per PMH.

About 50 percent of logging area reached travel intensity category 4 after skidding. However, only about

30% of this area reached travel intensity category 4 after forwarding. From this point of view, the harvester and forwarder system could have less impact on logging sites and residual trees than the other two systems.

Effects of stand, harvest, and machine factors on system cost and production are also under examination but were not ready for inclusion in this paper. Other factors that should be considered in future studies include the effect of deck location and alternative machine operating patterns.

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Forest Restoration in Southwestern Colorado

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ABSTRACT: The Ponderosa Pine Forest Partnership in southwestern Colorado is investigating the feasibility of restoring a ponderosa pine forest ecosystem to an 1870s pre-settlement condition and reintroducing fire as part of the ecosystem process on the San Juan National Forest. The Partnership is a cooperative effort of federal agencies, state and local government, the Colorado State University system, and the Colorado Timber Industry Association. The project involves both economic and environmental studies. This paper describes the economic and policy portions of the study of harvesting efficiencies and attempts at development of markets for small-diameter pine.

Key Words: forest restoration, timber harvesting, ponderosa pine

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Introduction

In 1993, the Ponderosa Pine Forest Partnership was formed in response to problems associated with pine forests and rural development in Montezuma County, Colorado. Members include Montezuma County, the San Juan National Forest, Renewable Resources Staff, Region 2 USFS, Colorado State Forest Service, Ft. Lewis College, Colorado State University Extension Service, the College of Natural Resources, and the Colorado Timber Industry Association. These groups are working together to develop a forest restoration project that will improve the ecology of a ponderosa pine (*Pinus ponderosa*) forest and create viable economic development in Montezuma County.

At the turn of the century, the original, natural forest in Montezuma County was railroad logged. The logged area was left to naturally regenerate and shortly thereafter was included in the National Forest system by Presidential proclamation. The forest was protected from fire, logging, insects, diseases, and other disturbances. Attempts at forest management were limited.

Over the years, the forest regenerated, became quite dense, and many of the trees became deformed. The quality of the trees was so poor and their size so small that no significant markets existed for use of the wood. This became a concern to the county, which sought to encourage rural development and jobs for its citizens. Insects, disease, and especially wildfire became significant forest management problems.

During the 1990s, Dr. William Romme of Ft. Lewis College began conducting fire ecology research on the San Juan National Forest, determining that fire had been an integral part of the original forest ecosystem which existed prior to the 1870s. In the area described in this paper, he found that from 1729 to 1879 there had been a median fire frequency of 10 years with a range from 2 to 31 years. He also found that there had not been a fire in this specific area in the last 100 years, a significant change from the fire frequency of the previous 300 years.

His research further determined that the original forest was structurally much different than the present forest. The original forest consisted of small groups of large, old growth ponderosa pines surrounded by openings of grass and forbs. Unlike the present, very little oakbrush (*Quercus gambelli*) existed in the understory (Romme 1996). His findings stimulated interest in restoring the forest to its pre-settlement condition. But many of the small diameter, deformed trees in the forest would have to be removed.

Thus the San Juan National Forest, as are many other National Forests in the West, was at a crossroads. Forest health issues related to wildfire and insect epidemics are endangering forest ecosystems. Rural communities are struggling because of the changes in the availability of timber supply. In this case, the pine-oak forests in Southwest Colorado are overstocked compared to historic stand conditions, but this translates to low value, small diameter material for which there is little market demand. In addition, the declining forest industry of the area is primarily geared to utilize large diameter pine. These concerns, coupled with the rising interest in forest restoration associated with Dr. Romme's work, appeared to present an opportunity to try a new forest management strategy.

The Ponderosa Pine Forest Partnership was formed. Previous timber sales incorporating small-diameter material had been rejected as too risky by the forest industry and typically had gone no bid. Therefore, Montezuma County purchased an administrative timber sale from the U.S. Forest Service. The sale contained five units and was offered as a research and demonstration study sale at reduced stumpage rates to determine the potential for forest restoration and its contribution to the rural economy.

Study Sale Objectives

Layout and preparation of the study sale was under the direction of Forester Phil Kemp of the Dolores District of the San Juan National Forest. In cooperation with Dr. Romme, Mr Kemp instructed the timber markers in the ecological prescription suggested by Romme's research. The larger, older trees were marked for retention in groups. All trees 5 inches dbh and up outside the groups were left for removal. Regional oversight and assistance in timber sale appraisal and contract development came from Lawson Starnes, Program Manager for Timber Sale Preparation in Region 2 of the Forest Service, USDA.

The objectives for this study sale are stated in the contract between Montezuma County and the U.S. Forest Service. These objectives, as provided to the researchers in this study, are as follows:

> Research and Demonstration Project Requirements: Purchaser shall conduct the following studies and shall be responsible for all incurred costs of the studies including any costs related to wood chipping, transportation, data gathering, materials and supplies, and final report preparation:
> Logging Production Analysis: The purchaser shall establish fall, buck and skid production rates, and costs for large sawtimber, small sawtimber, and products other than logs categories. Separate production rates shall also be compiled for each equipment type used in the administrative study, e.g. feller buncher, shears, conventional logging methods.
> Product Sorting: The purchaser shall sort at the landing logged materials into the following product categories: sawlogs, posts and poles, chips to be utilized in other value-added products, residual biomass to be used for energy production.
> Purchaser shall estimate the time and cost of product sorting and the total volume of materials derived by product category, by harvest unit. Purchaser shall also document the destination and quantity of log flows to manufacturing facilities. (Special Contract Provision, R2-CT6.69-8/95).

In addition, the study was to analyze policy barriers to forest ecosystem restoration on federally managed land in southwestern Colorado.

Study Design and Analysis Procedures

The Department of Forest Sciences, Colorado State University, was asked by Montezuma County, the Forest Service, and the Colorado Timber Industry Association to assist in the development of a timber harvesting study for the sale to examine products, markets, harvesting efficiency and costs. The principal researchers for the study are Dr. Dennis L. Lynch, professor, and Catherine Jones, research associate. Field data collection and observations were conducted from August 1995 to December 1996. Data analysis is still underway at the time of submission of this paper. Unit 1 of the sale, containing 125 acres, was considered a trial unit to develop an understanding of study variables and harvesting methods. The scope and intensity of the study was limited by the budget and resulted in the employment of only one field observer.

An actual count by diameter class of all trees felled was made by the cutters doing the felling. Skidder operators also made an actual count by diameter class of logs per turn and the number of turns per day. These data were collected each day, field checked, and recorded in a spread sheet by the field observer. In addition, cycle times were collected randomly to check felling, limbing, and bucking times as well as skidding turn times. The loader operator kept a record of the number of logs per load and loads per day from the sale. Trucks passed over a certified scale, and the gross, tare and net weights for each truck were recorded. Samples of trees were taken from the deck prior to loading to determine cubic foot volume and weight relationships.(Markstrom *et al.* 1982) These were used to convert truck weights into cubic foot volumes for Unit 1. In subsequent units, a certified Forest Service scaler scaled loads of POL and sawlogs to determine weight-volume relationships.

Costs for harvesting and transportation activities were based on actual costs experienced by the operator. Thus, actual counts, weights, costs, and product values were utilized as a basis for the study. Comparisons were made between product values, logging costs, and measurements to determine the relationship of data from this unit with similar situations in other areas. During the analysis, many different relationships of data were examined to determine harvesting efficiency, potential alternatives, the effects of estimates versus actual amounts, and profit (loss) results.

Logging System Operation

Unit 1 was purchased from Montezuma County and logging was accomplished by Ragland & Sons Logging, a family owned and operated business located in Dolores, Colo. Since Unit 1 was the key demonstration unit for the sale, felling was accomplished using chainsaws to insure that no damage occurred to the residual stand and that a proper fuel bed was developed for prescribed burning of the slash. Typically, three to four saws were operated, and trees were directionally felled to avoid damage to the residual stand. The cutters were very aware that this was a demonstration unit and that appearance of the area was important, so stumps were flush cut with the surface of the ground. Limbing and bucking were done at the stump with chainsaws. Slash was scattered to create a relatively uniform fuel bed.

Skidding was done by a Cat 518 and JD 540 rubber tired skidders that were equipped with swinging grapples. Usually both skidders were in operation. Skidder operators had to search for logs lying in the slash, and the skidder operator would have to make a turn by moving logs together. Logs were not sorted, and the skidder would bring in whatever comprised a turn regardless of whether it was sawlogs or small diameter material. Skidding distances were typically about 200 to 250 ft to a spur road that had been constructed through the unit by a road grader. Unit road construction simply consisted of blading a clear area over the surface of relatively flat ground. Decks were built perpendicularly to the roads. The skidder would place a turn in the deck and then use its blade to push logs up into the deck. A knot bumper worked at the deck, taking off limbs that were not cut during limbing in the woods and bucking any material broken in the process of skidding and decking.

Loading was conducted by a hydraulic knuckle boom loader on a truck chassis. Conventional log trucks would park on the unit spur road, and the loader would swing logs on to them from the deck. The loader sorted the logs by product, which in this unit consisted of waferwood for an oriented strand board plant, pine excelsior logs, and sawlogs. If there were not enough waferwood logs in a deck to make a load, the truck and the loader would move forward to the next deck and the load would be completed there. Two or three moves were necessary in some cases to complete a load. Thus, trucks were delayed until this was completed. Waferwood and excelsior loads consisted of 5- to 11.9-inch material plus any 12+ inch material that was too deformed to make efficient sawlogs.

Hauling was to the Louisiana Pacific waferboard plant in Olathe, to Western Excelsior in Mancos, or to the Stonertop sawmill near Dolores. All trucks were weighed and logs per load were counted.

Comparison of Logging Costs with Other Studies

One of the concerns in this study relates to the justification of logging efficiency in Unit 1. To analyze logging costs, comparisons were made with other studies and data from USFS cost collection.

Three other studies were utilized. One was from the Mescalero Apache Reservation in New Mexico where ponderosa pine was harvested for chips for the liner board plant in Snowflake, Ariz (Watson and Stokes undated). Another study from eastern Oregon involved the production of biomass for power generation from two stands and the production of sawlogs from a third stand (Hemphill 1989). A third study by the NEOS Corporation for the Fort Apache Timber Company in Arizona considered costs in biomass production (NEOS Corporation, McTague 1994).

When comparing to costs in those studies, the logging costs for waferwood were found to be typically higher. However, logging costs for the sawlog material in Unit 1 appeared quite competitive with costs in the studies. Thus, the logging costs experienced in Unit 1 were considered to be at an acceptable level, given the technology used.

Comparison of Stump to Truck Logging Costs with Regional Average Costs

Costs compiled by the U.S. Forest Service in Region 2 for the Central Rocky Zone and listed in the Timber Appraisal Handbook (FS Handbook 2409.22 1995) indicated a total average regional logging cost of $60.35 per CCF for felling, bucking, limbing, lopping, skidding, loading, and overhead. Total actual waferwood costs for the same production elements in Unit 1 were $59.94/CCF ($16.70/ton), while total sawlog costs were $55.52/CCF ($15.47/ton). Thus, Unit 1 costs were less than the average costs experienced in the Region, supporting the belief that the logging costs for this Unit were reasonable but could be reduced even more.

Revenues, Costs, and Profit (Loss) by Product and Destination

Three types of products were realized from the trees cut in Unit 1. These were waferwood, pine excelsior, and sawlogs. Both waferwood and excelsior were trial markets, since ponderosa pine had not been previously used by either of the manufacturing plants. The following is a summary of the profit and loss for these products.

Waferwood:
Revenue: $31.00 per ton
Total Costs (stump to mill): $34.36 per ton
(Loss): $-3.36 per ton
Total Amount Cut: 2,322.75 tons
Loss for this product: $-7,804.44

Excelsior:
Revenue: $17.00 per ton
Total Costs (stump to mill): $26.65 per ton
(Loss): $-9.65 per ton
Total Amount Cut: 145 tons
Loss for this product: $-1,399.25

Sawlogs:
(Since the logger also owned and operated the sawmill, the sawlogs delivered to the mill were valued by use of transaction evidence from other mills. Sawmills from Espanola, N.M., to Grand Junction, Colo., that utilize ponderosa pine were contacted and their price information analyzed. On the basis of that study, the following revenue and cost information emerged.)
Estimated Revenue: $32.69 per ton
Total Costs (stump to mill): $28.10 per ton
Profit: $ 4.59 per ton
Total Amount Cut: 1,232.76 tons
Profit for this product: $5,658.37

Note that this is an estimate of the potential value and profit that could have been realized if the logs had been sold for fair market value to a buyer at the Stonertop mill location. It is a "paper profit" estimate and not a record of an actual transaction. Since two existing markets for sawn material were lost, the logs were not milled until almost a year later and the owner reported that the market declined during that time.

It was, of course, disappointing that the first unit was not economically profitable. However, this was not unexpected. All parties knew that there were substantial risks in harvesting the small diameter, deformed trees and developing a market for them.

We now are completing the analysis of costs and revenues on four other units in the sale. Preliminary figures indicate that a profit was only achieved in one unit and that losses were substantial in the other three units. On the other hand, there were several aspects of the experience that could be counted as progress toward understanding the problems associated with southwest pine forest restoration.

Policy Barriers to Forest Restoration

Understanding existing federal land policy is key to developing viable new approaches to forest management. Current Forest Service policy favors "tree measurement" sales with payment based on cruise estimates rather than log scaling.

Risk to purchasers is higher with this method because of the potential that a sale may cut out short of the estimated volume. This risk is further accentuated in forest restoration sales where the coefficient of variation can be exceptionally high due to the diverse nature of the material to be removed. Tree measurement sales also are more expensive for the Forest Service to prepare than scaled sales. Given the low value nature of the material removed, the risks of volume estimates, and the expense incurred with such sales, this study is assessing the use of total weight scaling to reduce costs and risk. At this point, the results have been sufficiently encouraging to result in a change in policy to allow weight scaling in low-value forest restoration sales.

The National Forest Management Act of 1976 requires that designation, marking when necessary, and supervision of harvesting be conducted by persons employed by the Secretary of Agriculture who have no personal interest in the purchase or harvest of products. Cut or leave trees are normally marked with paint above and below stump height in Individually Tree Marked (ITM) units.

While this is a long-established practice in partial cut situations, it is also results in significant preparation costs for the Forest Service. In forest restoration projects the designation of low-value material using paint can become very expensive. Thus, designation by prescription may be a more appropriate and cost effective method for many forest restoration projects where weight scaling is used and where silvicultural objectives are simple and clear.

Recent Forest Service policy requires the valuation of timber using transaction evidence procedures instead of the residual value method. The shift to transaction evidence eliminated the requirement to conduct expensive logging cost collection and mill recovery studies. However, this study points out the need to have accurate logging cost and value recovery data when designing forest restoration projects where market data for small diameter and multi-product materials lack well-developed markets.

Another concern related to forest restoration projects is that Forest Service timber sale program accomplishment is measured by volume offered instead of volume sold or area treated. Measuring volume sold or the area of forest restored to a desired ecological condition would provide additional incentive to develop viable restoration projects and avoid "no-bid" situations. Forest restoration projects have to be carefully designed to achieve break-even results.

Reduced federal budgets make conventional service contracts that pay for thinning unfeasible. Commercial timber sales, where appropriate, can help improve cost effectiveness but restoration projects typically lack quality sawlog material. Where sawlog material is limited and small diameter material dominates, particular care must be given to developing sales which balance higher value material against low-value material. Thus, sales of sawlog material in areas in need of forest restoration may achieve accomplishment targets but diminish the prospects for future restoration of the area.

Appraisals must also recognize the higher logging costs associated with small material, especially where additional sorting and long hauls to multiple destinations are necessary.

CONCLUSIONS

While final data analysis is not fully complete at the writing of this paper, some conclusions can be offered.

Forest restoration projects must be based on sound ecological information. It is clear to everyone involved in the Pines Partnership that public support for this forest restoration project would have been weak or nonexistent without the research results and credibility of Dr. Romme. Additionally, collaborative efforts by the members of the Ponderosa Pine Partnership have fostered understanding, trust, and commitment to the vision of forest restoration for this forest.

Small-diameter material in southwestern Colorado is expensive to log, process, and market. Hauling is a major cost.

Accurate logging cost and revenue data is critical to realistic stumpage pricing and sale design. Pricing structures used with larger diameter sawlog sales frequently result in no bids when applied to forest restoration sales. Application of research findings has led to adjustments in pricing structure which resulted in successful bids for two FY 1997 timber sales that are key to the pine-oak restoration in southwest Colorado.

Local market development for 5- to 8-inch dbh pine material is critical for future long-term restoration projects. Effective utilization of 8- to 11.9-inch material for higher value products is essential to profitability.

Federal policies and procedures associated with standard timber sales can be a barrier to restoration projects. There is some room for policy adjustment within existing laws and regulations.

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An Investigation of Factors Influencing Returns on Investment in the Southern Logging Industry

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ABSTRACT: The logging industry is capital intensive. Managers need to be attentive to financial as well as operational measures of performance. Through a revised version of the Auburn Harvesting Analyzer, this paper illustrates the sensitivity of the financial performance of a logging enterprise to both external and internal factors. Results are displayed through model income statements, DuPont analysis, and leverage measures.

Key Words: logging, profitability, returns on investment

INTRODUCTION

Logging is a capital intensive, commodity-oriented business. This has traditionally focused the attention of logging contractors, managers, and researchers on the cost per unit of production (Lanford and Stokes 1996, Keegan *et al.* 1995). Financial measures commonly used in other industries have been used less often. This paper reviews financial measures and financial planning models widely used in business and provides examples of each in a logging context.

PROFILE OF THE LOGGING INDUSTRY

Dun and Bradstreet (1993) surveyed a broad range of logging enterprises to collect financial ratio information. The distribution of total assets of the entities was as follows: less than $100,000, 6%; $100,000-$250,000, 15%; $250,000-$500,000, 24%; $500,000-$1,000,000, 25%; $1,000,000-$5,000,000, 27%; and greater than $5,000,000, 3%. With a median net profit margin (net profit relative to sales) of 2.6%, the overall sample achieved a return on assets (net profit relative to total assets) of 4.5% and a return on equity (net profit relative to shareholder equity) of 12.1%. Almost one half (46.9%) of the firms' total assets were financed with debt.

For his survey of 24 independent logging businesses in the southeastern USA, Loving (1991) divided costs into six components: consumable supplies, labor, equipment, insurance, contract hauling, and administrative overhead. Consumable supplies included repair and maintenance supplies, parts, fuel, oil, tires, tubes, and saw expenditures. Without contract hauling payments (revenue) included, the breakdown of costs was found to be as follows: consumables (27%), labor (29%), equipment (27%), insurance (5%), contract hauling (10%), and administrative overhead (2%).

FINANCIAL PLANNING MODELS

Financial planning models are used by managers to improve their evaluation of alternative growth plans, financing and investment choices, and expense control options. Two techniques, leverage analysis and the Du Pont system of analysis, can be incorporated into financial planning models to improve the utility of their output. In this section, the two techniques will be reviewed and critiqued. In the next section, the techniques will be applied to examples from the logging industry in the southern U.S.

Leverage Analysis

Managers can increase the sensitivity of their firm's earnings per share (EPS) (or, for entities other than corporations, profits per ownership unit) to revenues in two general fashions: by orienting their cost structure toward fixed costs (often resulting from increased use of fixed assets) and/or a greater portion of financing represented by debt. The utilization of varying levels of fixed costs influences a firm's degree of operating leverage (DOL), while the reliance upon varying portions of debt financing alters a firm's degree of financial leverage (DFL). Another approach for describing the two forms of leverage is shown in Figure 1. With respect to the model income statement, DOL measures the sensitivity of operating income to revenues. In contrast, DFL measures the sensitivity of EPS to changes in operating income. When DOL and DFL are combined, the degree of combined leverage (DCL) measures the sensitivity of EPS to changes in revenue.

DOL, DFL, and DCL can be estimated as follows:

$$DOL = Q(P - VC)/(Q(P - VC) - FC) \quad (1)$$

$$DFL = OP/(OP - I) \quad (2)$$

$$DCL = Q(P - VC)/(Q(P - VC) - FC - I) \quad (3a)$$

or alternatively,

$$DCL = (DOL)(DFL) \quad (3b)$$

where:

Q	quantity of sales per period (tons/week)
P	price per unit ($/ton)
VC	variable cost per unit ($/ton)
FC	periodic fixed costs ($/week)
OP	periodic operating profits ($/week)
I	periodic interest expense ($/week).

While leverage can magnify a firm's change in EPS for a given positive change in revenues, its use can also magnify reductions in EPS as revenues decrease. Thus, as part of the risk management process, managers should carefully consider their firm's exposure to both DOL and DFL. For example, if a firm's DOL is already very high relative to others in the industry, then its managers may want to ameliorate risk by targeting a relatively low DFL.

Du Pont System of Analysis

The Du Pont System of analysis integrates a variety of financial ratios (Block and Hirt 1994, Brigham and Gapenski 1994). The underlying premise of this technique is that return on equity (ROE) should be the primary benchmark for assessing alternative strategic, operating, and financing decisions. ROE is a measure of a firm's profitability relative to the amount of shareholder equity committed to the enterprise. By decomposing ROE into its determinants, a manager can gain a better understanding of one plan relative to another.

Figure 2 is a graphic representation of the Du Pont system. At level 1, ROE is shown to be a function of profitability relative to total assets (ROA) and the equity multiplier (EM). ROA is a summary measure of relative profitability. The EM is a proxy for the degree of financial leverage. A firm using no debt in its capital structure has an EM of 1.0; those with debt have EMs greater than 1.0. If a firm has already reached the ceiling of financial leverage—perhaps because of creditor restrictions—then ROE can only be improved through a better ROA. In contrast, if a firm has already considered and incorporated every known mechanism within a given plan for maximizing ROA, then the only option for further increasing ROE would be through greater financial leverage. Of course, increased financial leverage will lead to increased risk, as indicated by a higher level of operating profits needed to achieve break-even EPS, greater periodic volatility in EPS, and more severe volatility in ROE.

At level 2 in Figure 2, ROA is shown to be a function of two dimensions: net profit margin (NPM) and total asset turnover (TAT). The NPM is influenced by the pricing decision, effectiveness relative to expense control, and a firm's effective tax rate. Improved asset management—of inventory, accounts receivables, cash, and fixed assets—can increase a firm's total asset turnover. When an operating decision, such as pricing, is expected to have conflicting impacts on NPM and TAT, then managerial resolution will generally be based on the anticipated long-term impact on ROA.

Prior to applying the Du Pont system of financial analysis, a manager needs to prepare a set of pro forma

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Revenue
Less: Operating Expenses
Equals: Operating Profit
Less: Interest Expense
Equals: Profit Before Taxes
Less: Income Taxes
Equals: Net Income

DOL
DFL
DCL

Figure 1. The model income statement and degree of operating leverage (DOL), degree of financial leverage (DFL), and degree of combined leverage (DCL).

ROE = NI/SE

Level 1: ROA = NI/A X EM = A/SE

Level 2: NPM = NI/R X TAT = R/A

ROE	Return on Equity	NI	Net Income
SE	Shareholders' Equity	ROA	Return on Assets
A	Assets	EM	Equity Multiplier
NPM	Net Profit Margin	R	Revenues
TAT	Total Asset Turnover		

Figure 2. The Du Pont system of financial analysis.

financial statements for each competing plan. After comparing the expected ROEs for each plan, the manager should then decompose this summary measure of financial performance into its determinants. Not only will this step help identify the major reason(s) for any divergence from expected ROE, but also it can serve as a reality check. Absolute magnitudes of the critical determinants should be carefully compared to historical levels as well as industry averages to gain a better perspective of the plan's feasibility. A high favorable variance associated with the critical determinant should be scrutinized with respect to its likely achievement.

SENSITIVITY OF FINANCIAL PERFORMANCE

The Auburn Harvesting Analyzer (Tufts *et al.* 1985, Greene and Lanford 1997) is a widely used spreadsheet for estimating logging costs. It was extensively modified to incorporate the above financial performance measures. Profit or loss was estimated by inclusion of a contract rate. Weekly production was varied and determined cost per ton and profit/loss per ton for the week. Base-case assumptions were representative of typical logging operations in Georgia and market prices in early 1997 (Table 1). For this analysis, consumable supplies and contract hauling were assumed to be variable costs. All other costs were considered to be fixed. By incorporating the base-case assumptions into the Auburn Harvesting Analyzer, all model income statement items, DuPont analyses, and leverage analyses were estimated.

Model Income Statements

With base-case assumptions, the operation yielded net profits of $36,530 on sales of $1,022,385 (Table 2). Interest expense was $36,148 for financing 80% of equipment investment of $800,000 at 10% annual interest.

Negative net profits were obtained in three alternative scenarios—off-road diesel fuel prices at $1.25 per gallon, capital investment increasing to $1,000,000, and contract rates of $11 per ton. Higher diesel prices increased operating expenses, higher capital investment increased interest, and lower prices reduced sales.

In another example that drastically reduced profitability, weekly production of 60 loads per week, instead of the base 65 loads, reduced annual profits from $36,530 to just $4,957. Profits rose dramatically as fuel prices, interest rates, capital investment, or debt financing fell or as production or contract rates increased.

Leverage Analysis

At a production level of 1,704 tons per week (65 loads per week at 26.215 tons per load), the operating profit per week and the net income per week were estimated to be $1,582 and $731, respectively. This production level is about 207 tons (8 loads) beyond the operating profit break-even level:

$$\begin{aligned} BEVOP &= FC/(P - VC) \quad (4) \\ &= \$11{,}435/(\$12.00 - \$4.36) \\ &= 1{,}497 \text{ tons per week} \end{aligned}$$

where:

BEVOP = break-even volume, for operating profit to equal zero.

The base-case production level is only about 113 tons (4 loads) greater than the net profit break-even level:

$$\begin{aligned} BEVNI &= (FC + I)/(P - VC) \quad (5) \\ &= (\$11{,}435 + \$723)/(\$12.00 - \$4.36) \\ &= 1{,}591 \text{ tons per week} \end{aligned}$$

where:

BEVNI = break-even volume, for net income to equal zero.

With production relatively close to the operating break-even volume, the DOL is fairly high: 8.32. Thus, if

Table 1. External and internal factors and their range of values used in this analysis.

Factor	*Low value*	*Base case*	*High value*
Employee Benefits, % of wages	10%	15%	20%
Off-Road Diesel Fuel, $/gallon	$0.70	$0.85	$1.25
Equipment Purchase Prices, $	$600,000	$800,000	$1,000,000
Interest Rates of Equipment Loans, %/year	8%	10%	12%
Pricing of Cut and Haul Contracts, $/ton	$11.00	$12.00	$13.00
Debt Financing of Fixed Assets, %	70%	80%	90%
Weekly Production, loads per week	60	65	70

Table 2. Results of changes in financial assumptions on model income statements.

Change from base case assumptions	*Annual sales*	*Operating expenses*	*Earnings before interest and taxes*	*Interest expense*	*Profit before taxes*	*Income taxes*	*Net profits after taxes*
Base Case	$1,022,385	$943,261	$79,124	$36,148	$42,976	$6,446	$36,530
Benefits @ 10%	$1,022,385	$936,066	$86,319	$36,148	$50,172	$1,841	$48,331
Benefits @ 20%	$1,022,385	$950,457	$71,928	$36,148	$35,781	$5,367	$30,414
Diesel @ $0.70	$1,022,385	$922,645	$99,740	$36,148	$63,592	$5,062	$58,530
Diesel @ $1.25	$1,022,385	$998,237	$24,148	$36,148	($12,000)	$0	($12,000)
$600K Equipment	$1,022,385	$900,401	$121,984	$27,562	$94,422	$11,193	$83,229
$1000K Equipment	$1,022,385	$986,122	$36,263	$44,733	($8,469)	$0	($8,469)
Interest @ 8%	$1,022,385	$936,842	$85,543	$28,806	$56,737	$3,417	$53,320
Interest @12%	$1,022,385	$949,827	$72,558	$43,541	$29,018	$4,353	$24,665
C&H Rate @ $11	$937,186	$943,261	($6,075)	$36,148	($42,223)	$0	($42,223)
C&H Rate @$13	$1,107,584	$943,261	$164,322	$36,148	$128,175	$19,568	$108,607
Debt @ 70%	$1,022,385	$943,261	$79,124	$31,629	$47,495	$7,124	$40,370
Debt @ 90%	$1,022,385	$943,261	$79,124	$40,666	$38,458	$5,769	$32,689
60 loads per week	$943,740	$901,761	$41,979	$36,148	$5,831	$875	$4,957
70 loads per week	$1,101,030	$984,761	$116,269	$36,148	$80,121	$6,331	$73,790

production (Q) is increased by 1 ton per week (or 0.05868%), then the expected increase in operating profit is 8.32 x .05868%, or 0.4883%. With a DFL of 1.84 at the base-case production level, a 0.4883% change in operating profit would be expected to increase net income by 1.84 x .4883%, or 0.8984%. Notice that the expected change in net income is about 15.14 times (8.32 x 1.84, or 0.8984%/.05868%) greater than the percentage change in output.

If production fell by 1 ton per week, then the expected decreases in operating profit and net income would be of similar magnitudes.

Given the high levels of operating leverage in the logging industry, even modest changes in external factors can have significant impacts on operating profit and net income (Table 3). At the production levels above BEVOP, cost increases or reductions in production increase the DOL. In four examples, negative values result for DCL. These result from operating profits falling and not covering interest expenses in the case of higher fuel prices, interest expenses increasing beyond operating profits in the case of higher investment levels, and insufficient operating profits when the contract rate fell to $11 per ton or production dropped to 60 loads per week.

If this hypothetical firm could push its production well beyond the break-even points, say to 1835 tons (or 70 loads) per week, then its DOL, DFL, and DCL would decrease substantially to 5.99, 1.45, and 8.69, respectively. Net income would, however, still be rather sensitive to production level changes. For every 1.0% change in production, net income would change by 8.69%.

To address the impact of high operating leverage on the volatility of logging operating profits, firms could seek greater levels of equity financing. However, as shown

Table 3. Results of changes in financial assumptions on degrees of operating, financial, and combined leverage.

Change from base case assumptions	*Sales quantity, tons/week (Q)*	*Price, $/ton (P)*	*Varioable cost, $/ton (VC)*	*Fixed cost, $/week (FC)*	*Operating profits, $/week (OP)*	*Interest expense, $/week (I)*	*Degree of operating leverage (DOL)*	*Degree of financial leverage (DFL)*	*Degree of combined leverage (DCL)*
Base Case	1704	$12.00	$4.36	$11,435	$1,582	$723	8.23	1.84	15.14
Benefits @ 10%	1704	$12.00	$4.36	$11,291	$1,726	$723	7.54	1.72	12.97
Benefits @ 20%	1704	$12.00	$4.36	$11,579	$1,439	$723	9.05	2.01	18.19
Diesel @ $0.70	1704	$12.00	$4.12	$11,435	$1,995	$723	6.73	1.57	10.56
Diesel @ $1.25	1704	$12.00	$5.01	$11,435	$483	$723	24.68	-2.01	-49.66
$600K Equipment	1704	$12.00	$4.36	$10,577	$2,440	$551	5.34	1.29	6.89
$1000K Equipment	1704	$12.00	$4.36	$12,292	$725	$895	17.95	-4.28	-76.85
Interest @ 8%	1704	$12.00	$4.36	$11,306	$1,711	$576	7.61	1.51	11.47
Interest @12%	1704	$12.00	$4.36	$11,566	$1,451	$871	8.97	2.50	22.43
C&H Rate @ $11	1704	$11.00	$4.36	$11,435	($122)	$723	-93.11	0.14	-13.40
C&H Rate @$13	1704	$13.00	$4.36	$11,435	$3,286	$723	4.48	1.28	5.74
Debt @ 70%	1704	$12.00	$4.36	$11,435	$1,582	$633	8.23	1.67	13.70
Debt @ 90%	1704	$12.00	$4.36	$11,435	$1,582	$813	8.23	2.06	16.92
60 loads per week	1573	$12.00	$4.30	$11,435	$679	$723	17.84	-15.44	-275.55
70 loads per week	1835	$12.00	$4.41	$11,435	$2,486	$723	5.60	1.41	7.90

Negative values for DOL, DFL, and DCL are mathematical results but cannot be realistically interpreted.

in the next sub-section, such an activity would dilute expected levels of ROE.

Du Pont System of Analysis

Given our base-case assumptions, the logging operation is more profitable than the median values reported by Dun and Bradstreet (1993). The expected net profit margin is 3.57% compared to 2.6% reported by D&B. Return on assets is 6.09% compared to D&B's 4.5%, while ROE is 31.31% compared to the 12.1% of D&B. Deviations from the base case example clearly illustrate the sensitivity of ROA and ROE to changes in net profit margin (NPM).

In Table 2, highest net profits after taxes resulted when the contract rate was increased to $13 per ton. However, the ROE after reducing the capital investment (because of lower purchase prices) to $600,000 is nearly identical to that of increasing the contract rate. Increasing weekly production by five loads doubles ROE from 31% to 63%. Changing capital investment, contract rate, and weekly production changes the total asset turnover ratio by either changing asset value or annual sales. Greater use of debt financing increases ROE by increasing the equity multiplier from 3.60 to 9.00.

Finally, note in Table 4 that cost per ton in every scenario is less than the $12 per ton contract rate assumed in the base case. This cost per ton is computed using the usual approach of a logging contractor where monthly payments for machines are used to calculate fixed costs instead of using depreciation and an after-tax analysis. In two cases where the annual after tax profit was negative (higher fuel prices and higher capital investment), this delivered cost per ton was still less than the contract rate, implying a profitable operation. In the case where the rate was dropped to $11.00 per ton, the delivered cost would still be calculated at $11.07, implying small losses.

CONCLUSIONS

Financial measures such as leverage and DuPont analysis can help identify where logging operations are vulnerable to market or management changes. These measures are easily incorporated into logging planning models such as the Auburn Harvesting Analyzer or easily computed from periodic financial reports provided from financial accounting records maintained by a logging firm.

Dependence on delivered cost per ton as a sole measure of financial performance can be misleading, especially when common shortcuts to calculating the value are used. Depreciation and tax factors should also be

Table 4. Results of changes in financial assumptions on DuPont analysis.

Change from base case assumptions	*Delivered cost per ton, $*	*Annual after-tax profit, $*	*Net profit margin (NPM)*	*Total asset turnover (TAT)*	*Return on assets (ROA)*	*Equity multiplier (EM)*	*Return on equity (ROE)*
Base Case	$11.07	$36,530	3.57%	1.70	6.09%	5.15	31.31%
Benefits @ 10%	$10.99	$48,331	4.73%	1.70	8.06%	5.14	41.43%
Benefits @ 20%	$11.16	$30,414	2.97%	1.70	5.07%	5.14	26.07%
Diesel @ $0.70	$10.83	$58,530	5.72%	1.70	9.76%	5.14	50.17%
Diesel @ $1.25	$11.72	($12,000)	-1.17%	1.70	-2.00%	5.14	-10.29%
$600K Equipment	$10.57	$83,229	8.14%	2.23	18.19%	5.14	93.56%
$1000K Equipment	$11.57	($8,469)	-0.83%	1.38	-1.14%	5.14	-5.87%
Interest @89%	$11.00	$53,320	5.22%	1.70	8.89%	5.14	45.70%
Interest @12%	$11.15	$24,665	2.41%	1.70	4.11%	5.14	21.14%
C&H Rate @ $11	$11.07	($42,223)	-4.51%	1.56	-7.04%	5.14	-36.19%
C&H Rate @$13	$11.07	$108,607	9.81%	1.85	18.10%	5.14	93.09%
Debt @ 70%	$11.07	$40,370	3.95%	1.70	6.73%	3.60	24.22%
Debt @ 90%	$11.07	$32,689	3.20%	1.70	5.45%	9.00	49.03%
60 loads per week	$11.47	$4,957	0.53%	1.57	0.83%	5.14	4.25%
70 loads per week	$10.73	$73,790	6.70%	1.84	12.30%	5.14	63.25%

considered when measuring financial performance to obtain objective, reliable cost estimates. Future studies will extend the analysis to impacts on cash flows.

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A New Harvest Operation Cost Model to Evaluate Forest Harvest Layout Alternatives

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Abstract: In this paper we develop a new model for harvest operation costs that can be used to evaluate stands for potential harvest. The model is based on felling, extraction, and access costs and is unique in its consideration of the interaction between harvest area shapes and access roads. We illustrate the model and evaluate the impact of stand size, volume, and road cost when determining harvest layouts. Since the approach lays the foundation for operational and tactical integration, future research will integrate the two levels for both the single and multi-period problem.

Key Words: Harvest scheduling problem, operations research modeling.

INTRODUCTION

In his widely accepted book, *Cost Control in the Logging Industry* (1942), D.M. Mathews introduced and articulated the reasons for proper spacing of roads and landings. In this paper we develop a new operational cost model based on determining the optimal number of landings and their locations. The approach is unique in its consideration of the interaction between harvest area shapes and the landing, skidding, and roading costs. The model specifies the optimal number of landings and their locations given the total size of the tract. The spacings between the landings and roads are solved implicitly so that the optimal number of landings and roads can be placed within the boundaries of the tract. The model also offers the flexibility of alternate road routing while maintaining a plan that minimizes total costs.

Forest planning decisions tend to be hierarchical with long-term strategic decisions setting the limits for shorter-term tactical decisions, which in turn are implemented with actual forest operations. Integrating the decision-making across all levels will lead to improved solutions, but it also increases the difficulty of the problem solving process. One of the difficulties of effectively integrating decision-making at the operational and tactical levels is simply due to spatial issues.

Main road projects must be carefully planned due to the increasing demand for multi-resource activities. Spatial constraints prohibit the progressive cut approach, therefore, access roads must be built in a very systematic manner to the stands selected for harvest. Also, from a silvicultural perspective, minimal roading impact is desired. Thus, it is extremely important to integrate the roading projects at the operational and the tactical levels to minimize impact. We will show how this can be accomplished in our approach.

There seem to be two areas of concentration in the literature regarding the number and the placement of landings. One area considers the uniform density case where the skidding regions have regular shapes. A number of contributions (Peters 1978, Suddarth and Herrick 1964, Sessions and Guangda 1987) have been made in this area since Mathews (1942). These approaches have concentrated on finding the optimal road and landing spacings for unbounded tracts.

The other area of concentration has been for irregular-shaped, nonuniform-density tracts. Peters and Burke

(1972) and others (Greulich 1991, Donnelly 1978) have located landings over entire, irregular-shaped tracts. Models for evaluating the optimal amount of roading for irregular-shaped tracts are difficult to develop so the emphasis has been landing locations and average skidding distances. We will consider the uniform density case, but for a bounded region or tract.

MOTIVATING EXAMPLE

The primary motivation of this paper is to develop an operational cost model that can be used to evaluate the harvesting costs of bounded tracts of timber with uniform densities and regular shaped skidding regions. Other approaches to this problem have concentrated on finding the most economical spacings of roads and landings, given the volume of timber over unbounded regions. Total costs are found using these spacings which may or may not be the final spacings, given the dimensions of the tract. Figure 1 illustrates the result of such a model.

Our approach considers the size of the bounded tract initially, and then determines the most economical landings, roading, and skidding. We implicitly calculate the spacings by determining the number and shapes of the grids in the tract, where a grid is defined as a rectangular area that is served by a single landing located in one corner of the grid.

In Figure 2 there are 8 grids, 2 landings and 0.75 $\sqrt{A}$ of roads where A defines the area of the entire tract. Since there are 4 rows and 2 columns of grids, the shape of the grids is rectangular where one side is twice as long as the adjacent side.

We will develop a model to optimally determine the number of landings and their placement considering landing, skidding, and road costs.

EXTRACTION COST MODEL

The following parameters will be used. Note that some parameters could vary by species of trees on a particular tract. Also, some tracts will have more than one product class; therefore, the different volumes per tree should be accounted for in the model.

A = total area of tract considered
a^f = volume per tree in a tract
a^d = density of trees per unit area
c = volume capacity of the skidder
f = total number of skidder loads
= $(Aa^f a^d)/c$
s = variable skidding costs
x = fixed skidding cost per turn
r = road cost per unit distance
l = fixed cost per landing

Our cost model is based on the sum of felling (F) and extraction (E) costs; that is, the total cost, C, is found as follows:

$$C = F + E.$$

We assume that felling costs are a function of the area (A) and the density of timber on the harvest area, but not its shape (P), since felling costs are related to the number and size of the trees harvested.

We assume that the extraction costs are a function of the area, density, and shape of the harvest area since extraction costs are based on the number of landings, the distance from the trees to the landings, and the technology used to extract the trees; that is,

$$E = g(A, a^d, P).$$

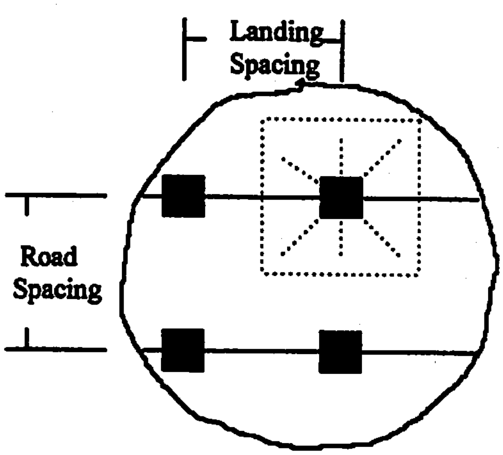


Figure 1: Optimal Spacing of Roads and Landings

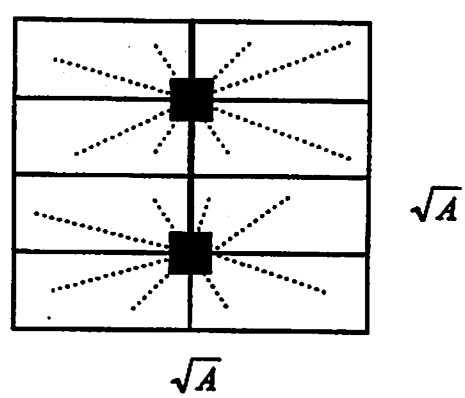


Figure 2: Bounded Tract with Equal-Sized Grids

We define total extraction costs to equal the sum of the landings costs, L, and the skidding costs, S, and the road costs, R; i.e.,

$$E = L + S + R.$$

As we noted earlier, E is a function of A, a^d, and P. In particular, P is a function of the following two decision variables: g (the number of grids) and n (the number of landings), where a grid defines an area that is harvested from one landing. Note that a tract is typically partitioned into multiple grids where up to four grids can be harvested from one landing.

Assumptions

In the following model we assume:
1. grids are rectangular;
2. skid distances are proportional to rectilinear distances (or can be adjusted with some proportionality constant, as suggested by Greulich (1991));
3. there will only be one means-of-egress to a stand;
4. all roads are orthogonal to the x and y axes;
5. the capacity of the skidder is fixed *a priori*.

Approximate Extraction Cost Model

After splitting the area into g grids, we then need to choose our n landing locations. Thus, we construct a model to determine both the optimal g and n for a given area. Note that since n is a function of g, we will use $n(g)$ to denote this.

Mathews (1942) explained in detail the economic differences of placing a landing on the boundary of a tract versus building a road and placing the landing on the interior of a tract. So it is reasonable to say if g is less than or equal to 2 then there would be one landing located on the boundary of the tract that served each of the two grids. Alternatively, as long as $g > 2$, it seems reasonable to approximate $n(g)$ as:

$$L = n(g) = g/4. \tag{1}$$

This indicates that the tract will be split into multiples of 4 with one landing serving 4 grids.

If we divide the tract area, A, into equal-area grids, we can determine the number of skidder loads per grid. Since the grids are not always square, we must modify the equation to allow for rectangular shaped grids. Thus,

$$S = sf\left(\frac{1}{a} + \frac{1}{b}\right) + fx \tag{2}$$

where a and b represent the number of grid rows and columns. Although a and b could be interchanged to represent the rows or the columns in this equation without changing the resulting value of S, we will show later that $a \geq b$ must always hold.

Generally, the amount of roading required is that which provides access to each of the landing locations. We can construct a table that shows the amount of roading required based on the size of the tract and the number of grids. For every harvest pattern we can calculate a constant value that can simply be multiplied by the length of one side of the square area to get the total amount of roading required. Table 1 shows the results of a number of different harvest patterns.

We approximate the total cost of roading, R, with the following equation:

$$R = r\left(\frac{\sqrt{A}}{a}\left((a-2)\frac{b}{2} + 1\right) + \frac{\sqrt{A}}{b}(b-2)\right) \tag{3}$$

where a and b represent the number of columns and rows of grids. Note that (3) requires that $a \geq b$ and $b \geq 2$. As we will show later, the harvest pattern could rotate, thus, a could represent the rows or the columns and likewise for b. So, a does not necessarily represent the columns or the rows but the greater of the two, unless the columns and rows are equal. It follows then that $g = ab$.

The cost of roading is approximated well by (3). In fact, (3) appears to provide the exact amount of roading costs as long as b is even and ≥ 2. Notice that in Table 1 all of the possible b's are even or one. This is due to there not being a feasible solution where b is both odd and greater than one when there are $g/4$ landings. Note from the Roading column in Table 1 that for

Table 1. Grid, road, and landing combinations.

Pattern	*Grids*	*Col.*	*Rows*	*Landings*	*Roading*
1	2	1	2	1	0
2	4	2	2	1	0.500
3	8	2	4	2	0.750
4	12	2	6	3	0.830
5	16	2	8	4	0.875
6	20	2	10	5	0.900
7	24	2	12	6	0.916
8	16	4	4	4	1.750
9	24	4	6	6	2.000
10	32	4	8	8	2.125
11	40	4	10	10	2.200

each of the harvest patterns in the table we have assumed that a tract has one means-of-egress, but its location is not fixed. In reality, tracts that are located adjacent to existing roads may have multiple means-of-egress. However, in a large forest there will be very few tracts adjacent to existing roads. Of course, (3) could be modified to approximate the amount of roading with more than one means-of-egress, but for purposes of consistency here, we make this generalization.

We have approximated *L*, *S*, and *R*, and now we are ready to write our total cost model. Detailed derivations of these three models can be seen in Clark *et al.* (1997). We can approximate E as follows:

$$E = L + S + R \qquad (4)$$

We know the following about the components of total extraction cost function, *E*. The landings cost, *L*, linearly increases with respect to *n*. The total skid cost, *S*, is convex in *n*. And although we cannot show that the roading cost function, *R*, is convex in *n* (since *R* is not convex in *a* or *b*), *R* is increasing in *a* and *b*, and is approximately linear in both *a* and *b*. Therefore, we will use convex analysis to determine the values of a^* and b^* (which imply g^*). The continuous values of a^*, b^*, and g^* are utilized to find optimal integer values for *g* and *n*.

Minimizing the total extraction cost, *E*, is found by taking the first derivative of our total extraction cost function, (4), with respect to *a* and *b*, setting them equal to zero, and solving the two equations simultaneously for a^* and b^*, and ultimately *g*.

$$\frac{\partial E}{\partial a} = \frac{lb}{4} - (sf\sqrt{A} - rb\sqrt{A} + r\sqrt{A})a^{-2} = 0 \qquad (5)$$

$$\frac{\partial E}{\partial b} = \frac{la}{4} - \frac{sf\sqrt{A}}{b^2} + r\sqrt{A}\left(\frac{1}{2} - \frac{1}{a} + \frac{2}{b^2}\right) = 0 \qquad (6)$$

Note that since *g* must be integer, adjustments to a^*, b^*, and g^* must be made.

Let's look at some examples. For our base case, let's assume the following: $A = 647{,}476$ sq m (160 acres); $f = 3322$ loads (a^d x $a^f = 256.5$ cu m/ha and $c = 5.0$ cu m/skidder load); $s = \$.0134$/m ($0.0041/ft.); $x = \$2$ per turn; $r = \$6.56$/m ($2 per ft) and $l = \$300$. Solving (5) and (6) simultaneously for a and b gives $a^*=10.83$ and $b^*=2.92$. Therefore, $g^*=31.62$.

Before we consider how to adjust the continuous value of g^*, let us consider the following parametric changes to this base case:

Change	g^*
double landing cost; $l = \$600$	22.26
cut s in half; $s=\$0.0067$	17.21
cut area in half; $A=323{,}738$	26.52
cut area and turns in half; $f=1661$	14.76
cut area by a factor of 4; $A = 161{,}869$	22.26
double s; $s = \$0.0268$	56.10

Thus, the model behaves as expected.

To find the final integer value of *g*, one would need to evaluate (4) with $\lceil g^* \rceil$ and $\lfloor g^* \rfloor$ from Table 1, and choose the harvest pattern that produces the smaller total extraction cost. The harvest operation cost model may be used to quickly determine the most efficient number of landings and grids in an area to be harvested.

Once the number of grids are known we can determine the harvest pattern; i.e., the number of landings and their placement, and the amount of roading. By referring to Table 1, we can see how we've reduced an infinite field of solutions to a finite number of alternatives. These, of course, vary by the number of grids, the grid shapes, the number of landings, and the amount of roading. Since there could be more than one harvest pattern for a specific number of grids, the total extraction cost must be evaluated to determine the least cost alternative.

EXAMPLE PROBLEMS

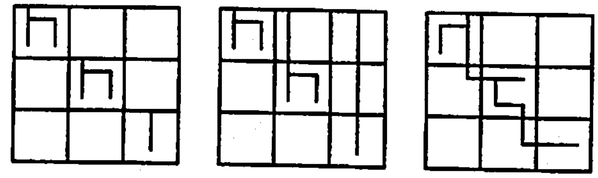
In this section, we will illustrate the operational cost model by solving a number of example problems. We will consider examples where we will employ (4) to model the total extraction costs. The problems have been chosen to show the impact of different parameter values.

First, we solve three problems all with the same cost parameters, but with different volumes. The cost parameters are equivalent to the ones used in the example problem earlier, including a road cost of $6.56 per meter. We consider three volumes: 139.9, 209.8, and 279.8 m^3/ha (24, 36, and 48 Mbf per acre). In the 139.9 m^3/ha case, we solve (5) and (6) simultaneously for *a* and *b* we get $a^*=8.51$, $b^*=2.32$ and $g^*=19.74$. By referring to Table 1, we can round g^* to the nearest *g* in the table and select the corresponding harvest pattern. From there we determine *g*, *a*, *b*, *n* and then evaluate (4) to find *E*, the total extraction cost. The results for this case and the other two volumes are shown in Table 2. In the second set of examples we increased the variable skidding cost by 25% to \$0.01675 per meter. The results are shown in Table 3. Note that with the increased skid cost the shapes of the grids change to compensate for the increased cost.

INTEGRATION OF OPERATIONAL AND TACTICAL PLANS

The operational plan, as we've defined it, considers only the cost for harvesting a specific stand. The tactical plan specifies where and when to harvest specific tracts. The two must be integrated at some point in order to develop the overall harvesting plan. Since roading is a major decision variable at both levels, it could be a means by which the two levels are integrated. This integration could lead to multiple stands sharing the same roads. After the most economical landing and road placements are known at the operational level this integration could be enhanced.

Another reason for multiple roading alternatives is to provide a basis for the integration of these operational plans with the tactical plan. For example, consider a forest with nine stands with an access road running along the northern boundary and we select three of those stands for harvest in the first period. Furthermore, assume that the harvest patterns are similar to those in Figure 4(a), then we have the flexibility to manipulate the harvest patterns while maintaining minimum harvesting costs. Also, we might be able to share hauling roads in an effort to minimize the total amount of roading. If we can't share the roading, the result to the tactical plan might resemble Figure 4(b). But with shared roading, the result might resemble Figure 4(c). It is clear that some additional costs must be incurred to upgrade the roads for additional capacity, but this cost might be incurred in any plan.



(a) (b) (c)

Figure 4. Integration of roading

CONCLUSIONS AND FUTURE RESEARCH

In this paper we have developed a model of timber harvest costs that enables us to find the minimum operational costs. The model was developed such that the size of the tract is considered so that the harvest pattern could be found to minimize the cost of the harvesting operations. We showed how these operational harvest patterns can be used as a foundation for the integration of the operational and tactical plans.

Future research will cover two related areas. First, we will look at tracts that are not square. Obviously, with the increasing use of GIS, more and more information may be used to define tract boundaries in an effort to make better harvesting decisions. Topography, soil conditions, existing roads, stream locations, etc., will all have an impact on the tract shape.

The second area of future research is to develop an algorithm for efficiently solving the tactical level problem while considering the integration of the operational plan. The results in Nelson and Brodie (1990) and O'Hara *et al.* (1989) indicate that in order to solve larger problems the use of a heuristic-search algorithm will be required.

Table 2. Results of three example problems

Volume (m^3/ha.)	a^*	b^*	g^*	Grids (g)	Columns	Rows	Landings	E(\$)
139.9	8.51	2.32	19.74	20	2	10	5	18,031
209.8	9.52	2.95	27.43	24	2	12	6	23,819
279.8	10.11	3.43	34.67	32	4	8	8	28,343

Table 3. Results of three example problems with increased skid cost

Volume (m^3/ha.)	a^*	b^*	g^*	Grids (g)	Columns	Rows	Landings	E (\$)
139.9	8.86	2.65	23.47	24	2	12	6	20,884
209.8	9.90	3.31	32.81	32	4	8	8	27,354
279.8	10.85	3.82	41.45	40	4	10	10	31,707

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Integrated Approach for Determining the Size of Group-Selection Openings

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ABSTRACT: The use of group-selection methods is becoming more widespread as landowners and forest managers attempt to respond to public pressure to reduce the size of clearcut blocks. Several studies have shown that harvesting timber in smaller groups or clumps increases the cost of operations for both cable and ground-based logging systems. Recent regeneration studies have shown that the number of stems, numbers of shade-tolerant and intolerant species, basal area, and volume are affected by the size of opening created. Size of opening and resulting vegetation also affects the wildlife species that use these small openings. We integrated the results from several cable and ground-based logging studies with those from several regeneration studies to determine the most effective size of group-selection openings. Managers can avoid serious economic losses by using groups of 1.25 acres or larger. These results should be valuable to managers, loggers, and planners considering group-selection methods.

Key Words: group-selection, break-even, logging systems, integration, economics

INTRODUCTION

Public concern about clearcutting has resulted in the increased use of group-selection methods by landowners and forest managers. The small openings created by these techniques allow the harvesting of timber without impairing the visual quality of the site. Yet managers interested in keeping logging costs under control are concerned about the potential loss of production and profit in choosing group-selection over conventional forms of clearcutting.

Group-selection entails harvesting small groups or clumps of trees in a somewhat random pattern across a stand to capture mortality and insect and disease infestations, regenerate stands, and harvest financially mature trees. Group-selection has certain advantages over single-tree selection: 1) Older mature trees can be harvested more economically and with less damage to the residual stand; 2) managers are afforded greater flexibility in creating environmental conditions that favor successful reproduction; and 3) reproduction develops in well-defined, even-aged aggregations. The latter is a substantial advantage over single-tree selection in developing good tree form, particularly in hardwoods (Smith 1986).

Group-selection cuttings also create openings or gaps in the forest canopy that can increase the area of desirable habitat for wildlife. Many species of wildlife benefit from the combination of environmental conditions existing within and along the boundaries between the young reproduction and older adjacent trees. A wide array of protective cover is available in proximity to various food plants that may be created by the broad spectrum of microclimatic conditions existing between the edges and the centers of the young groups.

Harvesting studies of group-selection in eastern hardwoods have shown that the economic success of such harvests relies heavily on product markets, tree species and quality, and logging costs (Bell 1989, Boucher and Hall 1989, LeDoux *et al.* 1991, Brummel 1992, Erickson *et al.* 1992, LeDoux *et al.* 1993). Other studies have attempted to define group-selection harvests and when they can be used (Roach 1974). In general, harvesting costs increase rapidly as size of opening decreases. Results suggest that costs may be prohibitive for groups smaller than 1/2 acre (LeDoux *et al.* 1991).

Regeneration studies have shown that species composition can be affected by group-selection treatments (Walters and Nyland 1989, Dale *et al.* 1995). Small clearcuts also have a larger proportion of their total area influenced by the surrounding forest than larger clearcuts (Marquis 1965). The increased competition for water and nutrients due to these edge effects influences tree growth (Minckler *et al.* 1973, Smith 1981, Dale *et al.* 1995). Reductions in total height and merchantable height growth of new regeneration were reported near the opening edge for 10 to 30 years following small group-selection cuts (Minckler and Woerheide 1965, Sander and Clark 1971, Willison 1981, Hilt 1985, Dale *et al.* 1995).

We integrated harvesting data available from LeDoux *et al.* (1991, 1993) with those from Dale *et al.* (1995) to determine the most effective size of group-selection openings. The results presented here combine the most recent data available on logging costs and regeneration responses for group-selection treatments.

METHODS

Dale *et al.* (1995) reported 30-year regeneration results from 89 group-selection plots located in West Virginia, Illinois, Ohio, and Kentucky. The units ranged in size from 0.04 to 1.61 acres. Because the stand characteristics were so highly correlated with opening size, Dale *et al.* pooled the data from all regenerated plots and used non-linear regression techniques to develop equations for estimating number of trees, basal area, total cubic-foot volume, and merchantable volume as a function of opening size. Using these equations and data, we reconstructed the 30-year-old individual-tree stands for 1/4-, 1/2-, 1-, and 1 1/2-acre groups (Table 1).

Data on individual-tree stands by unit size was put into the MANAGE simulation model (LeDoux 1986). A computer program written in FORTRAN V, MANAGE integrates harvesting technology, silvicultural treatments, market price, and economic concerns over the life of a stand. The simulation is a combination of discrete and stochastic subroutines. Individual subroutines model harvesting activities, silvicultural treatments, growth projections, market prices, and discounted present net worth (PNW) economic analysis.

MANAGE was calibrated to produce stand attributes that are identical to those calculated from data in Dale *et al.* (1995) for the initial 30-year-old stands. The growth and products development of each stand was then projected to a rotation age of 90 years for comparison. The delivered log prices used in this integration by species and grade are shown in Table 2.
The criterion used was the PNW at age 30. The simulated PNW by unit size is shown in Table 3.

RESULTS

The results in Table 3 show that larger groups are cheaper to harvest than smaller ones, i.e., larger groups start out with more and larger trees/acre than smaller ones. The interactive effect of larger groups, larger trees, and more trees/acre results in increased revenue as size of opening increases. This effect integrated with harvesting efficiencies results in greater PNW yields per acre at age 90 for larger units.

For example, units of 1.5 acres return \$37.86/acre in PNW. By contrast, units of 0.25 acre return \$10.73/acre in PNW, a 72% reduction in financial yields over a 60-year period. This equates to net loss in PNW of \$0.45/acre/year.

When PNW is graphed by size of opening (Figure 1), PNW yields/acre level off with units of 1.25 acres or greater.

These results match initial results of Dale *et al.* (1995) and LeDoux *et al.* (1991, 1993) for cable and ground-based logging of group-selection units. Ledoux *et al.* found that production rates and yarding costs for units of 1.0 acre were similar to those for large clearcuts. However, Ledoux *et al.* found that total logging and layout costs for 1.0 acre groups were four to six times more expensive than those for large clearcuts. Dale *et*

Table 1. Attributes of reconstructed stands at age 30, by opening size (from Dale *et al.* 1995) [a].

Size of opening	*Number of trees*	*Basal area*	*Total volume*	*Merchantable volume*	*Quadratic stand diameter*
Acres		*ft²*	*ft³/acre*		*Inches*
0.25	330	38.97	980.51	270.70	4.65
0.50	388	54.88	1460.05	451.84	5.09
1.00	440	71.66	1931.86	651.27	5.46
1.50	457	78.56	2107.87	738.76	5.61

[a]Species composition: hickory, black oak, white oak, chestnut oak, scarlet oak, northern red oak, yellow-poplar, red maple, black cherry, ash, black locust, birch, beech, elm, dogwood, holly, magnolia, redbud, and sassafras.

Table 2. Delivered log prices by species and grade, in dollar/Mbf, international 1/4-inch rule (from Worthington *et al.* 1996).

Species group	*Grade 1*	*Grade 2*	*Grade 3*	*Pulpwood**
Hickory	210	160	100	40
Black Oak	450	250	100	40
White Oak	450	250	100	40
Chestnut Oak	450	250	100	40
Scarlet Oak	450	250	100	40
Northern Red Oak	561	397	138	40
Yellow Poplar	268	174	98	40
Red Maple	200	125	50	40
Black Cherry	571	400	259	40
Ash	420	297	169	40
Birch	107	86	85	40
Beech	106	91	86	40
Elm	76	76	76	40
Other Hardwoods	76	76	76	40

*In dollars/cord

Table 3. Simulated PNW and stand attributes for reconstructed stands at age 90, by size of opening.

Size of opening	*Total volume*	*Average stand dbh*	*PNW**	*Cash flow*
Acres	*ft^3/acre*	*Inches*	- - - - *Dollars/acre*	- - - - -
0.25	2507.37	10.02	10.73	63.22
0.50	3134.22	10.87	16.92	99.69
1.00	4123.97	11.57	33.58	197.84
1.50	4259.74	11.75	37.86	223.06

*PNW at age 90; real discount rate = 3%

al. (1995) found that regeneration in blocks of 1.0 acre or larger was similar to that in large clearcuts.

Although size of opening and resulting vegetation also affect wildlife species that use these small openings, we did not analyze the relationship between size of opening and wildlife impacts. This is best evaluated in the field by managers familiar with actual conditions. For example, several small openings located close to each other among different types of forest cover will be used differently by wildlife than one large opening surrounded by a single type of forest cover.

CONCLUSIONS

Logging costs decrease and the number of regenerated trees/acre increases with increasing group size. The quadratic mean dbh of regenerated trees increases with increasing group size. More and larger trees/acre result in more merchantable volume/acre.

The results of this investigation suggest that group-selection units should be 1.25 acres or larger to take advantage of the interactive effect of logging costs and regeneration efficiencies and thus avoid serious economic losses.

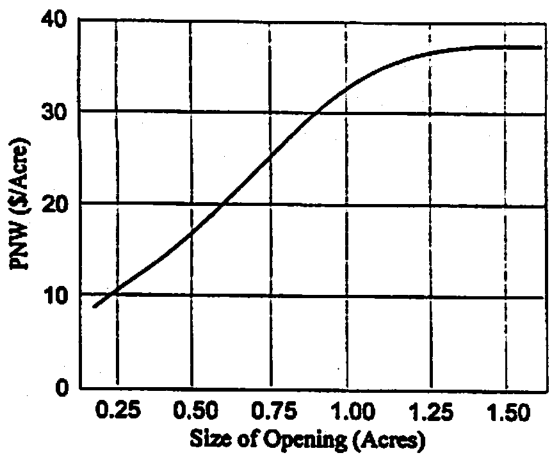

Figure 1. Simulated PNW/acre by group-selection unit size.

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Production Functions for Cut-to-Length Harvesting in Bunched and Unbunched Material

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ABSTRACT: Three different harvest / processor configurations and a single forwarding configuration were analyzed. Each machine and each operating format was evaluated for its productivity through detailed time and production studies. Data from the time studies were used to develop predictive models of the individual work cycles of each machine. In the conventional thinning format, the highest percent productive time was realized by the Timbco T425/Pika 600 at 87.7%. Based on a limited number of observed cycles, pre-bunching had a dramatic effect on the percent productive time of both the Hitachi EX 150/Keto 500 and the Komatsu PC95/Hahn HSG 140, raising their percent productive time from 81.2% to 99.5% and 62.1% to 94.7% respectively. On a cost per piece basis, the Komatsu PC 95 / Hahn HSG 140 proved to be the lowest cost alternative for both the conventional thinning format and pre-bunched processing format at $ 0.74 and $0.48/piece respectively.

INTRODUCTION

Cut-to-length/forwarder harvest systems have become increasingly important in the Pacific Northwest. These harvest systems have gained popularity for their productivity advantage over conventional systems, in thinning small timber, and for their ability to meet silvicultural goals that include retention of nutrients on the site and minimization of soil impacts and residual stand damage.

Generally, cut-to-length/forwarder systems employ two expensive and complex machines, the harvestor / processor and the forwarder. Working together, these machine have a high capacity for producing timber products from overstocked, smaller diameter stands. The challenge for the operators of these machines is to fully utilize the production capacity of the system while still maintaining the silvicultural objectives for the site.

The first two harvest/processors, a Hitachi EX150 with Keto model 500 processing head and a Komatsu PC95 with Hahn HSG140 processing head, were observed working in a conventional thinning format as well as processing material from pre-bunched piles. The third system, a Timbco T425 with Pika Model 600 processing head, was only observed in a conventional thinning format. While each of the harvest / processors perform similar functions, they operated in unique ways, had operators of varying skill levels and were studied individually. Detailed time and motion studies provided data on the production elements and delay factors for the individual machines.

SITE CONDITIONS

Harvest operations were observed in three separate locations. Site 1 was located in northern Idaho on a university-managed experimental forest. Site 2 and Site 3 were located on industrial private lands in northwestern Montana.

The harvest / processor operation on Site 1 was observed working on a north facing slope of approximately 5 acres. Slopes ranged from 10% to 25% and averaged 20%. The harvest / processor thinned the stand from approximately 450 stems per acre, averaging a butt diameter of 8.3 inches, to 150 stems per acre. This site also contained pre-bunched tree length material consisting primarily of *Abies grandis* (grand fir) with an average butt diameter of 11.8 inches.

Site 2 involved harvesting and forwarding in both conventional thinning and pre-bunched processing formats. Slopes on the 5-acre site faced southwest and ranged from 0% to 40%, with an average of 25%.

The initial stand conditions at this site consisted of 3425 stems per acre of primarily *Pseudotsuga menziesii* (Douglas fir) and *Larix occidentalis* (western larch). The harvest / processor was unable to work in these conditions without prior treatment of small trees through a slashing operation. The slashing operation cut 2970 stems per acre. Slashed material was less than 3 inches in diameter and was left on the site as coarse woody debris. The harvest/ processor then thinned the slashed stand to a residual of 250 stems per acre. Pre-bunched material on site averaged a butt diameter of 8.7 inches and an average height of 62.3 feet.

Site 3 was also located on industrial forest land, and harvesting and forwarding operations were observed in an area of approximately 4 acres. The initial stand conditions at this site consisted of 2950 stems per acre of primarily Douglas fir and western larch. This site also required pre-treatment through a slashing operation that cut 2475 stems per acre. The harvest/processor thinned the slashed stand to its final conditions of 250 stems per acre. Harvest system and site information for all sites are summarized in Table 1.

MACHINE DESCRIPTIONS

Hitachi EX 150 Excavator with Keto 500 Harvest / Processing Head

The Hitachi EX 150 is a medium size (150hp), standard use excavator which had been guarded for forestry use. The Keto 500 head is a dangle design that allows the operator to process trees from either side of the machine. The processing head utilizes metal rollers to draw the stem through delimbing knives. A hydraulic chain type cutoff saw is used for falling and bucking cuts. Based on the average spacing of the trails the usable boom reach of this machine is 24 feet and the average trail in the study was 16 feet wide.

The system was observed operating on gentle terrain with an average slope of 20%. The processor could operate freely in the stand and generally processed timber from both sides of the trail in an uphill and downhill direction. Trees were processed in front of the machine, leaving a mat of tops and branches on the trail ahead of the machine. No attempt was made to sort products during the processing step.

This machine was also observed processing pre-bunched material. In this case, the processor took pieces from the bunch on the left side of the trail, processed them in front of the machine, and placed the products on the opposite side of the trail. No effort was made by the harvest / processor to sort products.

Komatsu PC95 with a Hahn HSG 140 Laydown Harvest/Processing Head

The Komatsu PC95 is a small (71hp), standard use excavator, which had been heavily guarded for forestry use. This machine had been fitted with a small dozer blade to stabilize the machine during the harvest/processing cycle. The mounting configuration of the Hahn HSG 140, laydown harvest/processing head only allows for forward and backward movement of the head. A hydraulic ram mounted on the head allows clockwise rotation of 90 degrees to the right. This design restricts the harvest / processing cycle to a 90 degree zone in front of the machine as illustrated in Figure 1.

Table 1. Harvest System And Site Information

Harvest system	*Stems/acre removed*	*Residual stems/acre*	*Basal area (ft^2) removed*	*Average slope (%)*	*No. of acres*
Hitachi EX 150 / Keto 500					
Conventional Thinning	300	Unknown	Unknown	20	4
Hitachi EX 150 / Keto 500					
Pre-bunch Processing	260	Unknown	Unknown	5	1
Komatsu PC 95 / Hahn HSG 140					
Conventional Thinning	205	250	82	25	5
Komatsu PC 95 / Hahn HSG 140					
Pre-bunch Processing	205	250	82	5	3
Timbco T425 /Pika 600					
Conventional Thinning	175	250	57	35	5
Timberjack 230-A					
Forwarding	Unknown	250	Unknown	30	7

Two metal drums with teeth draw the stem through the delimbing knives. A hydraulic chain-type cut off saw is used for falling and bucking cuts. Based on the average distance between trails this machine has a usable boom reach of 21 feet. The average trail in the study was 15 feet wide.

The machine was observed on variable terrain with slopes of 0% to 40% and an average slope of 25%. Processing was done in both an uphill and downhill direction, perpendicular to the slope. The steepest sections were processed in a downhill direction, using the dozer blade for added stability. The configuration of this processing head allowed trees to be processed only in a 90- degree arc in front of the machine, leaving product sorts on the left side of the machine. A concerted effort was made to sort three product types and to concentrate volume for the forwarding phase during the processing operation. The three product sorts were saw logs, stud logs, and pulp logs.

This machine was also observed processing pre-bunched timber on flat terrain. Pre-bunching of tree lengths had been done by a small crawler tractor with a shearing head mounted on the front. Bunches consisted of 2 to 12 stems. Due to the operating characteristics of the harvest / processor, the ideal presentation of the bunched material was either directly ahead of the machine, or up to 45 degrees to the right of the harvest / processor path. The operator also noted that 5 to 8 stems per bunch was ideal. Space for product sorts was also necessary on the left side of the harvest / processor path. The tops and limbs were placed in the trail ahead of the machine.

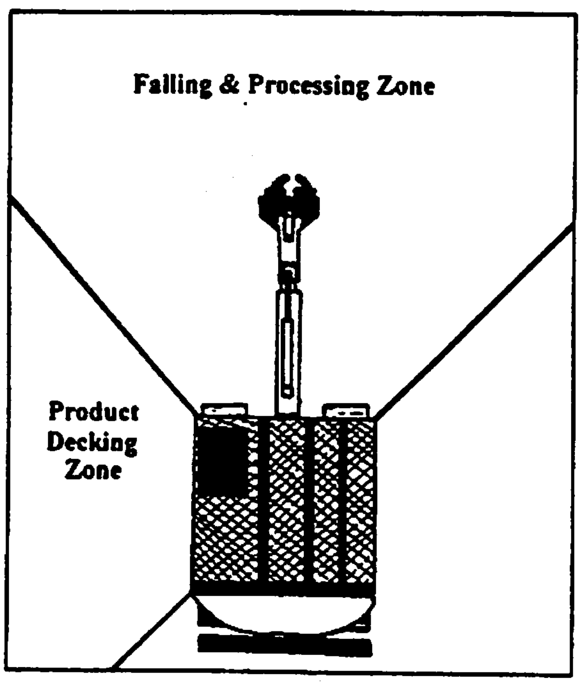

Figure 1. Operational Configuration of the Komatsu PC95 with Hahn HSG 140 Harvester Head

Timbco T425 with Pika 600 Harvest/Processing Head

The Timbco T425 (171hp) is a purpose built machine for forestry applications. It is self leveling to certain limits and has the ability to operate on slopes up to 50%. This machine had a snorkel type boom that provided for additional reach into standing trees. The Pika 600 head is a dangle design, allowing trees to be processed from either side of the machine. The head employs two metal drums with teeth to draw the stem through the delimbing knives. A hydraulic chain-type cut off saw is used for falling and bucking cuts. The machine has a usable boom reach of 26 feet, and, based on observations, the average trail was 15 feet wide.

The system was observed on steep terrain, with slopes ranging from 10% to 50% and an average of 35%. While this machine configuration allows for processing from both sides of the machine, the operator preferred to process trees from the left side of the trail, leaving the product logs to the right side of the machine. Tops and limbs were left on the trail ahead of the machine. Processing was done in an uphill direction only, and the machine was backed down the slope before starting up the next trail. No attempt was made to sort products during the harvest /processing operation.

Timberjack 230-A four wheeled forwarder.

The Timberjack 230-A is a purpose built, log forwarding machine. It is a four-wheel-drive, articulated forwarder with an 8 ton capacity. It utilizes a Loglift brand grapple loader for loading, unloading, and sorting.

The forwarder was observed operating in many conditions, with slopes ranging from 0% to 45% and an average slope of 35%. The forwarder operated on harvest/processor trails that were oriented perpendicular to the slope. The machine was backed to the upper end of the trail and was loaded as it traveled downhill toward the deck. Loading generally occurred from one side of the machine. Product sorting took place both in the woods and at the decking area. Forwarding turns included up to three products in various combinations. For example, there might be a single product in the bunk, there could be two products separated in the bunk, two products mixed in the bunk, or three products mixed in the bunks. The degree of sorting by the processor and the forwarder had a significant effect on the productivity of the machine.

PRODUCTION RESULTS

The production statistics for each machine and operation format are presented in Table 2. Harvest / processing and forwarding cycles were recorded as separate times so forwarding production does not match that of the processors.

The low percent productivity for the Komatsu / Hahn HSG 140 compared to the other machines can be attributed to some unique delay elements encountered by this system. For example, due to the smaller stem capacity of the harvest / processing head, the machine operator stopped the harvest / processing operation to hand fall and partially process oversized stems. This took a significant amount of time. A second delay element unique to this operation was the time spent moving up hills. The combination of increased slope and slashed material on the ground created some movement difficulties for this machine. In some cases, the boom had to be used to either push or pull the machine to the next processing location. The two other machines did not encounter these difficulties due to the larger stem capacity of their harvest / processing heads and much higher horsepower. If these delays are ignored, all three machines have productive cycle times which are comparatively close.

Table 2 also shows the productive and scheduled time in pre-bunched processing. Based on a limited number of observations, both the productive and scheduled cycle time decreased compared to conventional thinning operations. The decrease in productive and scheduled cycle time is most significant for the Komatsu PC 95 / Hahn HSG 140. The high productive and scheduled cycle times for the Hitachi EX 150 / Keto 500 can be partially attributed to the large stem sizes in this operation. These tested the capacity of the Keto head and slowed the operation.

Another factor contributing to high cycle times was the well-worn drive rollers which gripped the tree and fed the stem through the delimbing knives. In conventional thinning this was less of a problem, as the operator used the momentum of the falling tree to aid in delimbing. This technique could not be applied in the pre-bunched processing role. Thus, delimbing was slowed by the feed rate of the processing head.

The forwarding cycle was dominated by the loading element, representing 41% of the total scheduled cycle time. This element was highly dependent on the number of moves required to fill the bunk. The amount of sorting required was also a factor. Three product sorts were taken from the study sites. Full bunks of three mixed products resulted in very long unloading times. Full bunks of a single product resulted in long loading times due to the high number of moves required to fill the bunk. Partial loads of single products were fast, but did not fully utilize the capacity of the forwarder.

A solution to these problems rests in the ability to load more than one product at each loading stop and to keep the products separated in the bunk of the forwarder. A number of turns were observed in this configuration and they proved to have some of the lowest cycle times.

Table 2. Harvest/Processing And Forwarding

Harvest sytstem	*No. of cycles*	*No. of pieces*	*Ave. vol/piece (ft^3)*	*Productive cycle time (min)*	*Scheduled cycle time (min)*	*Percent productive time*
Hitachi EX 150 / Keto 500 Conventional Thinning	221	559	* 4.9	1.17	1.44	81.2%
Hitachi EX 150 / Keto 500 Pre- Bunched Processing	79	236	* 9.5	1.20	1.20	99.5%
Komatsu PC95 / Hahn HSG 140 Conventional Thinning	503	1516	*3.5	1.01	1.64	62.1%
Komatsu PC95 / Hahn HSG 140 Pre- Bunched Processing	211	624	*3.5	0.89	0.94	94.7%
Timbco T425 / Pika 600 Conventional Thinning	441	963	*3.2	0.94	1.07	87.7%
Timberjack 230-A Forwarding	51	3998	*3.5	31.28	32.07	97.8%

* Calculated using Smailien's volume formula
**Calculated using an average of 44 green lbs/ft3 (Caterpillar Performance Handbook)

A second factor influencing the loading element was the amount of effort made during the harvest /processing operation to separate the product sorts. A typical stem could contain a sawlog, a stud log, and a pulp log. Studies have shown that separating these products as they are processed does not have an adverse effect on the productivity of the harvest processing operation (Gingras 1996). In this study, the Komatsu PC 95 / Hahn HSG 140 operation made a concerted effort to separate products during the processing operation and the forwarder had an average cycle time of 29.86 minutes. The Timbco T425 / Pika 600 operation made no effort to separate products during the processing operation and the forwarder had an average cycle time of 33.02 minutes. While the total difference in average cycle times can not be completely attributed to the method of sorting, the amount of effort made to sort products during the processing phase seems to have some effect.

Table 3 shows the production rates for each machine and working format that was studied in pieces and cubic feet per productive machine hour (PMHr). These figures are delay free and represent the maximum potential of the machine. Production is also presented in pieces and cubic feet per scheduled machine hour (SMHr), including productive delay times, but not personal delays or major mechanical breakdowns.

REGRESSION ANALYSIS

Stepwise regression was used to analyze the effects of descriptive variables on the productive cycle time for each of the machines and operating formats. The strength of linear relationships was analyzed through the use of bivariate correlation coefficients and plotting of independent variables against total productive cycle time. Once the nature of the relationships was identified, transformations including squares, cubes, natural logarithms, selected cross products, and division of one transformation of a variable by another were used to minimize the effects of curved relationships and multicollinierity. Transformations of both dependent and independent variables were used. Independent variables and their transformations were run through a stepwise regression procedure and were evaluated for their ability to explain variability in the data. They were tested at a 0.05 level of confidence.

Table 4 summarizes the regression models that have been generated to describe the cut-to-length operations. The models for the Hitachi EX 150 / Keto 500 both used descriptive variables that were related to the stem size. Both the conventional thinning operation and the pre-bunched processing operation included stems that were close to the maximum capacity of the harvest/processing head. In the case of conventional thinning, plots of individual stem diameter versus total productive cycle time show the relationship to be nearly linear as stem volume approaches the capacity of the harvest / processing head. The relationship curves exponentially beyond this diameter.

No significant models could be produced for the total cycle time of the Komatsu PC 95 / Hahn HSG140 in conventional thinning or pre-bunched processing. The same was true for the Timbco T425 / Pika 600 operation. It appeared that the "Move" and "Handle Logs" elements were creating the problem since they did not occur on each harvest/processing cycle. A strategy of modeling the individual components of the cycle on a per stop basis was adopted. The productive elements per stop were made up of the following individual productive elements: position and grab, swing loaded, process and swing empty. These elements were summed for the individual trees per stop to find the total productive cycle time per stop. The total productive time per stop was used as the dependent variable in the modeling effort.

The models for productive cycle time per stop of the Komatsu PC 95 / Hahn HSG 140 in both conventional and pre-bunched processing used the number of trees per stop and the volume per stop as descriptive variables. The number of trees per stop is a measure of density removed and the volume per stop proved to be an important variable in all the harvest / processor models. Modeling of machine movement was attempted with unsatisfactory results. From observation, this machine required an estimated 28 moves per 530 feet of operation. The average time per move was 0.81 minutes based on 166 observed moves with an average move distance of 20 feet. There did appear to be a relationship between move time and slope as shown in Figure 2.

In the pre-bunched processing format, success in modeling machine movement was also limited. In the case of pre-bunched processing, machine movement appeared to be primarily dependent on the orientation of the bunches. As previously noted, the configuration of this machine limits processing to a 90 degree zone ahead of the machine. Proper orientation of the bunches was very important to minimize time spent moving between bunches, time required for additional handling of processed logs, and the number of moves for a given distance. Figure 3 shows move time as it relates to the two classifications of bunch orientation quality.
The model for the Timbco T425 / Pika 600 was done using the same format as that of the Komatsu PC 95 / Hahn HSG 140 operations. As with the other

Table 3. Production Summary

Harvest System	*Pieces PMHr*	*Pieces SMHr*	*Tons PMHr*	*Tons SMHr*	*ft^3 PMHr*	*ft^3 SMHr*
Conventional Thinning						
Hitachi EX 150/Keto 500	129.0	105	13.6	11.0	618.9	502.6
Komatsu PC95/Hahn HSG 140	177	110	14.2	8.8	645.4	400.8
Timbco T425/Pika 600	141	123	11.1	9.7	503.5	441.5
Pre-Bunched Processing						
Hitachi EX 150/Keto 500	149.0	148.0	27.3	27.2	1408.5	1401.9
Komatsu PC95/Hahn HSG 140	179	170	14.3	13.5	843.2	797.3
Forwarding						
Timberjack 230 A	150.0	147.0	12.0	11.7	547.4	535.6

harvest/processor models, the volume per stop and the number of pieces processed at each stop were important. Success in modeling machine movement in this operation was again limited. The operating format for this machine involved processing in an uphill direction, which included many small moves, and backing down the entire slope to start processing the next strip. The longer moves appeared to be dependent on the total strip length. The shorter uphill moves between processing stops were more difficult to describe, but there did seem to be some relationship between slope and moving time as shown in Figure 4. The long downhill moves are not included in this figure. The forwarding cycle was modeled by its component elements including the following: travel unloaded, load, move, travel loaded, and unload. R2 for these models ranged from 0.16 for the unloading model to 0.78 for the model describing loading. The total productive cycle was also modeled and yielded an R2 value of 0.57. Table 5 shows the coefficients and constants for each model.

Percent of bunks filled was the most significant descriptive variable and was found to be important in three out of five elemental models as well as the com-

Table 4: Regression Models For Harvest / Processors

Model Description	*Coefficients*	*R^2 Value*
Conventional Thinning		
Hitachi EX 150/Keto 500		
* LOG (Total Cycle Time)	- 1.0123	
	+ 0.02190(# of Logs/tree)2	
	+ 0.20823($\sqrt{}$Butt Diameter in inches)	0.54
Komatsu PC 95/Hahn HSG 140		
* $\sqrt{}$Total Cycle time/stop	- 0.14852	
	+ 0.13053 (LN Tree Vol/Stop in cubic feet)	
	+0.62580 ($\sqrt{}$# of Trees per stop)	0.89
Timbco T425/Pika 600		
* $\sqrt{}$Total cycle time / stop	+ 0.48859	
	+ 0.04159 (# of pieces / stop)	
	+ 0.09496 ($\sqrt{}$volume / stop in cubic feet)	0.91
Pre-bunched processing		
Hitachi EX 150/Keto 500		
*$\sqrt{}$Total Cycle Time	+ 0.67044	
	+ 0.01165 (Volume per tree in cubic feet)	0.59
Komatsu PC 95/Hahn HSG 140		
* $\sqrt{}$Total cycle time/stop	+ 0.45409	
	+ 0.05499(Trees / stop)	
	+0.08467 $\sqrt{}$ Volume / stop in cubic feet)	0.95

* All total cycle times and total cycle times per stop are represented in minutes

plete cycle time model. Upon inspection of correlation coefficients, it was found that "% bunks filled" and "number of moves" were highly correlated, and the cross product term was added to account for the interaction of these terms. (Ott 1993).

In some cases, one of the three product sorts had been identified with paint while it was still in the woods. This was done to facilitate product identification by the forwarder operator. Turns taken from areas in the woods with one product sort painted were assigned a value of 1 while turns taken from areas where no product sorts were painted were assigned a value of 0. This descriptive variable was statistically significant in the model for movement between loading cycles. The value of 0 or 1 is associated with a negative coefficient, which shows that the identification of one product sort in the woods decreased the time spent moving between loading cycles.

The low R^2 values associated with the travel unloaded and travel loaded models were unexpected as these are generally the most predictable elements in harvesting models. The model for travel loaded used the descriptive variable of distance out and the model for travel unloaded used the descriptive variable distance in. The low correlation coefficient may be partially explained by the fact that the majority of our sample was taken from areas within a small range of slopes (25% -35 %) and a small range of external forwarding distances (700 to 800 feet).

The model for unloading at the roadside deck proved to be the poorest of the elemental models. The only descriptive variable found to be statistically significant was "% of bunk filled." This was unexpected as the number of sorts in the bunk appeared to affect time spent unloading. From observation the configuration of the product sorts in the bunk may be more important than the number of sorts. If the product sorts were clearly separated in the bunk of the forwarder, the time spent unloading appeared to not be compromised. Problems occurred when multiple products were mixed in the bunk. If the forwarder could not unload the products at a single location, the operator would have to set one product aside, unload the other products, reload the first product, and move to the appropriate deck to fully unload the turn. This yielded long unloading and total cycle times.

PRODUCTION COSTS

The total dollar per hour cost for equipment was calculated for each piece of machinery using the method outlined in the Caterpillar Performance Handbook (1992). The cost analysis is based on new and used equipment prices of machines similar to those that were studied.

Table 6 summarizes the owning, operating, labor, and total costs associated with each machine studied.

The total dollar per hour costs were then combined with the production figures to find the dollar per unit cost for each of these systems. These costs are presented in Table 7.

Costs per unit for each machine are detailed. In the conventional thinning format the harvest/processor with the highest per piece cost was the Timbco T425 / Pika 600 with a cost per piece of $1.22. The second highest was the Hitachi EX 150 / Keto 500 at $1.14 per piece. The Komatsu PC 95 / Hahn HSG 140 had the lowest cost per piece at $ 0.74. These costs are based on new equipment prices, 1260 scheduled operating hours per year, and include an allowance for overhead,

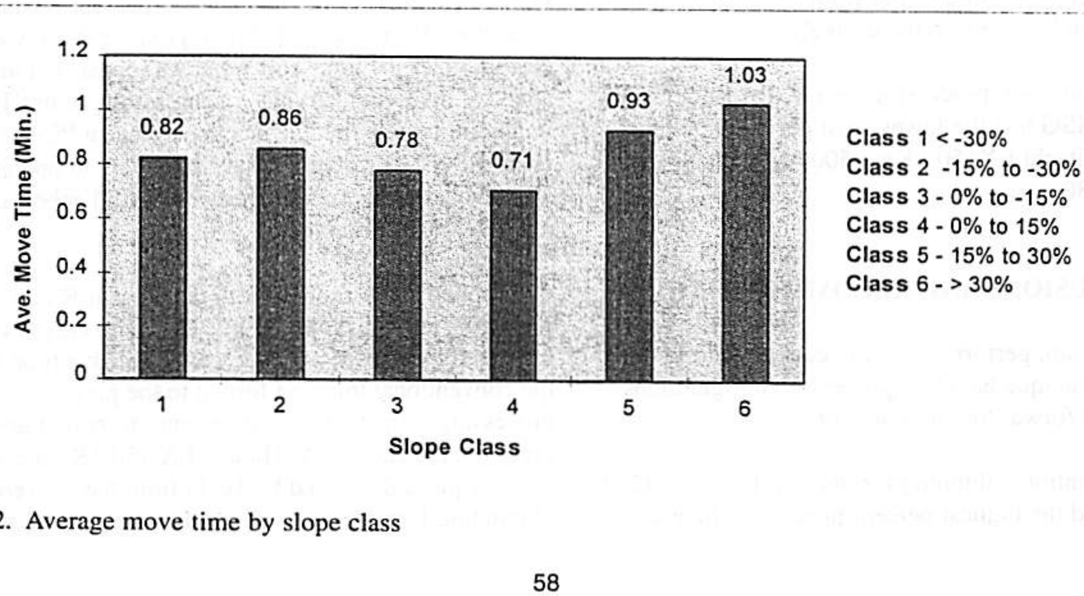

Figure 2. Average move time by slope class

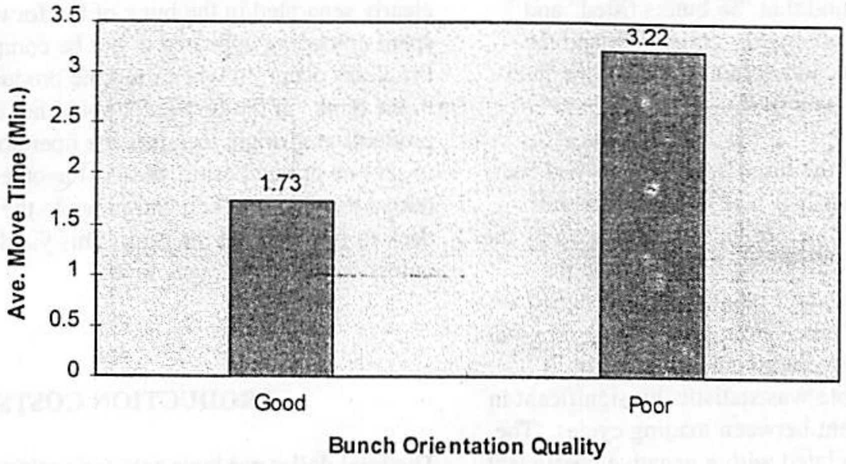

Figure 3. Average move time by bunch orientation classification

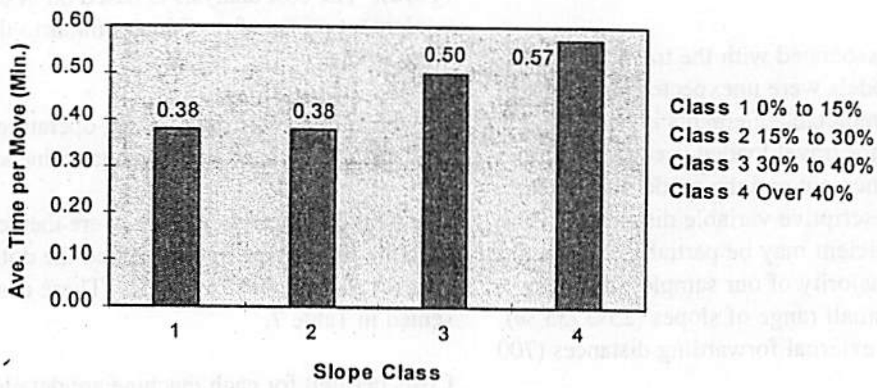

Figure 4. Average uphill move time by slope class

profit, and risk costs. The order of results are the same if the analyses are done using new equipment costs, 1600 scheduled hours per year, and with no allowance for overhead, and profit and risk costs. A subsequent analysis with used equipment prices narrowed the range between the Timbco and Kamatsu systems to \$.92/piece and \$.74/piece respectively.

In the pre-bunched processing format, the Komatsu PC 95 / Hahn HSG had the lowest cost per piece at \$0.48 while the Hitachi EX150 / Keto 500 had a per piece cost of \$0.80.

CONCLUSIONS AND RECOMMENDATIONS

The production, performance, and cost per unit of output of three unique harvest / processor configurations and a single forwarding unit are compared.

In the conventional thinning format, the Timbco T425 / Pika 600 had the highest percent productive time at 87.7%. This operation produced 123 pieces per scheduled hour, or 9.7 tons per scheduled hour at a cost of \$15.45 per ton, based on new equipment prices, 1260 scheduled hours per year and with an allowance for overhead, profit and risk. While the smaller Komatsu PC 95 / Hahn HSG 140 had a lower percent productive time of 62.1% it was still able to produce at a lower cost of \$9.25 per ton. This trend was consistent in all analyses involving varying costing assumptions. It is important to note that the smaller Komatsu PC95 / Hahn HSG 140 would not have been able to operate as effectively on the steep slopes where the Timbco T425 / Pika 600 was observed.

Our limited study showed both the Hitachi EX150 / Keto 500, and the Komatsu PC 95 / Hahn HSG 140 increased their respective percent productive time from the conventional thinning format to the pre-bunched processing format. The cost per unit decreased accordingly. In the case of the Hitachi EX 150 / Keto 500 the cost per piece decreased by \$0.34 from the conventional thinning format to pre-bunched processing format.

Table 5. Timberjack 230-A forwarding models

Model Description	Coefficients	R square R^2	Significance Prob > F
Travel Unloaded	+ 1.75519	—	0.0018
	+0.00433 (distance out)	---	0.0000
	Durbin-Watson Value 1.5	0.42	0.0000
√ Loading	+ 0.93149	—	0.0046
	+ 0.02219 (% of bunks)	---	0.0000
	+ 0.17581 (number of moves)	---	0.0001
	- 0.00113 (%bunks x number of moves)	---	0.0204
	Durbin-Watson Value 1.8	0.78	0.0000
√ Movement Between loading cycles	+ 0.61205	—	0.0229
	- 0.71877 (paint)	---	0.0083
	+ 5.40853 x 10^{-7} (distance in)^2	---	0.0107
	+ 0.00115 (collection distance)	—	0.0010
	+0.011067 (% of bunk)	---	0.0013
	Durbin-Watson Value 1.6	0.48	0.0000
Travel Loaded	+ 2.56260	—	0.0000
	+3.53836 x 10^{-6} (distance in)^2	---	0.0000
	Durbin-Watson Value 2.0	0.29	0.0000
LN (Unload)	+ 0.61358	—	0.0039
	+ 0.011378 (% of bunk)	---	0.0000
	Durbin-Watson Value 1.3	0.16	0.0039
√ Total Cycle Time	+ 8.78037	—	0.0000
	+ 0.05798 (% slope)	—	0.0086
	- 3.10233 (number of sides)	---	0.0004
	+ 9.20211 x 10^{-4} (distance out)	—	0.0171
	+0.001456 (% bunks x number of Moves)	—	0.0000
	Durbin-Watson Value 1.9	0.57	0.0000

- Distance out The distance traveled from the deck to start of loading cycles. Data Range (225 to 1668 feet)
- % Bunk filled The percent of the bunk that was filled prior to unloading. Data Range (25% to 100%)
- Number of moves The number of move cycles required to fill the bunks Data Range (2 to 17)
- % Bunks x Number of Moves The cross product term of % Bunks filled and Number of moves.
- Paint A dummy variable taking the value of 0 if no sorts were identified with paint, and 1 if one sort had been identified with paint in the woods.
- Distance in The distance from the final loading point to the final deck. Data Range (30 to 360 feet)
- Collection distance The distance required to fill the bunks. Data Range (30 to 873 feet)
- Slope The average percent slope of the ground expressed as a whole number. Data Range (0% to 40%)
- Number of sides The number of sides the operator could load from Data Range (1 or 2)
- Prob > F The probability to which the regression is significant.
- LN This means the natural logarithm in base e

The cost per piece decreased by $0.26 from the conventional thinning format to the pre-bunched processing format for the Komatsu PC 95 / Hahn HSG 140 operation.

The pre-bunching operations may also have streamlined subsequent product handling and lowered site impacts in the form of residual stand damage and soil compaction. Whether these increases are enough to offset the costs of the pre-bunching operation was not analyzed in this study. However, these results suggest that productivity gains could be realized if a cost effective pre-bunching format is utilized. Further studies involving a larger sample size and covering more variability in terrain, and bunching configurations are needed to fully analyze the effectiveness of pre-bunching on processor operations.

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Table 6 : Owning And Operating Cost Summary (based on new equipment prices, 1260 Hours per year and including risk and overhead costs)

Machine description	*Owning cost $/SMHr*	*Operating cost $/PMHr*	*Labor cost $/SMHr*	*Profit and risk $/SMHr*	*Total cost $/Hr*
Hitachi EX150 / Keto 500*	49.87	18.62	25.04	25.40**	118.93
New Komatsu PC95 Hahn HSG 140	27.61	12.51	25.04	16.37**	81.53
Used Komatsu PC95 Hahn HSG 140	25.42	15.81	25.04	15.48**	81.75
New Timbco T425 / Pika 600	67.47	25.04	25.04	32.54**	150.09
Used Timbco T425 / Pika 600	40.70	26.57	25.04	21.03**	113.35
Timberjack 230A*	24.80	9.63	25.04	15.79**	75.27

* These machines were only analysed using new equipment prices as used prices were not available.
** Overhead, profit and risk calculation can be found in Appendix D.

Table 7. Production Costs (based on new equipment, 1260 hours per year and including overhead, profit and risk)

Machine description	*$/Piece PMHr*	*$/Piece SMHr*	*$/ft^3 PMHr*	*$/ft^3 SMHr*	*$/ton PMHr*	*$/ton SMHr*
Hitachi EX150 / Keto 500						
Conventional thinning	0.92	1.14	0.19	0.24	8.73	10.76
Hitachi EX150 / Keto 500						
Pre-Bunched processing	0.80	0.80	0.08	0.08	3.84	3.86
Komatsu PC95 / Hahn HSG 140						
Conventional thinning	0.46	0.74	0.13	0.20	5.74	9.24
Komatsu PC95 / Hahn HSG 140						
Pre-Bunched processing	0.46	0.48	0.13	0.13	5.70	5.98
Timbco T425 / Pika 600						
Conventional thinning	1.07	1.22	0.30	0.34	13.55	15.45
Timberjack 230A						
Forwarding	0.50	0.51	0.14	0.14	6.25	6.39

Methods Used to Evaluate the Effects of Forest Operations on the Remaining Vegetation and Soil: Review and Recommendations

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Abstract: The effects of forest operations on the physical attributes and ecology of a forest site are of great concern to landowners, forest managers, equipment operators, and the environmental community. Consistent, accurate, and economic methods for evaluating effects are needed. In this paper, we will review methods from the literature that are being used to evaluate the physical effects of forest operations on the remaining vegetation and soil. These will include methods to evaluate residual tree damages, damage to understory plants and seedlings, degree of soil displacement, and degree of soil compaction. From this review, we will recommend specific methods for evaluating these effects.

Key Words: forest operations, evaluation methods, tree damage, site disturbance, soil compaction

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INTRODUCTION

Forest operations, such as timber harvesting, road building, site preparation, and mechanical planting, can affect the physical attributes and ecology of a forest site. Typical effects include physical damage to remaining trees and plants, displacement and mixing of soil layers, and compaction of surface soil layers.

These effects can be either intended or unintended in the particular operation being conducted. They can also be considered desirable or undesirable relative to the management objectives for the site. Most operations result in some combination of intended/desirable, unintended/desirable, and unintended/undesirable effects. Although a fourth category exists, namely intended/undesirable, we don't believe anyone intentionally creates undesirable effects in forest operations.

Examples of intended/desirable effects include removing vegetation and organic soil from a road right-of-way, clearing the competing vegetation and humus in a spot scalping operation, or opening a slit in the soil to accept seedlings in a planting operation. Examples of unintended/desirable effects might include the soil scarification and associated seedbed preparation that often occurs in log skidding, the possible improvement in drainage efficiency associated with road construction operations, the possible increase in nutrient availability associated with site preparation operations, or the reduction in competition of undesirable vegetation with planted seedlings as a result of physical damage from the prime mover in planting operations.

The category of effects that is of most concern in forest operations is that considered unintended/undesirable. This includes unwanted damage to remaining trees and plants, unwanted displacement and mixing of soil layers, unwanted compaction of surface soil layers, damage to archeological resources, contamination of soil and water by oil and gas spills, and release of pollutants into the atmosphere. These effects sometimes lead to further undesirable effects, such as soil erosion, stream siltation, poor water quality, reductions in wildlife populations, increases in insect or disease populations, reductions in tree growth rates, increased tree mortality, changes in low plant communities, and a decrease in aesthetic quality of the site.

Knowledge of the magnitude and prevalence of these unintended/undesirable effects is important in order to minimize future impacts and maintain a healthy forest environment. A good methodology for measuring these effects is critical to properly assessing their extent and importance. A good evaluation system or method has the following attributes:

Accurate - The system should provide an accurate description of the physical effects that actually occurred as a result of the forest operation.

Consistent - Measurements should be objective so that they can be consistently and repeatably applied by different observers.

Easy to apply - It should be reasonably fast and easy to apply to minimize the cost of data gathering.

Provide useful information - It should provide useful and appropriate information for developing a clear picture of direct and possible indirect effects.

Statistically valid - It should provide methods and measurements that are statistically valid.

The purpose of this report is to review past and current methods being used to evaluate the effects of forest operations on the remaining vegetation and soil. From this review, we will recommend assessment methods we feel are appropriate for general use, as well as highlight research needs in this area.

DAMAGE TO RESIDUAL TREES AND PLANTS

Damage to residual trees and plants in forest operations can take many forms. Scuffs are scrapes that damage or remove a portion of the outer and/or inner bark from the bole, roots, or branches of a tree. These wounds can cause discoloration of the adjacent wood, affecting product value at the time of harvest (Ohman 1970). They also provide a pathway for insects, disease, and decay to infect and further damage or kill the tree over time (Shigo 1979).

Gouges are scrapes or punctures that extend through the bark layers into the wood. These wounds are presumed to have a similar but more serious effect on discoloration, decay, and insect and disease attack than scuff wounds (Bruhn 1986). Cuts are like gouges except they are done with a sharpened tool, such as a chainsaw, circular saw, disc saw, or pruning saw. Cuts and gouges have similar effects on the tree.

Other damages that can occur include pinned, leaning, broken, and uprooted trees and plants. Pinned trees are bent over with the leader pinned to or near to the ground. Leaning trees have been pushed partially over so they are standing at a different angle than before. Broken trees or plants have had their top broken off at some point along the stem. Uprooted trees or plants have been completely uprooted from the soil. Except for leaning trees, these damages generally destroy the growth and future value potential of the tree or plant.

Broken branches are a common form of crown damage in forest operations. This type of injury can result in effects similar to scuff wounds, as well as decrease the overall vigor and current growth potential of the tree (Nyland 1994). Frayed branch stubs in the tree crown are more likely to result in rot because they tend to trap and retain moisture (Anderson 1994). Broken branches may be inconsequential if only a few small branches are broken, or very serious to tree or plant health if many larger branches are broken.

Severed or crushed roots are common forms of root damage in forest operations. These injuries can result in effects similar to that of broken branches. Wounds in contact with soil are more susceptible to decay because the moisture provides a good environment for infection (Dey 1994). Discoloration and decay initiated in roots often extend into the butt log of the tree (Benzie et al. 1963). Root damage can occur without any visible disruption of the soil (Shepperd 1993), making assessment of actual root damage difficult. Severe root damage often occurs in conjunction with soil rutting. The partial protection provided by soil over the roots is lost when rutting occurs, leaving the roots vulnerable to damage.

Damage to residual trees and plants in forest operations can occur in several ways. A machine operating in the stand can damage vegetation directly by rubbing up against them, by running over them, or by swinging moveable parts against them. A machine can also indirectly damage vegetation by pushing or dragging other materials (such as trees, logs, rocks, and dirt) up against or past them.

A large portion of damage to residual trees and plants comes from unintended interaction with cut trees and logs. This occurs in felling as the tree falls, in extraction as the tree or log is moved from the stump to the landing or roadside, in decking as the tree or log is piled, and in loading as the tree or log is loaded.

Although the causes and effects of damage to low plants and seedlings are similar to those of residual trees, the methods used to assess damages to each are somewhat different. Reasons for differences include the smaller size and greater abundance of low vegetation, along with differences in the types of damages they normally sustain. Therefore, we will discuss the methodology associated with each separately.

Assessment of residual tree damage

Residual tree damage as a result of forest operations can be assessed in several ways. One is to evaluate damages as they occur (e.g., Wendel and Kochenderfer 1978; Kellogg and Hargrave 1985). This method provides exact knowledge of how the damage occurred, which can then be used to minimize future damages. More commonly, however, damage is evaluated after the operations of interest are complete (e.g., Lamson et al. 1985). Associating damages with their cause (i.e., felling, skidding, etc.) using this approach requires that the damage assessment be repeated after each individual operation is complete.

If the measurement area of interest is small enough, a 100% survey of all residual trees can be done (e.g., Sidle and Laurent 1986; Howard 1996). For larger areas, a sampling pattern must be employed. Sample plots can be laid out in a completely random pattern (e.g., Kelley 1983); a systematic pattern, such as plots with fixed spacings on lines with fixed spacings (e.g., McNeel and Ballard 1992); or some combination of random and systematic, such as plots with fixed spacings on randomly located lines (e.g., Baumgras et al. 1995), randomly spaced plots on lines with fixed spacings (e.g., Ostrofsky et al. 1986), or randomly selected points on a fixed grid (e.g., McLaughlin and Pulkki 1992).

Sample plots can be circular or rectangular. Circular plots can be fixed radius or variable radius. For fixed radius circular and rectangular plots, all trees larger than some minimum specified size falling within the plot boundaries are evaluated for damage (e.g., Ficklin et al. 1997). For variable radius plots, all trees larger than the minimum specified size identified as being in with a prism are assessed for damages (e.g., Meyer et al. 1966; Fairweather 1991).

A line transect can also be used to define fixed and variable width sample plots. A fixed width plot is formed when all trees within a given perpendicular distance from the transect line are measured (e.g., Nichols et al. 1993; Biltonen et al. 1976). A variable width plot is formed when a prism is used to define sample trees on either side of the transect line (e.g., Cline et al. 1991).

Pilkerton et al. (1996) compared four different sampling patterns for evaluating residual stand damage: fixed radius circular plots with fixed line and plot spacings, randomly located fixed radius circular plots, fixed width to either side of evenly spaced line transects, and fixed width blocks laid out perpendicular to the skyline road. They concluded that the sampling pattern using fixed radius circular plots with fixed line and plot spacings was the most efficient to install and provided an acceptable estimate of residual stand damage.

Plot sizes (in acres) used for fixed-area plots include 0.0125 (e.g., McLaughlin and Pulkki 1992), 0.025 (e.g., Lanford and Stokes 1995), 0.05 (e.g., Nichols et al. 1993), 0.1 (e.g., Bettinger and Kellogg 1993), 0.2 (e.g., Reisinger and Pope 1991), 0.5 (e.g., Miller et al. 1984; Meadows 1993), 1.25 (e.g., Schmid and Mata 1993), and on up to the full harvested area for 100% surveys (e.g., Bruhn 1986; Howard 1996). Several damage surveys employing variable plot boundaries used a basal area factor (BAF) 10 (square feet) prism (Fairweather 1991; Meyer et al. 1966; Thompson et al. 1995), whereas one used a BAF 75 prism (Cline et al. 1991).

The minimum size tree (diameter at breast height - dbh) evaluated for damages varies considerably between studies. Minimum tree sizes (dbh in inches) used have included 0.5 (e.g., Nichols et al. 1993), 1.0 (e.g., Wendel and Kochenderfer 1978), 1.5 (e.g., Thompson et al. 1995), 1.6 (e.g., Herrick and Deitschman 1956), 2.0 (e.g., Kelley 1983), 2.5 (e.g., Lanford and Stokes 1995), 3.0 (e.g., Cline 1991), 4.0 (e.g., Davis and Vollmer 1993), 4.6 (e.g., Fairweather 1991), 5.0 (e.g., Huyler et al. 1994), 6.0 (e.g., Reisinger and Pope 1991), and 8.0 (e.g., Nyland et al. 1976).

The number or percent of trees damaged is a common statistic reported in damage studies and will vary considerably if small trees are included. Although there are some very good reasons not to assess damages to small trees in some silvicultural systems, to ensure comparability of results, minimum tree size or size groupings should be kept consistent from one damage study to the next.

Common attributes recorded for damaged trees include tree species, tree dbh, distance from the tree to the nearest trail, distance down the trail to the landing, location of the damage (root, root collar, bole, or crown), whether or not it is a potential crop tree, and type of damage (outer bark scuff, exposed sapwood scuff, gouge, cut, pinned leader, leaning bole, broken bole, uprooted bole, broken branches, and broken or crushed roots). If the damage is a scuff, gouge, or cut, measurements taken include the length, width, area, and depth of the damage, the height to the base of the damage, and the quadrant that the damage is located in relative to the nearest trail and landing.

Pinned, leaning, broken and uprooted trees are noted as such, with the angle of lean and height to broken top noted. The height to and size of broken branches are noted, while the size of and distance from the root collar for severed or crushed roots are noted. Other factors that are assessed to help explain the observed damage rates include the number and size of the trees removed, the number and size of the trees remaining, the lengths of the products being removed, the operational systems used, the experience and care level of the operator, the terrain, the season of harvest, and other possible influencing factors. Different evaluation systems used to quantify residual stand damage vary considerably in relation to these measured attributes.

Recommended tree damage evaluation methods

There is a need to standardize the methodology used to assess residual tree damages resulting from forest operations (Bruhn 1986). A standard methodology will help provide for meaningful and unbiased comparisons between alternative systems, as well as ensure consistency in impact monitoring programs. As a starting point in this effort, we recommend the following:

Sample uniformly - The sampling pattern used should be uniform across the area of concern. Residual tree damages are often more prevalent along main extraction routes and close to the landing. Sampling the area uniformly will ensure the sample represents the entire area. Plot or transect lines should be evenly spaced and run perpendicular to the trails and corridors to lessen the risk of oversampling near or away from these extraction routes (Young 1994). Also, uniform sampling patterns are easier to install and at least as accurate as other possible sampling schemes (Pilkerton et al. 1996).

Sample intensively - Sample as intensively as possible to achieve a reasonable level of confidence in the data. Samples cost money, but incorrect conclusions could cost a lot more. Schreuder et al. (1993) discuss this in detail.

Use variable radius plots - Variable radius plots increase measurement efficiency by lowering the number of trees that must evaluated with no loss in accuracy (Dilworth and Bell 1977). McNeel et al. (1996) recommend that damage assessment be an extension of current inventory procedures. Variable radius plots are commonly used in forest inventory, making damage assessment by prism a natural extension of current practice.

Use a common mimimum tree size - The minimum tree size surveyed for damages will affect observed damage rates. The main effect will be due to a difference in the number of trees per unit area included in the survey. A secondary effect will be due to possible differences in damage rates based on tree size. For this reason, it is important to have a common minimum tree size or common size groupings between damage studies if they are to be compared. We recommend grouping trees by size into saplings (dbh from 1.0 to 4.0 inches) and larger trees (dbh greater than or equal to 4.0 inches).

Relate damage to a single operation - Each forest operation has unique factors that affect stand damage rates. Lumping the damages from more than one operation together makes it impossible to distinguish the damages associated with each particular operation, potentially biasing comparisons between equipment and operational methods. This can be done by watching the damages as they are occurring or surveying for damages after each individual operation.

Measure all pertinent data - Data we feel should be measured includes the following:

- Tree species
- Tree diameter at breast height -
  - Saplings $\geq$ 1.0 and < 4.0 inches
  - Larger stems $\geq$ 4.0 inches
- Potential crop tree - yes or no
- Distance to the nearest trail
- Distance along trail to the landing
- Damage location - root, root collar, bole, or crown
- Damage type
  - Outer bark scuff- length, width, height, quadrant
  - Exposed sapwood scuff - same as above
  - Gouge - same as above, also maximum depth
  - Cut - same as gouge
  - Pinned leader
  - Leaning bole - approximate angle of lean
  - Broken bole - height to break, diameter at break
  - Uprooted bole
  - Broken branches - height and size of each broken branch $\geq$ 2 inches diameter at break
  - Severed or crushed roots - size, quadrant, and distance from the root collar for each root
- Other pertinent information
  - Species, number, and size of the trees removed
  - Species, number, and size of the trees remaining
  - Type and lengths of products removed
  - Operational systems used in the harvest
  - Experience and care level of the operator
  - Local terrain and ground conditions
  - Season of harvest
  - Level of harvest planning and oversight

Damage to low plants and seedlings

Assessing damage to low plants and seedlings as a result of forest operations should not be confused with a regeneration survey, although similar methods are used. The purpose of a regeneration survey is to assess the adequacy of tree seedling stocking and composition, along with a measure of the competing vegetation present (Brand et al. 1991). This information can then be used to decide if further treatment or planting of the area is needed.

The purpose of a damage assessment is to determine how a particular operation impacted low vegetation. A distinction is often made between desirable tree regeneration and other low vegetation, with only the former being assessed in many cases (e.g., Gingras 1994). In some cases, the effect of operational damage is evaluated using changes in seedling stocking and composition as an indicator with no direct assessment of actual damages (e.g., McInnis and Roberts 1994). This approach blurs the line between damage assessment and regeneration surveys.

Damage to low vegetation is normally assessed using fixed-area plots of a much smaller size than that used to assess residual tree damage. This can be attributed to the larger number of species and individual plants generally present. Plot sizes (in square meters) that have been used include 3.1 (e.g., Tesch et al. 1990), 4.0 (e.g., Gingras et al. 1991), 5.0 (e.g., McInnis and Roberts 1994), 10.2 (e.g., Sauder 1992), and 16.2 (e.g., Gottfried 1987). In some cases, only one tree seedling in each sample plot is identified and evaluated for damage (e.g., Tesch et al. 1990). Continuous transect bands have also been used (e.g., Youngblood 1990).

Sample plots can be located using any of the patterns discussed previously to sample residual tree damage. The most common pattern used is evenly spaced plots on evenly spaced parallel transect lines running perpendicular to the main extraction trails (e.g., Gingras 1990; McInnis and Roberts 1994). If transect bands are used, they are usually evenly spaced, parallel, and running perpendicular to trails or yarding corridors (e.g., Youngblood 1990).

All recognized vegetation within the plot boundaries is evaluated. Tree seedlings or other woody plants are often separated into height classes (e.g., Gottfried 1987). Damages to these plants are often categorized into one of several classes, such as uninjured, injured, and destroyed (Sauder 1992) or undamaged, slightly damaged, moderately damaged, and severely damaged (Tesch et al. 1990).

Recommended evaluation methods for low plants

The damage assessment system used will depend on the informational needs of the study (as defined by the objectives), as well as on site characteristics, budget, personnel, and other factors. We recommend using the same guidelines as outlined for assessing residual tree damages, except for the following:

Use fixed-area plots - Variable radius plots cannot be used for low vegetation due to the small size. We recommend circular plots 5.0 square meters (radius of 1.26 meters) in size.

Integrate with tree inventory procedures - Define size and diameter limits of recognized vegetation relative to the limits used in the tree inventory phase (e.g. if a one-inch tree is the minimum size recognized in the tree inventory plots, just under one inch would be the largest tree recognized in this assessment).

Measure all pertinent data - Data we feel should be measured include the following:

- Species
- Height
- Damage class
  - Uninjured - No apparent injury
  - Injured - Obvious injury, but good chance of survival and subsequent growth
  - Destroyed - Obvious injury with little or no chance of survival and growth
- Other pertinent information related to the study objectives and operational system

SOIL DISTURBANCE

Soil disturbance in forest operations can be defined as an abrupt change in the chemical, biological, or physical characteristics of the soil as a direct result of the system operating on the site (Standish et al. 1988). Mechanical displacement of the soil by moving machinery, trees, and logs is the main mode of disturbance. Displacement of soil can result in a loosening and mixing of soil layers or the compacting of surface soils (Froehlich 1973).

Most forest operations rely on the use of heavy equipment, which nearly always results in some form of disturbance (Beets et al. 1994). Some is intended and desirable, such as when clearing the right-of-way and compacting the subgrade in roadbuilding, when preparing the surfaces of landings and access trails, and when creating an opening in the soil for tree planting.

Much of the soil disturbance that occurs in forest operations, however, is unintended and undesirable. The passage of loaded or unloaded equipment over the soil generally causes some movement, mixing, and compaction. The more passes made, the more severe the disturbance. Rutting results when soil is pushed out from under the tires or tracks. Trees or logs being removed from the forest can also result in disturbance of soil by direct contact with the ground.

Moving, mixing, and compacting the soil layers can affect site quality and plant community dynamics. Moving soil and damaging the vegetation that holds it together can sometimes cause further movement of soil by erosion. Erosion of the soil can further deteriorate site quality and lead to sedimentation of adjacent water resources, affecting water quality and fish habitat.

Compaction of the soil can directly affect soil porosity, vegetation growth, soil biota, and water infiltration rate (Reisinger et al. 1988). Recovery of compacted soils to original densities can be slow (Froehlich et al. 1985). Therefore, it is important to minimize the unintended/undesirable disturbance of soil in forest operations.

Krag et al. (1986) emphasize the importance of identifying the sources of soil disturbance to properly assess its significance, as well as categorizing the depths of disturbances to better assess severity. Roads, landings, and extraction trails (with trails sometimes broken down into primary and secondary) are the normal sources of disturbance that have been identified in past studies. With newer mechanized harvesting systems, disturbance created by feller-bunchers or harvesters should also be considered as a category.

Bockheim et al. (1975) observed that evaluating the merits of soil disturbance is complicated by the fact that the nature and degree of soil disturbance are neither uniform nor randomly distributed across a harvested area. The non-random character of the distribution precludes evaluation of impacts by random sampling of soils before and after harvesting. They then suggest a strategy for assessing the effects of timber harvesting on soils, summarized as follows:

- Classify the nature and intensity of soil disturbance by criteria distinguishable in the field.
- Determine the physical and chemical properties of the soils by sampling within the stratifications determined by disturbance categories.
- Interpret changes in soil properties in terms of beneficial and detrimental effects.
- Determine the area distribution of the various disturbance classes.
- Summarize the effects for the entire harvested area.

The systems used to classify disturbance resulting from forest operations are many and varied. Dyrness (1965) used the following four categories:

- Undisturbed - Litter in place, no compaction.
- Slightly disturbed - Three conditions fit this class:
  - a. Litter removed and undisturbed mineral soil exposed;
  - b. Mineral soil and litter intimately mixed, with about 50 percent of each;
  - c. Pure mineral soil deposited on top of litter and slash to a depth of at least 2 inches.
- Deeply disturbed - Surface soil removed and the subsoil exposed; the soil surface is very seldom covered by litter or slash.
- Compacted - Obvious compaction due to passage of a log or mobile equipment.

A number of other researchers have either used this scheme or expanded on it slightly. Bockheim et al. (1975), Miller and Sirois (1986), Sidle and Laurent (1986), Reisinger et al. (1992), and Aust et al. (1993a) all generally followed these categories. Martin (1988) expanded the classification to 10 categories as follows:

- Undisturbed - No visual disturbance of any type.
- Depressed - Forest floor not disturbed laterally, but depressed by equipment or by a falling tree.
- Organic scarification - Forest floor disturbed laterally, but no evidence of compression by wheels, tracks, or falling trees.
- Mineral scarification - Removal of the organic horizons but no disruption of the mineral soil.
- Organic mounds - Mounds of soil, still covered by organic material.
- Mineral mounds - Mounds of mineral or organic soil covered by mineral soil deposits.
- Organic ruts - Shallow wheel or track ruts within the organic horizons or deep compression ruts still lined with organic soil.
- Mineral ruts - Wheel or track ruts in mineral soil.
- Dead wood - Stumps or logs in contact with the soil or slash too dense to allow for evaluation.
- Rock - Bare rocks larger than 10 cm.

Turcotte et al. (1991) used a fairly similar scheme of nine categories, but grouped them into 4 consolidated categories as follows:

- Slash
- Intact forest floor
  - Undisturbed
  - Organic mound
  - Organic rut

- Bare mineral soil
  - Mineral scarified
  - Mineral mixed
  - Mineral mound
  - Mixed side rut
- Mineral ruts

McMahon (1995a) used one of the most detailed classification schemes, distinguishing between 15 disturbance types grouped into five classes:

- Undisturbed
- Shallow disturbance
  - Litter in place
  - Litter removed, topsoil intact
  - Litter and topsoil removed
  - Topsoil deposited on litter
- Deep disturbance
  - Topsoil removed, subsoil exposed
  - Erosion feature
  - Subsoil puddling
  - Rut 5 to 15 cm deep
  - Rut 16 to 30 cm deep
  - Rut >30 cm deep
  - Subsoil/baserock deposit
- Slash cover
  - 10 to 30 cm deep
  - >30 cm deep
- Non-soil

Two clarifying codes of C for compacted and M for mineral/subsoil were used with these classifications.

The classification systems presented here illustrate the amount of variation that exists between systems in common use. The system used to classify disturbance will ultimately determine whether or not the results are comparable to other results. Therefore, to ensure comparability, a standard classification system should be used when documenting soil disturbances.

Recommended disturbance classification system

We recommend a disturbance classification system similar to that used by Martin (1988) as follows:

- Undisturbed - No visual evidence of disturbance.
- Depressed - Some evidence of compaction, but no lateral movement of soil and litter still intact.
- Covered - All original soil layers intact and undisturbed, but covered by loose adjacent soil.
- Scarified, Organic - Forest floor disturbed laterally exposing organic soil with no evidence of compression by wheels, tracks, logs, or trees.
- Scarified, Mineral - Forest floor and organic soil disturbed laterally exposing mineral soil with no evidence of compression by wheels, tracks, logs, or trees.
- Mounded, Organic - Forest floor and organic soil displaced laterally and possibly mixed forming mounds with no disturbance to the mineral soil.
- Mounded, Mineral - Forest floor, organic soil, and mineral soil displaced laterally and possibly mixed forming mounds with no evidence of compression by wheels, tracks, logs, or trees.
- Rutted, Organic - Forest floor and organic soil mixed and compacted by wheels or tracks leaving a rut, no disturbance of mineral soil other than compaction.
- Rutted, Mineral - Forest floor, organic soil, and mineral soil mixed and compacted by wheels or tracks leaving a rut in the mineral soil.
- Muck - Organic or mineral muck in ruts precluding evaluation of depth and severity.
- Wood - Stumps or other tree parts covering the soil.
- Rock - Rocks larger than 15 cm on the surface.

We feel this system is sufficiently detailed to be informative, without sacrificing reproducibility by including too much detail.

Soil disturbance sampling

Because forest sites are usually too large to determine and map specific soil disturbances at every point, a sampling method is needed. Methods in use are based on classifying single points (e.g., Dyrness 1965; Sidle and Laurent 1986); the small area around a point (e.g., McMahon 1995a; Meek 1994; Reisinger et al. 1992; Gingras 1994); the length of intersecting line segments (e.g., Howes et al. 1983; Hatchell et al. 1970); or the intersecting area a fixed distance to both sides of a transect (McNeel and Ballard 1992).

For the classification of disturbance at discrete points or over small areas, sampling points can be located across the area of concern randomly (e.g., Li and Chaplin 1995), along straight lines (e.g., Bockheim et al. 1975), along zigzag lines (e.g., Krag et al. 1986; Hall 1996), or in clusters (e.g., Kleinn 1994). The most common method used is to locate sampling points along straight transect lines.

The transect lines used to locate sampling points or to evaluate disturbance continuously can originate from random starting points (e.g., Turcotte et al. 1991) or from fixed starting points (e.g., Lanford and Stokes 1995; Baumgras et al. 1995). Transect lines can run in either random directions (e.g., Martin 1988) or in fixed directions, such as parallel (e.g., Aust et al. 1993a), parallel but perpendicular to the main transect (e.g., Miller and Sirois 1986), or crossing to form a diamond pattern (e.g., Thompson et al. 1995).

McMahon (1995b) tested two sampling patterns while using the small area around a point method of assessing site disturbance. These patterns are as follows:

Point transect - Sampling points are evenly spaced along parallel, evenly spaced line transects that are laid out perpendicular to the predominant direction of travel.

Grid point intercept - A grid system with pre-defined line spacing is randomly oriented over a study site. At each intercept, four transects are run to form a cross, starting with a random bearing. Sampling points are then located at predetermined spacings along each transect.

Three point transect spacings (30, 50, and 80 m) and one grid spacing (60x60 m) were compared. Sample points were taken every 1 m along transects. Grid point transects were 30 m long. An intensive 1x1 m survey was used as the actual to which the other methods were compared. McMahon (1995b) concluded that the point transect method gave the most accurate and consistent estimate of disturbance in the sample area.

Recommended disturbance sampling method

We concur with Bockheim et al. (1975) that due to the non-random nature of disturbances from forest operations, sampling systems should be uniform across the site to provide an unbiased representation of effects that exist across the entire area. Also, plot or transect lines should be oriented generally perpendicular to major features, such as roads, landings, access trails, and yarding corridors.

Although McMahon (1995b) considers the line transect method (measuring disturbances continuously along the transect) too subjective, we intuitively feel this is the best method for assessing site disturbance. We feel it is the least data intensive method available to achieve a given level of accuracy. We have no scientific information supporting this conclusion, however. Several researchers have used this method with no mention of it being too subjective (e.g., Howes et al. 1983; Martin 1988; Hatchell et al. 1970; Aust et al. 1993a; Turcotte et al. 1991; Lanford and Stokes 1995).

We also feel that the survey should begin as soon after the operation as feasible before actual effects are changed or covered up by wind, precipitation, falling leaves, low plant growth, etc. Disturbances due to different operations (i.e., felling, skidding, etc.) should be assessed separately whenever possible.

Soil compaction

Following the recommendations of Bockheim et al. (1975), the physical properties of the soil are assessed within the stratifications outlined in the disturbance survey. One of the main properties of interest is soil compaction due to the influence it has on root growth and development, and the absorption of water into the soil (Adams and Froelich 1981).

Soil compaction is usually determined indirectly by measuring the change in soil properties that are influenced by compaction. Soil bulk density and porosity are the most direct quantitative measurements of soil compaction and are frequently used to express changes in soil properties due to machine traffic (Reisinger et al. 1988). Bulk density is most commonly determined by extracting core samples of the soil under study, determining volume and oven-dry weight of the sample, and calculating a value for bulk density (Blake and Hartge 1986).

Determination of bulk density from core samples is usually done in conjunction with laboratory analysis of other key soil properties, such as porosity and hydraulic conductivity (e.g., Aust et al. 1993b). Core sampling can be very physically demanding work, particularly in heavy clay soils. Rocky soils and soils with significant amounts of roots are also difficult to sample with a core sampler. Errors can occur with core samples due to accidental compaction of the the soil in the core resulting from incorrect sampling techniques (Raper and Erbach 1985).

The nuclear-gamma radiation gauge is an alternate method for determining soil bulk density and moisture content. Several researchers have used this technology when studying the effect of forest equipment on soil properties (e.g., Froelich et al. 1980; Donnelly et al. 1991; Davis 1992). The nuclear-gamma radiation gauge is operated in a non-destructive sampling mode, allowing resampling of the soil in-place before and after the operation. This approach (i.e., sampling the same soil in-place), minimizes the error associated with natural soil variation.

Murosky and Hassan (1991), in a study of the impact of tracked and rubber-tired skidder traffic on a wetland site in Mississippi, used both core sampling and a nuclear-gamma radiation gauge to determine dry bulk density and moisture content of the soil. The nuclear gamma radiation gauge was found to give consistently lower values for bulk density than the soil cores. A regression analysis of the results obtained with the two methods produced an R^2 value of 0.908, indicating that the results obtained with the nuclear-gamma radiation gauge could be corrected to soil core results with confidence. A potential problem with non-destructive sampling methods is that the presense of foreign objects such as large rocks or roots in the sampling area may not be detected.

A third alternative for measuring soil bulk density relies on manual excavation of the soil (Bradford and Grossman 1982). This method uses a lower resilient ring of foam plastic, which is molded to the shape of the soil surface by an upper rigid ring of acrylic plastic. The cavity formed by these rings is lined with plastic and filled with water to determine the base volume. A sample pit is then dug within the confines of the cavity, the excavated pit is lined with plastic and filled with water, and a volume for the excavated sample is determined by subtraction of the water volumes. The weight of the excavated sample and the excavated volume are used to calculate bulk density.

Shetron et al. (1988) used this technique in a study of the effect of multiple machine passes on surface bulk density for three reasons: it was easy to obtain the 0- to 5-cm layer of the wheel track; coarse fragments could be removed from the sample to calculate soil matrix density and porosity; and it was possible to sample a larger area of the wheel track to include both lug depression and space between the lugs.

Where conditions such as large numbers of rocks and roots prohibit the effective use of other methods, a method utilizing plastic-coated clods can sometimes be employed (Blake and Hartge 1986). The method consists of collecting a natural clod from the face of an excavation, applying a coat of plastic lacquer to seal it, and determining the mass and volume of the sample in the laboratory for a calculation of bulk density. This technique is labor intensive and requires extensive laboratory work, increasing the cost. The method has been used in several studies, however (e.g., Cullen et al. 1991; Thompson et al. 1995).

Soil compaction is also directly related to the resistance to penetration of the soil. The most common method for assessing soil penetrability of a forest soil in the field is with a cone penetrometer. A cone penetrometer is a device that measures the amount of force required to push a rod with a standard-size cone point into the soil at a constant rate of speed (Bradford 1986). The penetration force data by soil depth provides a relative measure of the amount of soil compaction that has occurred (e.g., McDonald et al. 1995; Van Miegroet et al. 1994).

Soil compaction is often measured during studies of the impacts of equipment on forest sites as a consequence of harvesting or other forest operations. Sampling in these studies generally concentrates on impacted and immediately adjacent non-impacted areas. The normal guidelines of experimental design apply to these studies. The high natural variability found in forest soils generally requires that large numbers of samples be taken to ensure that treatment effects can be identified.

This high natural variability also makes it difficult to extrapolate the results obtained from a finite number of samples to larger areas with confidence. This is particularly important if management decisions are being based on evaluations of soil properties from samples, such as a decision to suspend operations when a threshold level of soil moisture content is reached. The data supporting that decision need to have been obtained in a statistically valid and defensible manner.

Howes et al. (1983) have developed initial guidelines for sampling physical conditions of surface soils and for properly extrapolating the sample results to stand level values. It is important that these techniques be further developed and used in management practices and decisionmaking.

Very little is yet known about the long-term effects of soil compaction on forest productivity, partly due to the complex nature of the problem, and partly due to an inadequate level of research effort. Consistent data collection methods are needed so that large-scale, long-term studies of the effect of forest operations on productivity can be conducted efficiently, and in a manner that will lead to widely applicable results. Studies comparing the various methods for analyzing soil compaction are needed as a first step toward developing consistent data collection methods in this area.

Recommended soil compaction sampling methods

Soil compaction assessment should be intimately tied to the disturbance classes present on a site and the associated areas in these classes. Except for undisturbed (control) areas, only the disturbed areas where compaction is likely to be present need to be assessed. Assessment should occur as soon after the operation as feasible. An effort should be made to separate the effects of compaction due to different operations (e.g., felling, skidding). Soil moisture during the operation should be assessed if possible due to the influence of this variable on compaction.

Because of the high natural variability in forest soils, non-destructive testing methods, such as the nuclear gamma radiation gauge, that can re-sample the same soil repeatedly (before and after operations) are very desirable for studies where treatment effects are being monitored over time. These instruments are accurate, but time-consuming and expensive to use, favoring the use of other methods in most cases (Smith 1987).

Measurements taken with a cone penetrometer, on the other hand, are quick and easy, but quite variable. This requires that a large number of points be sampled. Laboratory analysis of clod samples is also expensive, and the resulting bulk densities often quite variable. For these reasons, we have concluded that, for simple bulk density measurements, either the core sampler or excavation methods work best. The core sampler works well in reasonably uniform soils, while the excavation method works well in rocky soils.

DISCUSSION

The methods used to assess the effects of forest operations on the remaining vegetation and soil will depend on the particular needs and objectives of each individual study or monitoring program. Proper planning is essential to ensure that all necessary data are being collected and all unnecessary data are not. For studies with several objectives, locating sample points, lines, or plots in association with other measurements can simplify and integrate data collection efforts, lowering costs and increasing the value of the data.

Research is needed to evaluate the methods used to assess the effects of forest operations on the remaining vegetation and site. This is especially true for the sampling patterns used in these assessments. This will help identify the most accurate, consistent, easy to apply, useful, and statistically valid methods. This work should be conducted in cooperation with scientists from other disciplines and on-the-ground managers to be of highest value in the management of ecosystems.

We recognize that assessment techniques will vary for good reason. However, the recommendations we have made in this paper can serve as a starting point for planning residual tree damage assessments, low plant and seedling damage surveys, site disturbance evaluations, and soil compaction studies. Increased use of standard assessment techniques will improve the comparability and usefulness of information on the operational effects of forest equipment.

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Comparison of Damage Characteristics to Young Douglas Fir Stands from Commercial Thinning Using Four Timber Harvesting Systems

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ABSTRACT: Each harvesting system leaves its own type of damage to crop trees during thinning operations. Understanding the impact of different harvesting systems helps forest managers to achieve management objectives associated with sustainability and quality control. Damage to residual trees from commercial thinning was characterized and compared with four common harvesting systems in western Oregon: tractor, cut-to-length, skyline and helicopter. This study was conducted in six young (30 - 50 years old) Douglas-fir (*Pseudotsuga menziesii*) stands having various residual densities. Scarring by ground-based systems was more severe: scar sizes were bigger, and gouge and root damage was more prevalent than that caused by skyline and helicopter systems. Crown removal and broken-top damage was more common with skyline and helicopter logging. The damage levels varied among different thinning treatments and logging systems. The levels were heavily influenced by many compounding factors. In the cut-to-length system, the harvester caused more wounding to crop trees than the forwarder, but forwarder scars were larger and sustained severe gouge damages.

KEY WORDS: logging damage, commercial thinning, harvesting systems

INTRODUCTION

Intensive forest management practices in western Oregon increasingly require the use of thinning prescriptions for both private and public land. Sessions *et al.* (1991) surveyed the use of thinning practices in western Oregon. Managers responsible for industrial forests indicated that within 25 years, current management intensities would require thinning on about two thirds of their forest lands. For public lands in the same survey, the Forest Service and Bureau of Land Management (BLM) planed to implement intensive management on virtually all of their forested acres allocated to timber production in western Oregon. Under their 10-decade management plan which began in 1991, the area to be thinned was projected to increase by five times over the 10-decade period.

These trends are the same in Washington State. McNeel *et al.* (1996) surveyed forest land managers in western Washington and found that public land owners have increased the acreage thinned on their managed lands by almost 200% in the past 5 years.

During fiscal year 1995, the Oregon Department of Forestry estimated that 627,668 acres of forest land had merchantable logs removed from them. Partial cut and clear cut areas were 524,701 acres (84%) and 102,967 acres (16%) respectively. Partial cuts include shelterwood, seed tree, selective, preparation, intermediate, improvement, and salvage cuts.

Since any type of damage to remaining trees is a byproduct of thinning operations, it is of interest to forest managers and researchers. The understanding of logging impacts to residual stands is more important than ever to ensure the sustainablity and quality control of future stands.

Lanford and Stokes (1995) compared two thinning systems on logging damage to 18-year-old loblolly pine trees. They reported that the feller-buncher/ skidder system scarred significantly more trees, 62 trees per ha (tph, 25 trees per acre (tpa)) than did the cut-to-length system, 25 tph (10 tpa). Compared to the cut-to-length system, the skidder system had 10 times larger scars and 24 times more scar area per acre.

A residual stand damage study of a cut-to-length system in the Pacific Northwest was conducted by Bettinger and Kellogg (1993). They found 39.8% of Douglas-fir trees sustained some damage with only 0.8% of trees sustaining major damage. The majority of logging damage was relatively small. Total scar area per acre was 1.2 m^2 (12.85 ft^2), which was far greater than Lanford and Stokes's observation, 0.046 m^2 (0.5 ft^2). They also noted that most of the damage occurred within 4.6 m (15 ft) of a trail centerline and originated within 0.9 m (3 ft) of the ground line.

Aho *et al.* (1983) compared the amount of damage from commercially thinned, young-growth stands of true fir, Douglas-fir, and ponderosa pine with two logging methods: conventional logging practices and logging procedures designed to reduce damage to residual trees. In the five conventionally thinned young-growth stands surveyed in northern California, 22% to 50% of the residual trees were wounded. The level of damage in four stands that were thinned using techniques designed to reduce logging skidding injuries were substantially lower, ranging from only 5% to 14%.

Damage to leave trees is less severe with skyline thinning than with conventional skidding or tractor-based operations (Aulerich *et al.* 1976, Carvell 1984, Fairweather 1991). Aulerich *et al.* (1976) reported that 11% of trees after tractor thinning had wounds over 46 cm^2 (7.1 in^2), and 7% of the stems following skyline thinning had wounds of this size. In the tractor thinned unit, 58% of the scars were either on roots or the lower 30 cm (11.8 in) of the tree trunks. Ninety-eight percent of skyline thinning wounds were over 30 cm (11.8 in) above ground, and 22% of these scars were more than 1.52 m (4.6 ft) above ground. In a skyline logging study, Kellogg *et al.* (1986) reported that most yarding damage (66.6% of total scar area) occurred within 6 m (20 feet) of the skyline corridor centerline. They also noted that selective thinning caused greater residual stand damage than a herringbone thinning.

In a commercial thinning using a small helicopter with a payload capacity of 1,133 kg (2,500 pounds), Flatten (1991) found that damage to a young Douglas-fir stand appeared to be far less than typically found with skyline systems.

The questions of a maximum acceptable damage level and what constitutes a damaged tree arise whenever penalties for damage are an issue. Government agencies and private industry have answered these questions in their policies, but they are not consistent. Some of the rules are written with ambiguous language resulting in different interpretation. The minimum scar size to constitute damage varies from agency to agency, ranging from 6.5 cm^2 (1 in^2) to 464 cm^2 (72 in^2) or no written definition. A maximum acceptable damage level consisting of scarring, crown and root damage is also not consistent: 3%, 5% of total damaged tree or an inspector's decision.

Damage to residual trees is related to several factors besides the logging system, including thinning intensity, planning and layout, season of harvest, species, felling patterns, yarder size, skyline deflection, tree distance from skid trails, tree size, tree length being harvested and site conditions (slope, soil texture, rockiness, etc.). However, researchers agree that the most critical factor affecting the damage level is a worker's skill and efforts (McLaughlin and Pulkki 1992, Hoffman 1990; Cline *et al.* 1991; Ostrofsky *et al.* 1986; Kellogg *et al.* 1986).

The results of the first half of this project were presented at the annual Council on Forest Engineering (COFE) meeting last year (Pilkerton *et al.* 1996), which included skyline and helicopter thinning units. In this paper, we compare the characteristics of stand damage in relation to various thinning treatments and to four logging systems including the results from last year (helicopter logging). We also discuss the harvesting variables affecting damage level.

METHODS

Study Sites and Thinning Prescriptions

Data for this study were collected on commercially thinned young stands in the central Cascade Mountains of Oregon. Table 1 describes the characteristics of stands and thinning systems used for the study areas. For the purpose of stand damage comparison, one cable (3 units), one cut-to-length (3 units), and two tractor sales (5 units) were selected on the Willamette National Forest, totaling 210 ha (521 acre). The study areas were administrated by three different Forest Service Ranger Stations. These second-growth stands areas were previously clearcut between the early 1940s and 1950s, broadcast burned soon afterward and allowed 2-4 years to regenerate naturally before being interplanted with Douglas fir. Stands were dominated by Douglas fir with two layers of scattered western hemlock and individual or clumps of big leaf maple (*Acer macrophyllum*).

Table 1. Study areas and stand descriptions before commercial thinning in the Willamette National Forest *.

Sale Name	Logging System	Study Area	Mean Tree Age	Mean Tree DBH	Mean Tree HT	# of Trees	Basal Area	Slope
		ha (ac)	years	cm (in)	m (ft)	/ha (/ac)	m^2/ha (ft^2/ac)	%
Walk Thin	Skyline	57.4 (142)	45	26.4 (10.4)	22 (74)	667 (270)	27 (118)	5 - 80
Mill Thin	Tractor	49.3 (122)	43	30 (11.8)	24 (78)	573 (232)	40 (172)	0 - 15
Tap Thin	Tractor	25 (62)	46	27.4 (10.8)	22 (73)	531 (215)	33 (145)	0 - 40
Flat Thin	Cut-to-length	90.9 (225)	45	28.7 (11.3)	23 (77)	504 (204)	43 (186)	0 - 20

Three thinning treatment units were located on each of the study areas (four replications). Three different residual stand densities after thinning were: (1) heavy thinning (123-136 tph, 50-55 tpa), (2) light thinning (272-297 tph, 110-120 tpa), and (3) light thinning with patch clearcuts (approximately 0.2 ha (1/2 acre)) openings. Trees left uncut were healthy dominant and co-dominant Douglas fir and western hemlock marked by Forest Service crews before thinning. Thinning primarily removed selected commercial value trees from the mid-size diameter classes (18-41 cm (7-16 in)).

Timber Harvesting Systems

Three thinning systems were compared: skyline, tractor, and cut-to-length. The equipment used was small and appropriate for thinning. These timber harvesting systems are commonly used in the Pacific Northwest. Each sale was contracted with different loggers and their thinning experiences varied from less than 6 months to over 10 years.

Skyline logging system: The skyline logging system consisted of chainsaw tree felling, limbing, and bucking, followed by cable yarding. Cable yarding was done using a smallwood yarder, Koller 501 with Eaglet mechanical slackpulling carriage in a shotgun skyline system. Skyline roads were determined and marked before felling by the contractor. Intermediate supports and tailtrees were rigged on 16% and 84% of skyline roads, respectively. Logs were partially suspended. Landing patterns in Walk Thin were mainly fan-shaped (75%) with some parallel skyline roads (25%).

Cut-to-length logging system: The cut-to-length logging system consisted of two pieces of equipment: harvester and forwarder. The harvester was a 2618 Timberjack (tracked carrier) with a South Fork Squirt Boom and a Waterous 762b hydraulic harvesting head. The forwarder was a 1210 Timberjack. A harvester worked on the designated skid trails spaced approximately 20 m (60 feet) apart and completed felling, delimbing, and bucking of the tree into log segments. The harvester cut trees up to 56 cm (22 inches) in diameter but had increasing difficulty with trees over 48-51 cm (19-20 inches). Manual felling was required for some large trees. The forwarder traveled on the designated trails that the harvester passed over and transported the logs to the landing or roadside.

Tractor logging system: The tractor logging system consisted of chainsaw tree felling, limbing, and bucking, followed by skidding with a small crawler tractor or skidder. Trees were directionally felled to facilitate winching and to minimize stand damage. The tractor or skidder was equipped with a winch line so that designated skid trails were spaced approximately 40 m (120 feet) apart. There were three different logging contractors in tractor units; two in Mill Thin and one in Tap Thin. Skidders used in Tap Thin units were John Deere 550 winch line and 540 grapple (rubber tired) while Case 550 and D-5 Cat crawler tractors were used in the Mill Thin units.

Procedure

Damage to residual trees was surveyed during summer of 1996 and spring of 1997 after commercial thinning was completed. Trees in each unit were sampled using fixed circular plots, except for the Heavy thinning in Mill Thin. This unit was only 1 ha (2.5 acres), thus all trees in the unit were checked for logging damage.

The sampling pattern was a systematic grid having the sample units, with a constant distance between sampling units within rows equally spaced. These rows were perpendicular to the primary direction of yarding or skidding to landings. If this was impossible due to fan-shape yarding or skidding patterns, we stratified the unit to avoid locating the rows parallel to skyline roads or skid trails. Plot sizes were 0.04 ha (1/10 acre) for Light thinning treatments or 0.08 ha (1/5 acre) for Heavy thinning treatments. The sample size of each unit was calculated using (Thompson 1995):

$$n_0 = \frac{N * p(1-P)}{(N-1)\left(\frac{d^2}{z^2}\right) + p(1-P)}$$

$$\text{Sample size} = \frac{n_0}{t * p * s}$$

n_0 = number of damaged trees required in sample
N = total number of trees in the unit
p = estimate of percentage damaged trees in unit
d = allowable sampling error, 10% was used.
z = 1.96 for 95% probability
t = number of trees per unit, ha or acre
s = plot size, 0.04 ha (0.1ac) or 0.08 ha (0.2ac)

Once the sample size was calculated, plots were uniformly distributed through the unit. The number of plots ranged from 20 to 27, sampling 2.1% to 34.7% of the area of each unit. In surveying tree damage, we numbered all damaged trees and marked undamaged trees in each plot using paint. This avoided counting the same tree twice or missing trees and facilitated remeasurement if needed.

If a tree was damaged, such as scarring, root and/or crown damage, we measured DBH and collected the data related to tree damage. For scarring damage, scar length, width, and height from the ground level were measured. A scar was defined as removal of the bark and cambial layer, exposing the sapwood. Each scar was traced onto regular paper and these tracings were measured for scar area using a planimeter. If a scar was bigger than the paper size, the scar was traced onto several pieces of paper, measured by piece, and then summed for a total scar area. The scars that could not be reached by hand were measured with Bettinger and Kellogg's method (1993) that uses a camera equipped with a 70 - 210 mm zoom lens. A picture of the scar included a scale, which was mounted on a level rod. Scars were numbered if there were more than one scar per tree.

Scar locations on the bole were noted by four quadrants: (1) quadrant #1 facing the landing, (2) quadrant #2 facing the corridor, (3) quadrant #3 facing the tailtree or tailhold, (4) quadrant #4 opposite to quadrant 2. Each scar was checked to see if the wood fibers were removed, called gouge damage. If a scar had gouge damage, the gouge area and the gouge depth were categorized by three levels: (1) < 25% and < 1 cm, (2) 25% to 50% and 1 cm - 2 cm, (3) > 50% and >2 cm. The distance from the corridor centerline and landing (skyline units only) for every damaged tree was recorded.

If the tree top was removed, it was recorded as a broken-top. Crown damage described when half or more of the crown was removed from the base of the live crown to the top. Any visual scar or severing of the root system was defined as root damage.

To study the wounding caused by the harvester or the forwarder, 3.9 ha (9.7 acres) of the Light thinning unit in the Flat Thin sale was selected. The area included one landing and 5 equipment trails ranging from 365 m (1200 feet) to 669 m (2200 feet) in length. All of the trees in the area were observed for damage after the harvester passed and before the forwarder operation. Paint was sprayed on the wounded area to differentiate the damage created by the forwarder. Every tree in the study area was checked again after the forwarder operation.

RESULTS

Damage Level and Scar Size

The most typical type of damage to the crop trees in every logging system unit was scarring, accounting for more than 90% of the total damage. Crown damage was more prevalent in skyline logging units than in ground based logging systems. Crown removal and broken-tops were caused by lateral excursion of the skyline during lateral inhaul. Ground based systems created more severe root damage than skyline. Root systems below the ground line were easily damaged by repeated passes of equipment and logs being dragged. Skidder blading to level the surface of skid trails also severed root systems. These three types of damage constituted the damage related to thinning operations in this study.

Highest incidence of damage to residual trees was 41.3% in the Light thinning unit of the cut-to-length system (Table 2). The units thinned by the harvester and forwarder sustained higher damage levels (over 30%) than units thinned using a tractor (7.5% to 25.4%) or a skyline system (13.5 to 20.2%). The two lowest damage levels were measured at the Heavy

Table 2. Logging damage levels listed by the minimum size of scars considered as damage.

Sale (logging system)	Thinning Treat-ment	Logging Contractor[a]	Season of Logging	Damage Levels (%) based on the minimum size of scars			
				No Limit	> 155 cm^2 ($24 in^2$)	> 465 cm^2 ($72 in^2$)	> 929 cm^2 ($144 in^2$)
Walk Thin (skyline)	Heavy	A	Winter	18.8	8.3	2.6	1.5
	Light	A	Summer	13.5	5.9	3.8	1.6
	LTw/ patches	A	Summer	20.2	14.6	8.0	5.6
Mill Thin (tractor)	Heavy	B	Summer	25.4	18.7	10.0	4.5
	Light	B	Summer	18.4	9.8	3.9	3.9
	LTw/ patches	C	Summer	9.2	6.6	4.6	3.6
Tap Thin (tractor)	Heavy	D	Summer	7.5	3.3	1.9	1.4
	Light	D	Spring/ Summer	20.2	14.6	8.4	5.1
Flatthin (cut-to-length)	Heavy	E	Winter	34.2	19.2	6.8	4.1
	Light	E	Winter	41.3	14.3	4.7	2.3
	LTw/ patches	E	Summer	31.9	22.2	10.4	6.9

[a] A,B,C,D,E are different logging contractors

thinning unit in Tap Thin, tractor (7.5%) and the Light with patches unit in Mill Thin, tractor (9.2%). Relatively high incidences of logging damage occurred in tractor units, showing 20.2% in the Light thinning unit of Tap Thin and 25.4% in the Heavy thinning unit of Mill Thin. In skyline logging units, damage ratios ranged from 13.5% to 20.2%. No trend in damage incidences by different thinning treatments was observed.

Damage levels sustained during thinning are lower when only considering trees scarred above a minimum scar size (Table 2). For example, only two units, Heavy thinning unit in Mill Thin and Light with patches unit in Flat Thin had a damage level above 10% with scar sizes bigger than 465 cm^2 (72 in^2). When considering the minimum size of scars bigger than 929 cm^2 (144 in^2), all the units sustained logging damage lower than 10%. Damage levels in skyline units dropped significantly to 1.5%, 1.6% and 5.5% for the three thinning treatments.

In the cut-to-length system, the harvester damaged more than twice the number of residual trees than damaged by the forwarder (Table 3). Only 7.6% of the damaged trees were hit by both the harvester and the forwarder. However, the forwarder caused a higher number of scars per tree and bigger scars per tree on average. The average scar area per tree caused by the forwarder was 290 cm^2 (44.9 in^2) while that caused by the harvester was 202.6 cm^2 (31.4 in^2). Greater root damage was observed after forwarder passes.

Table 4 summarizes the results of damage levels and scar measurements in wounded trees caused by the three different logging systems. The average scar sizes observed in skyline units were smaller than those in the tractor and cut-to-length system units. The lowest value of an average scar size was 87 cm^2 (13.5 in^2) at Heavy thinning unit in Walk Thin. The average size of scars in tractor logging units were relatively high, ranging from 242 cm^2 (37.5 in^2) to 356 cm^2 (55.2 in^2).

Scar Height

The skyline logging system left the highest scar on average, followed by cut-to-length and tractor logging systems. Scars from tractor logging were concentrated at heights less than 61 cm (2 feet): 45.5% and 59.7% of scars in tractor logging units were located below 61 cm (2 feet) in Mill Thin and Tap Thin, respectively. The ratios of scars less than 61 cm (2 feet) height to the total were 12.2% in skyline and 29.3% in cut-to-length logging units. In the cut-to-length system, scars caused by the harvester were lower on average than those by the forwarder. Sixty-three percent of the scars caused by the harvester were lower than 1.3 m (4 feet) while 57% of the scars caused by the forwarder were lower than 1.3 m (4 feet).

Scar Locations in Quadrants

Figure 1 illustrates scar locations in relation to each quadrant for the three logging systems. Scars in tractor

Table 3. Comparison of damage characteristics caused by harvester and forwarder.

	# of trees damaged (224 trees total)	# of trees root damaged	Dist. from skid trails m (feet)	# of scars per tree	Scar height m (feet)	Scar width m (inch)	Scar length m (inch)	Scar area per scar cm^2 (in^2)
Harvester only	143 (63.8%)	4	5 (15.2)	1.4	1.6 (4.9)	1 (3.3)	2 (6.4)	144 (22.3)
Forwarder only	64 (28.6%)	6	4.2 (12.9)	1.9	1.9 (5.9)	1.2 (3.7)	2.4 (7.3)	179 (27.7)
Both	17 (7.6%)							

Table 4. Descriptive statistics of residual stand damage after commercial thinning in the Willamette National Forest.

Sale (Logging System)	Thinning Treatment	Damage Level (%)	DBH of Damaged trees cm (in)	# of scars (/tree)	Average Scar Height cm (in)	Average Scar Width cm (in)	Average Scar Length cm (in)	Average Scar Area cm^2/scar (in^2/scar)	Average Scar Area cm^2/ha (ft^2/ac)
Walk Thin (Skyline)	Heavy	18.8	34.8 (13.7)	2.3	17.3 (6.8)	8.9 (3.5)	12.4 (4.9)	87.1 (13.5)	2,755 (1.2)
	Light	13.5	31.8 (12.5)	1.8	21.3 (8.4)	7.1 (2.8)	18 (7.1)	153.1 (23.6)	5,510 (2.4)
	Light w/ Patches	20.2	30.7 (12.1)	2.4	21.1 (8.3)	10.4 (4.1)	26.2 (10.3)	265.8 (41.2)	11,020 (4.8)
Mill Thin (Tractor)	Heavy	25.4	35.3 (13.9)	2	8.9 (3.5)	12.7 (5)	21.1 (8.3)	241.9 (37.5)	11,020 (4.8)
	Light	18.4	32 (12.6)	1.2	8.6 (3.4)	13.7 (5.4)	22.3 (8.8)	337.4 (52.3)	7,806 (3.4)
	Light w/ Patches	9.2	34.3 (13.5)	1.2	4.8 (1.9)	11.7 (4.6)	30.5 (12)	356.2 (55.2)	4,362 (1.9)
Tap Thin (Tractor)	Heavy	7.5	36.8 (14.5)	1.1	4.6 (1.8)	11.2 (4.4)	20.3 (8)	322.6 (50)	2,296 (1)
	Light	20.2	34.5 (13.6)	1.7	13.5 (5.3)	14.7 (5.8)	20.1 (7.9)	314.9 (48.8)	15,152 (6.6)
Flatthin (Cut-to-length)	Heavy	34.2	39.4 (15.5)	2.2	17 (6.7)	9.9 (3.9)	17.8 (7)	180.6 (28)	24,335 (10.6)
	Light	41.3	37.8 (14.9)	1.7	14.5 (5.7)	9.4 (3.7)	14.2 (5.6)	113.5 (17.6)	11,249 (4.9)
	Light w/ Patches	31.9	36.8 (14.5)	1.2	7.6 (3)	15.5 (6.1)	32.5 (12.8)	387.1 (60)	25,483 (11.1)

logging units were highly concentrated on quadrant #2 facing toward the skid trails (53.4% in Mill Thin and 61.3% in Tap Thin). Skyline and cut-to-length thinning almost evenly had scars on every quadrant with the lowest portion (14.6% and 8.3%) in quadrant #1 and #4, respectively. In the cut-to-length system, the harvester evenly created scars on quadrant #1, #2, and #3 with the lowest in quadrant #4, while 45% of the scars caused by the forwarder were located on quadrant #2.

Gouge Damage

The highest gouge damage was caused by tractor logging (31.8%), followed by cut-to-length (26.3%) and skyline logging (16.8%) (Table 5). In tractor and cut-to-length logging units, more than 10% of the scars had gouge damage covering 25% or more of scar area, while only 4.2 % of scars in skyline logging units had this damage. The severe gouge damage occurred on trees along the skid trails or skyline corridors. For the depth of gouge damage, 16.8% of skyline logging scars had gouge damage more than 1 cm in depth. It was 31.8% and 26.3% in tractor and cut-to-length logging scars, respectively (Table 6).

Damaged Tree Distances from the Skyline Corridors/Skid Trails

Most of the damage (73.8% in Mill Thin and 73.1% in Tap Thin) occurred on the trees that were within 4.57

m (15 feet) of a skyline corridor or a trail centerline without any trend among thinning treatments. These damages were especially concentrated on the trees along the corridors/trails within 3 m (10 feet), accounting for 57.5% and 59.6% of the total damage for Mill Thin and Tap Thin. Skyline and cut-to-length thinning had 54% and 59.6% of damage to crop trees within 4.57 m (15 feet) of a skyline corridor or a trail centerline, respectively. The average distances of total damaged trees for three logging systems are shown in Figure 2. In the cut-to-length systems, the harvester and forwarder caused almost the same proportion (67.2% and 66.1%) of damage within 15 feet from the centerline of skid trails.

DISCUSSION

Many compounding variables affect stand damage in thinnings. One of these variables, width of skid trails, heavily affected wounding in tractor logging units. Several papers reported that damage occurrence was higher with tractor thinning than skyline thinning (Aulerich *et al.* 1976, Carvell 1984, Fairweather 1991). However, two tractor logging units, Heavy thinning in Tap Thin and Light with patches in Mill Thin sustained only 7.5% and 9.2% of damage levels, respectively. Old skid trails, which were 6 - 7.2 m (18 - 22 feet) wide, were used for skidding in these two units. We rarely saw wounding on trees along the skid trail in these units, while wounding was heavily concentrated on trees near the trails in other units. The width of skid trails in other tractor units was 4.6 m (14 feet) or narrower. Different intensities of thinning treatments could be another factor affecting damage level; however, there was no trend of wounding crop trees in relation to different thinning treatments in our study.

Damage levels reported are heavily affected by the minimum size of scar which constitutes damage. The minimum scar size varies among agencies and is often ambiguous. The damage level of Light thinning unit in the Flatthin sale drops from 41.3% to 4.7% if only scar sizes greater than 465 cm^2 (72 in^2) are considered a damaged tree. Most scars (69%) caused by the cut-to-length system were smaller than 232 cm^2 (36 in^2), while there were 45% in Tap Thin and 54% in Mill Thin, where a tractor system was used. In contrast, the damage level of Light with patches unit in Mill Thin sale only drops from 9.2% to 4.6% with scars larger than 465 cm^2 (72 in^2). This also indicates that tractor logging causes more severe scarring (bigger scars) to crop trees than cut-to-length logging.

The question of damage level also should be related to the impact of future stand development and expected

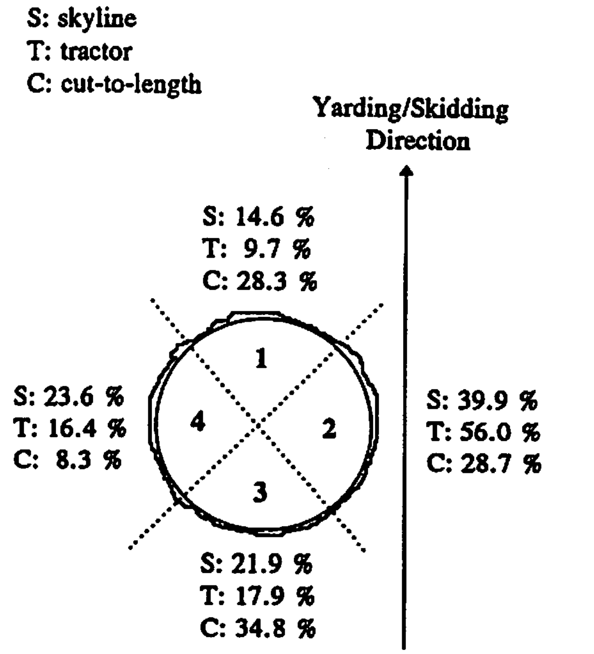

Figure 1. Scar locations created by three logging systems.

Table 5. Gouge areas.

Gouge areas [a](%)	Skyline [b](%)	Tractor [b](%)	Cut-to-length [b](%)	Helicopter [b](%)
0	83.2	68.2	73.7	0
1 - 25	12.6	19.9	15.7	0
25 - 50	4.2	7.3	5.5	0
> 50	0	4.6	5.1	0

Table 6. Gouge depths.

Gouge depth (cm)	Skyline [b](%)	Tractor [b](%)	Cut-to-length [b](%)	Helicopter [b](%)
0	83.2	68.2	73.7	0
> 1	15.3	28.4	22.6	0
1 - 2	1	2.7	3.3	0
> 2	0.5	0.7	0.4	0

[a] Values represent % of scar area occupied by gouge area.
[b] Values are ratios from total # of scars.

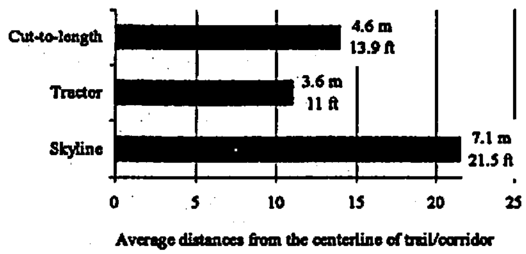

Figure 2. Location of damaged trees.

outcomes in timber volume and quality. Different logging systems cause different types of residual stand damage. For example, tractor logging often caused scarring at the butt log, where tree value is concentrated. These wounds tend to develop severe decay over time. In contrast, skyline and helicopter thinning does not cause any root damage. The scars caused by helicopter and skyline logging have very limited to no gouge damage. Eighty-four percent and 100% of scars had no gouge damage in Walk Thin (skyline) and our Hebo study unit (helicopter) (Pilkerton *et al.* 1996). Although the damage level (11.1%) at Hebo was higher than that (7.5%) in a tractor logging unit at Tap Thin, the residual trees at Hebo may be less affected by logging damages in their future growth and values than the trees in the tractor unit. In practice, the inspector determines the level of damage based on current and potential values of trees in the future in relation to species, size, age and growth rate.

In our studies, loggers often used "tree pads" to protect leave trees at the landing and along skyline corridors and skid trails. They used two types of tree pads, plastic and rubber, and preferred to use rubber because it stayed on the tree better. The rubber pad was heavier than the plastic. The results of scar height and locations should help people understand where and how high tree pads are needed. The results of scar locations in each quadrant also indicates the location that should be covered for each logging system.

A harvester operator should put more effort into minimizing stand damage than may be needed from a forwarder operator since the harvester causes more wounding (about 70%) than the forwarder (30%). However, wounding by the forwarder is usually deeper and larger than the harvester, especially leaving more root damage by its repeated traffic. The efforts by the two operators should be supported at the planning stage, such as optimal spacing of trails for the harvester and straight trails as much as possible for the forwarder.

Harvesting Variables affecting Damage Level

Based on our study results and observations during the thinning operations, the following harvesting variables affect residual stand damage:

(1) **Width of skid trail**: Trees near the trail are often scarred by logs and tire or tracks of skidders and forwarders. Root systems are also severed or scarred if a tree is located by the trail. When winching logs from a narrow trail, the skidder often hits trees when repositioning to avoid hang-ups due to a stump or other trees. Scarring or any root damage near the skid trail is usually large and severe because damage is created by a big or multiple impact from logs and equipment. Increased damage was noticed along the skyline roads where the skyline is not located in the middle of corridors.

(2) **Tree size**: When a large tree is falling, heavy bole or broken large branches scratch the bark and remove the branches of residual trees. Sometimes, tops of small trees are broken when felling large trees. With a single grip harvester, a large tree often requires the machine to be off the trails due to handling limitations with large diameter trees, resulting in a greater chance of creating damage to crop trees by the machine body and felling head.

(3) **Landing**: For ground-based systems, a large central landing which has a decking place tends to leave less logging damage to remaining trees. In continuous landings where landing areas are usually small and decking places are not available, severe scarring by sorting and loading activities frequently occurred. Also, since there is no decking place available, the sorted logs are leaned and rubbed against crop trees, scarring them. Landing locations and skid trail layouts must also consider soil disturbance and skidding production.

(4) **Condition of skid trail**: A trail which has old or new high stumps forces the skidder to one side of the trail, increasing the chance of impacting trees near the trail. Trees along a corner or sharp curve of the trail have high probability of being damaged by tires and logs. Root systems are often severed by skidder blading to level the trail surface. Cutting low stump heights in skid trails is important.

(5) **Skyline height**: Tree crown or tops can be removed by a high skyline which runs through or above the crown of crop trees. During lateral yarding, the lateral excursion of a skyline creates damage to the crown or the bole of remaining trees, depending on the skyline height. The use of intermediate supports or leaving rub trees reduces skyline lateral excursion.

(6) **Skid trail/skyline road spacing:** Wider spacing of trail/road requires increased winching or lateral yarding distance. This causes a higher chance of rubbing by a cable or of impact by logs being skidded. In thinning operations, loggers target an average spacing to 40 m (120 feet) for tractor and 50 m (150 feet) for skyline logging. If the spacing is greater than 16.5 m (50 feet) in the cut-to-length system, harvesters need to be off the trail to cut the trees due to their limited reach.

(7) **Felling pattern:** Directional felling or a herringbone felling pattern helps to reduce damage by reducing log swing during lateral inhaul or winching logs. In the cut-to-length thinning, the forwarder can control logs better when logs are bunched perpendicular to the hauling direction and are well sorted by the harvester according to diameter classes, and saw and chip logs.

(8) **Species:** We often noticed the rubbing trace on the bark of standing trees, which occurred during felling, skidding or winching. Because of its thick bark, Douglas fir tends to be less susceptible to scarring than western hemlock or other thin bark species.

(9) **Sale administrators:** The study areas were managed by the Forest Service. During the thinning operations, sale administrators kept reminding loggers to minimize the damage by saying that excess damage would not be tolerated. The penalty for excess damage includes the shut down of logging operations until sapflow stops completely. Sale administrators also have authority to permit cutting of trees that were originally designated crop trees, if trees are seriously damaged.

(10) **Planning and layout:** Planning is the most essential function to be performed in a thinning operation. It is essential because it provides the discipline that welds together all parts of the harvesting system, identifying and resolving conflicts, recognizing constraints, and providing for an orderly input of resources. During the planning process, all identified or possible problems can be removed.

(11) **Logger's effort and experience:** No matter how well planned and designed the thinning operation, loggers need to make an effort to minimize logging damage. Loggers' skill and experience supports their efforts to avoid stand damage.

SUMMARY

The most typical type of damage to crop trees in every logging system unit was scarring, accounting for more than 90% of the total damage. Crown damage and broken-tops were often observed in the skyline system, while root damage was prevalent in tractor and cut-to-length logging units. The highest incidence of damage, 41.3% to remaining trees, occurred at the Light thinning unit thinned by a cut-to-length system. This damage level drops to only 2.3% if only scar sizes greater than 929 cm^2 (144 in^2) were considered as a damaged tree. With the same consideration, damage levels significantly drop to 1.5%, 1.6%, and 5.5% in skyline units but are relatively high in tractor logging units. In the cut-to-length system, the harvester damaged 63.8% of residual trees, more than twice the damage created by the forwarder (28.6%). Only 7.6% of damaged trees were impacted by both the harvester and the forwarder. Attention to a number of important harvesting variables can affect stand damage level in thinning for skyline, tractor and cut-to-length logging systems.

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Evaluating the Effectiveness of Timber Harvesting BMPs on Stream Sedimentation in the Virginia Coastal Plain

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ABSTRACT: Three small watersheds in the Virginia coastal plain were monitored to evaluate the effectiveness of BMPs on stream sedimentation. One watershed was harvested with BMPs; one was harvested without BMPs; the third remained uncut, as a control. Pre- and post-harvesting water quality data were compared using the minimum detectable change (MDC) statistic. Harvesting *without* BMPs significantly increased concentrations and loadings of total suspended solids, while harvesting *with* BMPs did not, indicating that BMPs were effective in minimizing stream sedimentation.

Key Words: BMPs, timber harvesting, water quality

INTRODUCTION

Timber harvesting "Best Management Practices" (BMPs) (VDOF 1994) are operational techniques designed to protect stream water quality during and after logging operations. Their effectiveness has been documented in several studies in the southern Appalachian mountain region but by few in the southern coastal plain region. Since progress in forest water quality protection is often measured by the percentage of harvested sites implementing BMPs, it is critical to evaluate and document the effectiveness of these recommended techniques. Thus, the objective of this study was to evaluate the effectiveness of BMPs on the protection of stream water quality during and after timber harvesting in the Virginia coastal plain.

STUDY METHODS

Three small adjacent forested sub-watersheds located within the Nomini Creek watershed in Westmoreland County, Virginia, were chosen for the study (Figure 1). Slopes in the sub-watersheds range from 2-3% over most of the area to 30% along the deeply incised stream channels. Soils are sandy loams. Timber consisted of loblolly pine (*Pinus taeda* L.), with mixed hardwoods along the stream bottoms.

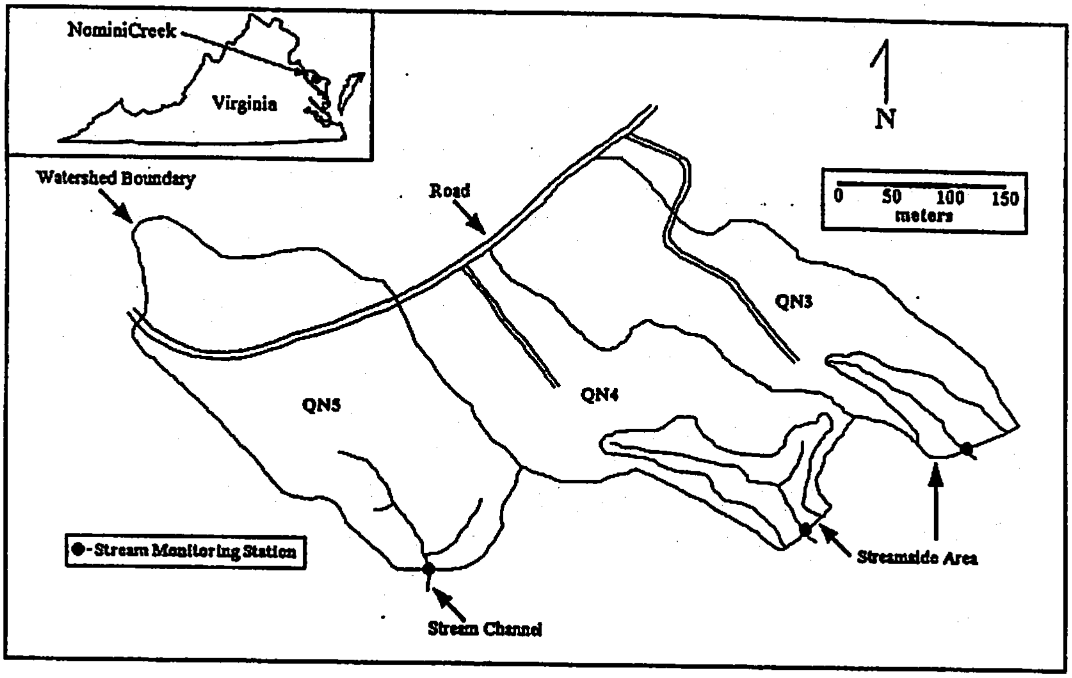
In August, 1991, stream monitoring stations (weirs) were installed at the outlets of the three sub-watersheds. Baseflow and stormflow water quality samples were collected by automatic water samplers at each station. The samples were analyzed at Virginia Tech for total suspended solids (TSS), as well as other water quality parameters.

During the period between January 31 - February 4, 1994, after 27 months of pre-harvest data collection, two of the sub-watersheds were simultaneously harvested. QN4 (8.5 ha) was clearcut with BMPs; QN3 (7.9 ha) was clearcut without BMPs; and QN5 (9.8 ha) remained undisturbed, as a control. Similar logging equipment and operating procedures were used on both harvests (rubber-tired feller-buncher/ grapple skidder systems). Manual chainsaw felling was employed in the steep streamside areas.

BMPs implemented on sub-watershed QN4 included:

1. A formal pre-harvest plan was developed and followed.
2. A streamside management zone (SMZ) 50 feet wide on either side of the stream was flagged. Approximately one-third of the basal area, primarily in larger diameter trees, was carefully removed with minimum ground disturbance, leaving two-thirds of the trees remaining uncut within the SMZ.

Figure 1. Nomini Creek forested sub-watersheds



3. Water-bars were installed immediately after harvest on all primary skid trails.
4. The landing was seeded with grass.

Post-harvest water quality data was recorded through April 1995. The impacts of timber harvesting on water quality was evaluated using the minimum detectable change (MDC) statistic (Spooner *et al.* 1987). The comparison of means test was performed for the three sub-watersheds. If the percent difference in mean sub-watershed response between the pre-harvest and post-harvest periods measured for a particular water quality parameter was greater than the percent MDC for that parameter, it was concluded that a significant change had occurred for that parameter. If the test determined that the control sub-watershed (QN5) had not changed significantly from the pre-harvest to the post-harvest period, however, then a change in the response from the harvested sub-watersheds could be attributed to the treatment applied (harvesting with or without BMPs).

RESULTS AND DISCUSSION

The post-harvest mean weekly total suspended solids (TSS) concentration from the "no-BMPs" (QN3) sub-watershed was 116% greater than the pre-harvest concentration (Table 1). The MDC for TSS on QN3 was 78%, so the difference between pre- and post-harvest means was statistically significant. The sediment concentrations from QN4, the sub-watershed harvested with BMPs, were not significantly impacted by harvesting. Since sediment concentrations in the control sub-watershed (QN5) did not change significantly from the pre- to the post-harvesting period, the difference in response between the harvested sub-watersheds can be directly attributed to BMPs.

Cumulative TSS loadings were similar for the BMP sub-watershed (QN4) and the control sub-watershed (QN5) throughout the study. Loadings from the no-BMP sub-watershed (QN3) began to increase dramatically during the fall of 1993, a few months prior to harvest, and continued to increase after harvest, particularly from April to August 1994. On-site observation of the weir for QN3 provided a possible explanation for this. When the weir was installed in 1991, the base of the flume was slightly above the bottom of the stream channel. This allowed a small amount of ponding to develop immediately behind the weir. This ponding may have trapped sediment, thus reducing TSS measurements at the start of the project. Later in the pre-harvest period, when the ponded area behind the weir filled up with sediment, the sediment suspended in the stream flow was readily passed through the weir, as indicated by the larger sediment losses from QN3.

Nevertheless, a statistically significant increase in sediment loading occurred from the pre- to the post-harvest period for sub-watershed QN3, harvested without

Table 1. Comparison of pre- and post-harvest mean total suspended solids concentrations and loadings.

Sub-watershed	Pre-harvest mean	Post-harvest mean	% change (pre --- post)	% MDC
	TSS concentration (mg/L)			
QN3 (no BMPs)	890 mg/L	1910 mg/L	116	+78
QN4 (w/BMPs)	210	150	-29	+49
QN5 (Control)	110	170	59	+60
	TSS loading (kg/ha/yr)			
QN3	4489	11502	156	+91
QN4	659	704	6	+52
QN5	300	680	126	+81

BMPs. No significant increase in sediment loading was documented for the sub-watershed harvested with BMPs (QN4). However, these results cannot be attributed strictly to the harvesting activity, since the sediment loadings from the control sub-watershed (QN5) also increased significantly from the pre- to the post-harvesting period. Therefore, changes in TSS loadings in QN3 may have been affected by additional sources of variability, such as climate and vegetation, as indicated by the response of QN5, the control sub-watershed.

The results of this study indicate that the impacts of timber harvesting on sediment discharge from forested watersheds in the southern coastal plain can be minimized by properly implementing BMPs.

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Maintaining Logyard Stormwater Quality at Minimal Cost

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ABSTRACT: The build up of bark on log storage and handling facilities can cause water quality problems. The stormwater runoffs from several yards in Louisiana were analyzed for pollutant content. Pollutants of major concern were chemical and biochemical oxygen demand (COD, BOD) and total suspended solids (TSS). Several low-cost treatments were tried and analyzed. The results of the project will generate an initial data base for reference in developing regulations and recommended measures for pollution control from log storage facilities.

Key Words: stormwater, runoff, log yards, water pollution

INTRODUCTION

Forests cover nearly half of the land area within Louisiana, making trees the number one "crop" in the state. Although forested areas contain essentially the same tree trunks and bark as log yards, the high concentration of material (especially bark) in log yards may cause undesirable concentrations of pollutants in waters draining from them. Since most log yards are already required to be permitted by a state agency for stormwater runoff, both industry representatives and regulators need to know what type of pollutants can be expected from these facilities, what concentrations to expect, and how pollutants can be minimized.

OBJECTIVE

Whereas a large percentage of the activities associated with forestry-related activities fall within the traditional definition of nonpoint source pollution, log sorting and log storage facilities are operations within the forest industry which have not been thoroughly investigated.

The Louisiana Forest Products Laboratory of the LSU Ag Center initiated a research project sponsored by the State of Louisiana Department of Environmental Quality (DEQ) and the US Environmental Protection Agency (EPA). DEQ states as its objective:

> The Louisiana Department of Environmental Quality, in cooperation with the Louisiana Office of Forestry and the Louisiana Forestry Association, proposes an investigation to identify the type and volume of pollutants found within wastewaters from log storage and forest products manufacturing facilities in order to create a general permit for this type of operation. Recommended control measures can also be evaluated to determine if they are effective in reducing identified pollutants. Those control measures can be incorporated into the permit requirements as minimum

measures of treatment required. In addition to producing a general permit, this wastewater and control measures information will also be incorporated into Louisiana's existing forestry educational program.

METHODOLOGY

To provide a credible, overall "picture" of the logyard segment of the forest products industry, a survey of the industry was conducted to ascertain sizes of yards, volumes handled, volumes stored, etc. (de Hoop *et al.* 1997).

Six sites (three in northern Louisiana and three in southeastern Louisiana) were selected for study. All handle southern pine almost exclusively. Pollutant parameters were studied for about 6 months. Then some low-cost treatments were tested. Two sites already had treatment facilities in place, simplifying testing. The types of mitigating treatments include: bark settling/oil skimming device, oil-absorbing boom, metal grate, metal grate with bark as filter, aeration pond, and long vegetated ditch.

It was hoped that some pollution parameters might be controlled effectively through the use of best management practices (BMPs), in this case a clean yard vs. a dirty yard, but attempts to set up this type of experiment failed.

All sites and mitigation methods were tested for the following parameters (priority pollutants):

- Biochemical Oxygen Demand (BOD_5)
- Chemical Oxygen Demand (COD)
- Total Suspended Solids (TSS)
- Total Dissolved Solids (TDS)
- pH
- Temperature

Most sites were also tested once each for heavy metals (Sb, As, Be, Cd, Cr, Cu, Pb, Hg, Ni, Se, Ag, Tl, Zn, cyanide, and phenol), volatile compounds (31 compounds; EPA test 624), semi-volatile compounds (56 compounds; EPA test 625), and pesticides (25 compounds; EPA test 608). The priority pollutant parameter tests were performed on campus, while the other tests were contracted out to private laboratories.

Water samples from sprinkler recirculation ponds were obtained manually at the researchers' convenience. Some stormwater samples were obtained manually during storm events, but this proved to be a difficult and illusory task. Automatic stormwater sample collectors were installed at runoff discharge sites that could collect up to 24 one-liter samples upon the commencement of threshold water flow levels. Flowmeters were attached to the samplers to monitor water flow levels and estimate runoff volumes. The samplers were programmed to pick up eight samples at 15-minute intervals, catching the first 95 minutes of each storm event. This seemed appropriate, as few storm events lasted much longer than this.

To estimate total pollutant discharge, total water flow had to be estimated; so some type of weir or flume had to be constructed at two of the sites. One, a V-notch weir, was constructed on a 4' x 8' sheet of plywood, transported to site by pickup truck and installed in two hours. The other flume was constructed of two pieces of 30-cm (12-inch) diameter pvc pipe installed side-by-side into vertical pieces of plywood. Both devices suffered from problems caused by debris accumulation.

RESULTS

There are an estimated 90 yards in the state. Seventy-two percent report having a stormwater pollution prevention plan in place.

All of the volatiles, semi-volatiles, and pesticide tests concluded that if these compounds were present, they were below detectable levels. All of the heavy metals tests indicated normal background levels, even in the recirculation ponds, with most numbers being close to or below detection limits.

Water temperatures were near normal for this climate, and pH levels were consistently between 5.9 and 8.1.

Total dissolved solids (TDS) values ranged from 62 to 1353 milligrams per liter, with typical values of 200 to 1100. The higher numbers tend to occur during the drier times of the year. Water from log sprinkler recirculation ponds showed levels within this same range. Since dissolved solids are extremely difficult to remove, the rest of this paper will concentrate on the remaining parameters of interest - Biochemical Oxygen Demand over 5 days (BOD_5), Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS).

Untreated water

Only one site presented the opportunity to obtain stormwater runoff from an active yard with dry log storage and no treatment or mitigation to the runoff of any sort. The ranges of results are:

BOD	6 to 48 mg/L
COD	0 to 14,724 mg/L
TSS	7 to 52,316 mg/L.

The last number occurred during a trace rainfall. The second highest number for TSS is 3,302. All of the higher numbers occurred during the initial samples of each storm event.

There were two log sprinkler recirculation ponds from which grab samples were taken directly. The ranges of results were:

BOD	6 to 10 mg/L
COD	0 to 298 mg/L
TSS	6 to 37 mg/L.

Throughout all the sampling at all locations, BOD was consistently low, indicating that COD and TSS are probably much more important. A question remains, however, whether the standard BOD test is appropriate for this type of water, as the microbes used to test BOD originate from municipal waste streams. It is unlikely that these microbes can digest bark and wood particles efficiently.

The highest levels of COD and TSS were generally found in the earliest samples in each storm event.

Treated water

Bark as filter. As stormwater gathers into discharge points, it often carries bark with it. By installing a metal grate near the discharge point, most of this bark will screen out and be deposited in front of the grate. While the holes in the grate are necessarily too large to act as a filter, this bark accumulates and becomes, in effect, a filter for subsequent stormwater events. The question then becomes whether the bark filter actually improves water quality or aggravates the problem. One yard had a metal grate with 200 feet of bark-filled ditch upstream from the grate, lending an opportunity to test the effect of a bark filter.

BOD levels appeared to increase (2% to 13%) as a result of the bark filter, while COD levels decreased .8% to 32% and TSS decreased 32% to 36%. Since BOD levels were low anyway (74 to 129 mg/L), it seems reasonable to conclude that using bark to filter stormwater runoff has a desirable effect.

Bark removal/oil skimming device. One sawmill had installed a concrete-lined bark removal device followed by an oil skimming device that was simple yet appeared to be effective. The bark removal device consisted of a concrete channel built so that the larger pieces of debris had time to settle to the bottom. A ramp was constructed on one side so that a front-end loader could scoop out the debris as needed. The oil skimming device consisted of a rubber hose loop that floated on the water. Any oil on the water adhered to the hose. An electric motor slowly circulated the hose over the water surface. Near the motor, the oil was wiped off of the hose and collected into a barrel.

This device turned out to be quite effective. It reduced BOD levels by 8% to 41%, COD levels by 31% to 71% and TSS levels by 13% to 89%.

The effectiveness of this device has led the researchers to take a closer look at the effect of an oil-absorbing boom. It is possible that the boom may improve TSS and COD as well as oil and grease parameters.

Detention pond. The same sawmill that installed the bark removal/oil skimming device described above followed up this device with a well-constructed detention pond. The detention pond was the most effective treatment of those tested. BOD removals ranged from 73% to 92%. COD removals ranged from 43% to 99.8%. TSS removals ranged from 57% to 97%.

Ratios

There appears to be a strong correlation between BOD and COD. On individual samples, BOD levels were 1% to 13% that of COD levels. Average ratios at each yard ranged from 4% to 7%.

Although less precisely defined, there was a strong correlation between COD and TSS during some rainstorms. TSS levels were usually a little higher than COD levels.

CONCLUSIONS

1. The COD and TSS levels were consistently higher than those of BOD in log storage yards and in log processing yards.

2. No correlation was found to exist between the parameter levels and the rainfall totals in both storage and processing yards.

3. An average BOD/COD ratio of approximately 0.04 - 0.07 was discovered for both storage and processing yards.

4. The COD and TSS parameters closely mimic each other in log storage yards.

5. A definite hierarchy of BOD, COD, and TSS removal efficiencies was discovered for the control measures. Ranked in terms of their decreasing removal

efficiencies for BOD, COD, and TSS, the control measures were the detention pond, combined bark removal/oil skimming device, combined screen and accumulated bark filter, and the individual screen.

RECOMMENDATIONS

1. Variables suspected of affecting the BOD, COD, and TSS parameter levels and mass emissions should be investigated. Some possible ones include yard traffic, rainfall intensity, time duration of rainfall, rainfall total, logyard size, number of logs present, and age of logs being stored.

2. Samples should be collected from all four seasons to ensure that there are no significant differences between the parameter levels for different seasons.

3. Several detention ponds with varying retention times should be investigated to see how significantly the retention time would affect the removal efficiencies of BOD, COD, and TSS. There is most likely a point at which it becomes uneconomical to build a larger pond (i.e. one with a larger retention time).

4. The effect of a dirty vs. a clean bark removal/oil skimming device on the removal percentages of BOD, TSS, and especially COD should be investigated. The length of time between cleanings should be varied to check whether a clean device contributes to higher or lower removal efficiencies.

5. Because the bark removal/oil skimming device was fairly effective in removing the BOD, COD, and TSS, an oil boom should be investigated as a possible control measure.

6. The TSS and COD removal percentages for the screen with an accumulated bark filter should be further studied by modifying the length, depth, and width of the associated bark filter, the contact time between the water and bark filter, the size and porosity of the bark particles, and the type of tree species from which the bark filter originated.

ONGOING ACTIVITIES

The researchers in this project are currently investigating the effects of an oil-absorbing boom and the effects of a long, vegetated ditch.

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Thinning Alternatives in Pole-Size Northern Hardwoods

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ABSTRACT: From a silvicultural standpoint, individual-tree selection is the most desirable method of thinning, but economics, equipment, or site impact considerations may require a departure from the ideal. Thinning alternatives—strip-thinning and two strip-with-selection-between-the-strips patterns—were compared to individual-tree selection in a typical pole-size northern hardwood stand. Strip thinning, blind to the size and quality of the trees being removed, retained the average tree size and distribution of the original stand. As the spacing between the strips increased, the structure of the thinned stand became more like the desired selection cut. Total growth in the thinned stands was similar, but more of the growth occurred on crop trees as the thinning approached the individual-tree selection pattern. These results can help to develop optimal combinations of equipment systems, thinning patterns, economics, and silvicultural objectives.

Key Words: crop trees, thinning patterns, site impacts, improvement cuts, stand damage

INTRODUCTION

There are more than 10.9 million acres of commercial forest land in the maple-birch type in the Lake States. Spencer (1986) estimated that 1.3 million of those acres need thinning, particularly in unmanaged, second-growth forests. Previously unmanaged, even-aged, second-growth, pole-size stands (5- to 9-inch diameter-at-breast-height (d.b.h.)) with a site index of 55 or greater at age 50 can be managed for high-quality sugar maple (Acer saccharum Marsh.), yellow birch (Betula alleghaniensis), and red maple (Acer rubrum) sawlogs and veneer (Erdmann 1986). However, before these stands can be brought under management, an initial improvement cut is needed to release the best quality dominant and co-dominant trees of desired species for accelerated growth.

Improvement cuts are performed to create the quality sawtimber stands of the future. The best results with very shade tolerant species like sugar maple are achieved with uneven-age management. An ideal uneven-age stand would have high quality trees distributed through all size classes. This distribution would allow cutting about 2,000 to 3,000 board feet of sawlogs every 10 to 15 years. If moderately shade-tolerant species like red oak (Quercus rubra) or yellow birch are preferred, even-age management would be used, and an ideal even-age stand would have seedlings of desirable species that are well established when the overstory is ready for harvest. With either management system, it is important to have quality seed sources to genetically improve the stand. The leave trees in thinnings should be selected based on species, stem quality, d.b.h., spacing, and the desired residual basal area and crown cover. If the stand is high-graded (only the largest and best trees cut) as so often happens, tree quality will deteriorate over time.

Although initial improvement cuts are necessary from a silvicultural point of view, they are time consuming, marking is expensive, and the products removed from the stand are typically of low value. These economic factors make the use of mechanized harvesting systems, with their high levels of productivity, an economic necessity. Because the management objective for northern hardwood forests generally is to optimize the production of quality hardwood sawtimber, the condition of the residual stand after a thinning is of utmost concern.

Particularly with mechanized harvesting and its inherent potential for residual stand damage, thinning methods are needed that can accomplish the silvicultural objectives without excessive damage to the residual stand.

Individual-tree selection is the most desirable method of thinning for un-even aged northern hardwoods from a silvicultural standpoint, but economic factors and harvesting equipment constraints may limit the feasibility of this method. Compromises between the desire to implement an silviculturally ideal thinning and the need to make the harvesting operation economically efficient may need to be made. Numerous studies have evaluated the economics of thinning operations (Biltonen et al. 1976, Mattson 1993), but the effects of less than ideal thinning treatments on silvicultural objectives have not been studied.

The impact of the passage of harvesting equipment over forest soils is also a matter of concern for forest managers. The relationship between machine traffic and soil structure and quality has been the subject of numerous studies (Reisinger et al. 1988, Martin 1988). It is commonly agreed that the passage of harvesting equipment, under improper conditions, can negatively impact forest soils. Restricting the travel of harvesting equipment to trails designated by the forest manager has been studied as a possible means of minimizing the impact of harvesting equipment on the site. Thompson et al. (1995), in a study of skidding and forwarding both with and without the use of designated trails, found that compromises will have to be made between productivity, cost, leave tree damage, and soil impacts. Concentrating the passage of harvesting equipment to designated trails in the stand could also create a less than ideal thinning situation from a silvicultural standpoint. Effectively, strip-thinning or strip-thinning with selection-thinning between the strips would be done, which is a departure from the ideal individual-tree selection-thinning.

This paper summarizes the results of a three phase study to evaluate the silvicultural effects of alternative thinning patterns in typical second-growth, northern hardwood pole stands in need of improvement cuts. In the first phase, stand data were collected for a computer analysis of the effect of alternative thinning patterns on silvicultural objectives. Field trials were conducted in the second phase to compare, on a silvicultural basis, thinning patterns that may be commercially acceptable compromises. The third phase measured the effects of alternative thinning patterns on tree growth after 10 growing seasons.

PHASE I — SIMULATED THINNING

A typical stand of even-aged, second-growth, northern hardwood poletimber, located in Houghton County of the Upper Peninsula of Michigan, was selected for study. The stand has relatively flat terrain, suitable for mechanized harvesting. The stand is comprised of about 85 percent sugar maple and 10 percent red maple. Yellow birch, black cherry (Prunus serotina), ironwood (Ostrya virginiana), American elm (Ulmus americana), and big tooth aspen (Populus grandidentata) make up the remaining basal area. The stand, near an area known locally as the Covered Road, is on land owned by the Mead Paper Company, Inc. Before experimental plots were identified, the entire stand was marked for a commercial thinning with typical marking guidelines used in the area.

Five square, 1-acre plots were established in the stand. Location, species, and diameter of all trees 2 inches d.b.h. and larger were recorded. Potential crop trees were identified on each plot based on tree quality, species, d.b.h., crown class, and spacing. Total height, crown ratio, crown class, and tree quality were also recorded for an average of 58 crop trees per acre. Sonderman's (1979) relative tree-quality index was used to monitor tree quality and to compare tree quality between plots (Table 1)

For each 1-acre plot, a thinning prescription was computer generated, and field checked on a tree-by-tree basis, to meet the guidelines recommended by Tubbs (1977). This individual-tree selection was assumed to represent the silviculturally ideal thinning for this stand and was used as the basis of comparisons among treatments. The criteria used for thinning were:

1. Release crop trees for growth,
2. Remove high-risk trees, culls, and undesirable species,
3. Thin from below to leave a well-spaced stand of dominant and codominant trees of the desired basal area.

Table 2 presents the characteristics of the stand before and after the simulated silviculturally ideal thinning, averaged for all plots. In addition, the

Table 1. Original stand and crop tree data

Stand age (years)	60
Site index (feet at 50 years)	60
Crop trees	
Average number per acre	58
Average d.b.h. (Inches)	11.0
Average height (feet)	74
Average crown ratio	6
Crown class (%)	
Dominant	39
Co-dominant	53
Intermediate	8
Relative quality index (%)	
Good	71
Medium	27

table includes data from the commercial marking of the stand to allow us to compare the results of typical local thinning practices to the ideal treatment. To obtain crown areas, crown radius was calculated from the following equation:

Crown radius (feet) = 2.1 + 0.73 d.b.h. (inches).

This equation, for northern hardwood species, was extrapolated from crown area by diameter classes data (Godman and Tubbs 1973).

Considering trees 5 inches d.b.h. and larger, the silviculturally ideal thinning would increase the average stand diameter by about 1 inch and reduce the crown cover by about one-half. In contrast, the commercial thinning would have decreased the average diameter and left more than 100-percent crown cover (Table 2). The projected residual stand structure also differed by type of thinning. After the silviculturally ideal thinning, most of the trees were concentrated in the 7- to 12-inch size class; the commercial thinning left many more trees in the 5- to 6-inch class and fewer in the 9- to 12-inch classes (Figure 1).

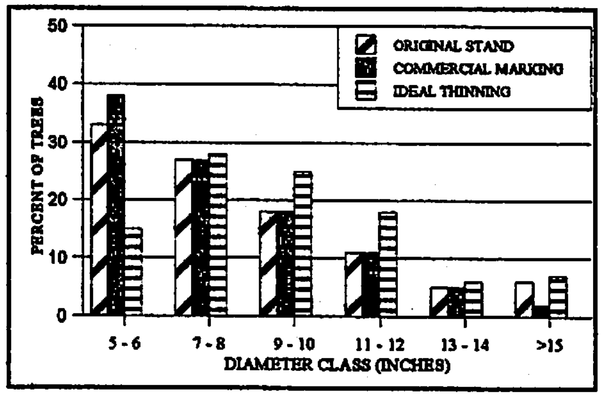

Figure 1. Diameter distribution of all trees ≥ 5 inches d.b.h. before and after simulated thinning.

PHASE II — FIELD TRIALS

The Covered Road stand was harvested in August 1984 by a local, independent logger producing pulpwood and firewood. His crew felled all the trees 2 inches d.b.h. and larger with chain saws, delimbed and bucked the trees at the stump, and forwarded the products out of the woods. Although this site was cut by chain saw, five different thinning patterns, selected to represent possible alternative mechanized harvesting practices, were randomly applied to the test plots. The rest of the stand was cut as commercially marked. The five test plots were established to provide "on-the-ground" demonstration areas and to allow comparisons between treatments both at the time of cutting and in the future. The thinning treatments applied were:

- No thinning (control) - One plot was left as is to show a typical untreated second-growth stand and to act as a control to determine the changes in growth due to the thinnings performed on the other plots.

- Strip-thinning - Strip-thinning allows simple access to the stand for harvesting equipment, and marking the stand is simple and inexpensive. To thin the stand as evenly as possible and to avoid large open areas, 10-foot-wide clearcut strips were used on the test plot. This spacing would be feasible for the use of small- to medium-size equipment. To reach the desired basal area in this particular stand (68 square feet/acre), the strip centers were spaced at uniform 26-foot intervals.

Table 2. Stand characteristics before and after simulated thinnings

	Original stand	Commercially marked	Ideal thinning
All trees 2-inches d.b.h. or larger			
Trees/acre	445	398	122
Basal area (square feet/acre)	132	96	67
Average d.b.h. (inches)	6.4	5.8	9.9
Trees 5-inches d.b.h. or larger			
Trees/acre	274	224	122
Basal area (square feet/acre)	123	86	67
Average d.b.h. (inches)	8.5	8.2	9.9
Crown cover (%)	146	107	77
Estimated cords removed[1]		14	22

[1]Estimates based on 79 cubic feet/cord and local volume tables (Erdmann et al. 1982).

- Individual-tree selection-thinning - The trees were marked according to the prescription generated for the silviculturally ideal thinning. Mechanized harvesting of such a selection cut would require the use of small, highly mobile equipment. In this plot the "leave" trees were marked as opposed to the normal practice of marking the "cut" trees. The logger felt that the feller, noting the better "leave" trees, took more care to prevent damage; ordinarily fellers concentrate on the trees to be cut.

- Clearcut strips with selection-thinning between strips - This thinning pattern has been demonstrated to be a potentially acceptable solution for mechanized thinning (Erdmann et al. 1986). The clearcut strips allow machine access to the stand, yet reduce the number of strips necessary. The between-strip spacing can be adjusted to suit the particular equipment to be used. In this study, one plot was thinned with 10-foot strips at 40-foot intervals, and another plot was thinned with 10-foot strips at 80-foot intervals. Normally the selection-thinning between the strips would be lighter, so that the overall stand would have the desired residual basal area. These plots originally had been marked to 68 square feet/acre, with the intent to add "leave" trees in the selection area to make up for the strips. However, there were not enough acceptable trees in the stand to make up the difference, so the stand was left at the lower basal area. Hence these two plots had residual basal areas of about 57 square feet/acre.

The differences in the visual effect of the thinning treatments were very striking. The selection-thinned areas had a clean park-like appearance. Although the strip-thinning was very obvious when viewed from the end immediately after cutting, the strips were almost invisible from any other angle because of the rather dense nature of the stand and the relatively narrow, 10-foot-wide clearcut strips. After several growing seasons, the strips could be identified only if the viewer knew they were there. In the strip-with-selection thinned plots, the strips were virtually indistinguishable.

After treatment, the individual plots fell within 4 percent of the desired residual basal area except for the strip-with-selection plots where the basal area was too low, as mentioned previously (Table 3).

Table 3. Field trials - plot data before and after thinning

	Control	Individual-tree selection	Strip thinning	Strip selection 40-foot intervals	Strip selection 80-foot intervals
Trees/acre -- before	294	272	290	241	274
-- after		109	176	81	95
BA (square feet/acre) -- before	128	138	110	117	121
-- after		70	68	55	57
D.b.h. (Inches) -- before	8.3	9.1	7.8	8.7	8.4
-- after		10.6	8.0	10.5	9.8
Crop trees/acre -- before	60	63	53	57	56
-- after		63	35	45	45
Crown cover (%) -- before	153	161	137	137	145
-- after		78	84	60	64
Est. Volume (cubic feet/acre) -- before	3890	4280	3300	3630	3710
-- after		2200	2030	1760	1780
Cords removed[1]		26	16	24	24

[1]Estimates based on 79 cubic feet/cord and local volume tables (Erdmann et al. 1982).

After several growing seasons, there was an increase in brush, mostly woody shrubs, on the plots. One corner of the selection-thinned plot showed a large number of aspen suckers.

A major concern with strip-thinning is the loss of potential crop trees in the machine-access strips. Although crop trees would not be specifically identified, the number of crop trees per acre in our study corresponds to the number of potential high-quality sawtimber trees in the stand. The strip-thinning cut 34 percent of the available crop trees; in the strip-with-selection cuts, 20 percent were cut. Theoretically, in the individual-tree selection thinning, no crop trees should have been cut, but 1 to 2 percent were cut accidentally.

Crown release and crown closure are critical factors in the growth and quality development of crop trees. Studies have shown significant increases in d.b.h. growth of pole-size hardwoods after crown release for up to 15 years (Erdmann and Oberg 1973, Erdmann and Peterson 1972, Erdmann et al. 1985, Stone 1977). A reduction in percent of crown cover for all treatments parallels the reduction in basal area. However, in the strip-thinned plot, the openings in the canopy benefited only the trees closest to the strip edges.

Because the strip-thinning was blind to the size and quality of trees removed, both the average tree diameter and size distribution of the strip-thinned plot, like the control plot, remained almost identical to the original stand. As the spacing between the strips became wider in the strip-with-selection treatments, the distribution became more like the desired selection cut, with most of the trees in the 7- to 12-inch size classes (Figure 2).

In a related study, various competition measures were calculated for the crop trees to determine the extent of release accomplished by each thinning

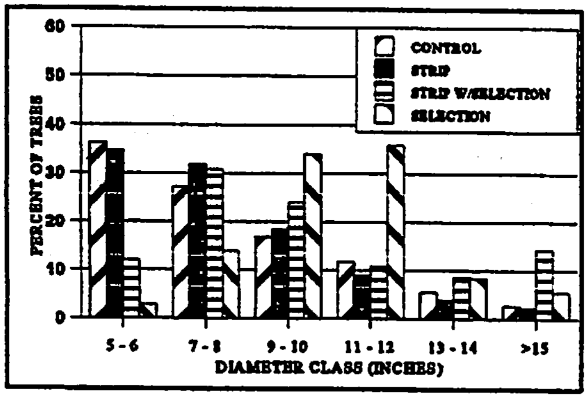

Figure 2 Diameter distributions of all trees ≥ 5 inches d.b.h. after treatments

treatment (Winsauer and Mattson 1990). Trees in all four thinned plots had significantly less competition than those in the control plot, but the trees in the strip-thinned plot suffered from more competition than those in the other thinned plots because more small trees were left after that treatment.

Epicormic sprouting, with its potential for log quality degradation, is a concern when opening up the canopy. Epicormic sprouts and branches on the crop trees were counted after two growing seasons. No correlation was found between the number of sprouts and the crown class or tree quality. About 70 percent of the crop trees had no sprouts in the 16-foot butt log. No statistical differences in the numbers of epicormic sprouts were found between treatments. A higher percent of the crop trees in the strip-thinned plot had epicormic sprouts in the butt log, but the difference was not significant.

PHASE III – TEN YEAR GROWTH RESULTS

The test plots were remeasured after ten growing seasons (Table 4). The net basal area growth in the plots ranged from 16.5 to 22.9 square feet/acre, the highest in the strip-thinned plot, the lowest in the two strip-with-selection plots. The d.b.h. growth was the highest in the individual-tree selection and strip-with-selection plots, ranging from 1.52 to 1.62 inches. D.b.h. growth was .81 inches in the control plot and .65 inches in the strip-thinned plot, reflecting the higher numbers of trees left in those plots. Considering only crop trees, net basal area growth ranged from 5.99 square feet/acre in the strip-thinned plot to 10.92 square feet/acre in the strip-with-selection plot with 40 feet between the strips. The individual-tree selection and strip-with-selection plots had almost twice the net basal area growth of the control and strip-thinned plots. Diameter growth on the crop trees was higher in all the thinned plots than in the control plot. The strip-thinned plot had a diameter growth of 1.44 inches, which is higher than that of the individual-tree selection-thinned plot. The reduced number of crop trees in the strip-thinned plot accounted for that difference.

Stand structure changed considerably in the 10 years between the original improvement cut and the remeasurement. Table 5 summarizes stand structure for the selection-cut plots taken as a group, the strip-cut plot, and the control plot. The data are reported in diameter classes corresponding to pole-size trees (5-9 inches d.b.h.), and three classes of sawlog-size trees (10-14, 15-19, and >19 inches d.b.h.). The stand structure goal for un-even age management is also listed in Table 5 (Tubbs 1977). The total number of trees per acre stayed about the same in the selection plots, with some movement into the larger size classes, while the total number of trees per acre in the strip-thinned plot increased about 10 percent, and the total number of trees per acre in the control plot decreased. More small trees were left in the strip-thinned plot which would account for the ingrowth, while natural mortality in the control plot is probably the reason for the decline in that plot. Basal area growth in all the plots was significant. Most of the growth occurred in the small and medium sawlog-size classes

DISCUSSION

Individual-tree selection is the most desirable method of thinning from a silvicultural standpoint, but economic considerations and equipment constraints may limit the feasibility of this method. A study was conducted to evaluate the silvicultural effects of using less than ideal thinning patterns in second-growth pole-size stands of northern hardwoods in need of thinning. A strip-thinning and two strip-with-selection-between-the-strips patterns were compared to a individual-tree selection-thinning and an unthinned control.

Considering the stands immediately after thinning, there was an obvious gradient in properties from the strip- thinned plot to the strip-with-selection plots to the individual-tree selection plot. Because the strip-thinning was blind to the size and quality of trees

Table 4. Ten-year growth data

	Unthinned control	Single-tree selection	Strip thinning	Strip selection 40-foot intervals	Strip selection 80-foot intervals
Trees 5-inch and larger					
Number of trees	287	109	203	81	93
D.b.h. growth (inches)	0.81	1.52	0.65	1.62	1.6
BA growth /tree (ft^2)	0.068	0.193	0.113	0.204	0.173
Net BA growth (ft^2/ac)	19.5	21.1	22.9	16.5	16.5
Crop trees					
Number of trees	60	63	35	45	44
D.b.h. growth (inches)	0.84	1.07	1.44	1.7	1.57
BA growth/tree (ft^2)	0.104	0.155	0.171	0.243	0.214
Net BA growth (ft^2/ac)	6.27	9.79	5.99	10.92	9.42

removed, both the average tree diameter and size distribution of the strip-thinned plot, like the control plot, remained almost identical to the original stand. As the spacing between the strips became wider in the strip-with-selection treatments, the distribution became more like the desired individual-tree selection cut, with most of the trees in the 7- to 12-inch size classes. The number of potential crop trees saved also increased as the treatments moved toward the individual-tree selection thinning.

Basal area growth in the plots was fairly similar. The key difference is where the growth occurred. In the two strip-with-selection plots, about 60 percent of the growth occurred on crop trees, while in the strip-thinned plot, only 26 percent of the growth occurred on crop trees. The strip-with-selection plots also had the largest diameter growth on crop trees, a key indicator of increasing value in the stand. The individual-tree selection plot had as much basal area growth as the strip-thinned plot and about as much basal area growth in crop trees as the strip-with-selection plots. A significantly larger number of crop trees on the individual-tree selection plot made the diameter growth of crop trees on that plot less than on the strip-with-selection plots. However, the larger number of potential crop trees on the individual-tree selection plot will allow more management flexibility as subsequent harvests are laid out in the stand.

In general, all the plots are moving toward a structure with more trees in the larger sawlog-size classes. The selection plots are closer to the desired stand structure primarily due to the smaller numbers of trees in the pole-size class. Combined with the growth being concentrated on potential crop trees in the selection plots, the value increase will be considerably higher in the selection plots.

Damage to the residual stand can be a serious problem in mechanical thinning. Damage from the harvesting operation was not considered in this study because the harvesting was strictly controlled to ensure that the desired test treatments were properly implemented. Erdmann et al. (1986) reported that up to 12 crop trees/acre (20 percent) were seriously damaged after mechanical felling and skidding of 10-foot-wide clearcut strips. Damage from felling or skidding that removes bark or injures roots can cause loss of value through discoloration and decay from fungi that enter through the wound. Wounds of more than 50 square inches are considered serious in northern hardwoods (Bruhn 1986).
Implementing the results of this study will require consideration of the potential for residual tree

Table 5 Stand structure as-cut and after ten years of growth

Trees per acre							
	Selection		Strip		Control		Goal
Diameter class (inches)	1984	1994	1984	1994	1984	1994	
5-9	41	23	140	140	216	179	65
10-14	43	55	35	53	77	91	28
15-19	9	13	4	8	5	14	17
>19	2	4	1	2	3	3	8
Total	95	94	180	203	301	287	118
Basal area (square feet/acre)							
	Selection		Strip		Control		Goal
Diameter class (inches)	1984	1994	1984	1994	1984	1994	
5-9	13.2	8.2	36.4	38.1	54.9	48.9	16
10-14	30	41.3	24.8	38.3	55.5	67	22
15-19	12.8	19.1	5.7	10.9	6.4	19.1	26
>19	4.6	9.9	2.2	4.6	13.3	14.7	8
Total	60.5	78.6	69.1	91.9	130.2	149.7	84

damage in connection with the equipment system being used.

The impact of harvesting equipment on the forest soil also must be considered. Further research needs to be done on this topic, but the passage of equipment in the stand may need to be limited to maintain soil quality and stand productivity over the long term. The results of this study may then be useful in developing the optimal combination of equipment systems, thinning patterns, economics, and silvicultural objectives.

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Cable Logging With Contoured Reserves — "Wiener" Logging

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ABSTRACT: Author presents experiences of implementing new technologies in cable harvesting utilizing a pattern of narrow alternating contoured clearcuts.

Key Words: Cable Logging, Visual Concerns, Strategic and Tactical Planning

INTRODUCTION

British Columbia's beautiful scenery and rustic atmosphere draw visitors from all over the world. Much of British Columbia's forest land is on steep mountainous terrain, which is highly visible from the highways and waterways. The steep slopes, coupled with the attention they receive, make harvesting activities a challenge. Ninety-five percent of the forest land base is managed as Crown land with strict environmental guidelines. Protecting water, soil, wildlife, and other resource values is critical to successfully operating on these lands.

British Columbia's interior has its own set of challenging conditions. Timber volumes are relatively low. Typical stands have a volume of around 350 cubic meters per hectare. The trees are also fairly small with stand diameters at breast height around 30-60 centimeters. Roads and landings are expensive to build and maintain due to the steep slopes, presence of rock, and numerous water crossings. Deflection is hard to find with the long continuous slopes.

Quality forest engineering layout and innovative harvesting techniques are required to maintain economically viable operations while minimizing environmental impacts (Aulerich 1992). For the past several years Forest Engineering Inc. has been working with the Vavenby Division of Weyerhaeuser Canada in the development and implementation of detailed strategic and tactical plans on many of their sensitive operating areas. This planning effort has clearly identified the need to introduce new harvesting technologies to address a variety of physical, economic, silvicultural, and environmental issues related to harvesting operations on these lands.

CONCEPT

One of these innovative harvesting techniques is the concept of narrow-contoured openings and reserves placed horizontally along the contour of the steep hillsides. The name "Wiener" logging comes from the shape of the narrow stacked openings (Figure 1). The long, narrow-contoured clearcuts are evenly spaced up and down the hill. Generally, the contoured openings and associated reserve areas are in the range of 25-50 meters wide and 200-400 meters in length. Approximately 50% of the stand will be harvested on a given skyline road. Depending on how many entries are designed, this may only be a quarter, third, or half of the surrounding stand. Long narrow strips of timber are left in between the contoured clearcuts. These reserves will be harvested once there is a young stand of timber established in the narrow openings. Logs are harvested out of the narrow openings and yarded through corridors in the reserve strips.

There are several benefits to using this concept over traditional methods:

1. The narrow openings are screened from view by the reserve areas, allowing harvesting to take place in areas once avoided due to steep slopes and high visual concerns. The reserve areas act as a screen to reduce the visibility of the narrow clearcut openings. Depending upon the steepness of the ground and the relative locations of the viewpoints, varying widths of both the openings and the reserves can be utilized to achieve the desired screening.

2. A clearcut system can be utilized for the narrow openings being harvested. Compared to partial cutting systems, clearcuts offer the advantages of reduced har-

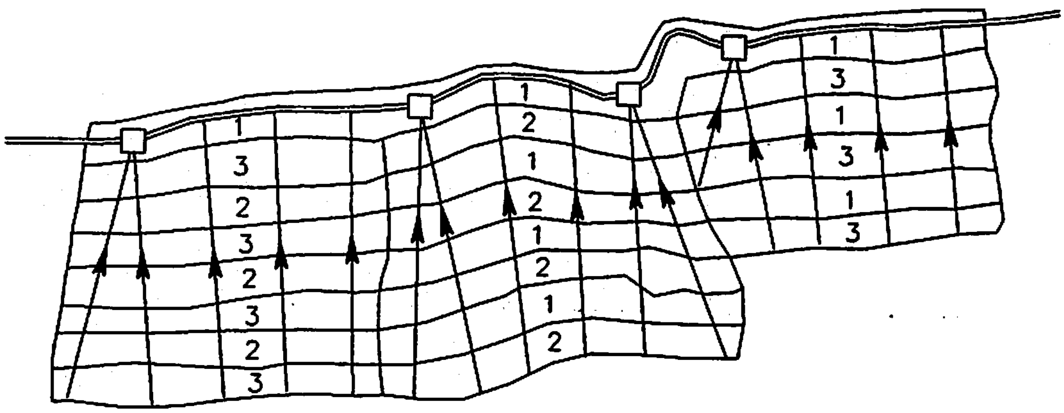

Figure 1. "Wiener" cutblock showing first, second, and third entry

vesting costs because trees can be harvested without the difficulties of working around standing timber and because of the efficiencies of higher volumes removed per area harvested. The ability to utilize small clearcuts has silvicultural advantages in these interior stands infected with *Armillaria ostoyae*. Group selection techniques minimize exposure to the fungus in comparison to other partial-cutting strategies (Cruickshank 1997).

3. Highly visual areas close to arterial highways can be successfully managed. The economics of these stands, close to transportation corridors, can benefit from a reduction in haul cost. They also are lower in elevation than other areas, which allows winter operations more flexibility to work in less snow.

ENGINEERING

Quality engineering is critical to the success of any harvesting operation. Group selection treatments require a sound foundation of logging planning by competent personnel (Edwards 1992). The detailed strategic and tactical plans implemented long before the first turn of logs into the landing determine the fate of all future forest activities. Choices made during the development and implementation of these plans directly influence the safety, economics, silviculture options, environmental impacts, operational flexibility, and political implications for all activities that follow. It is critical that quality information be efficiently collected and analyzed by knowledgeable staff so that all forestry expectations can be met or exceeded.

Engineering for "Wiener" logging first occurs at the strategic planning level. Strategic planning provides the overall guidance in road and landing location based upon a wide variety of conditions and constraints. For "Wiener" logging, the strategic plan focuses on maximizing uphill cable harvesting. Downhill cable yarding is not as preferable as uphill yarding when utilizing partial cutting systems or when yarding in narrow corridors. Downhill yarding through the reserve strips is difficult due to less control over the logs being yarded. The logs tend to swing around to the side with resulting hangups and damage to the trees on the edge of the corridor. Uphill yarding provides more control of the logs since the logs follow the carriage and remain in the corridor.

Once a strategic plan has been field implemented, the tactical planning level identifies all the individual details which affect the operation. The tactical plan field identifies all landings, structures, and anchors. Skyline roads are laid out perpendicular to the contours whenever possible. The reserve areas must be planned with the contoured openings. The engineered plan depicts exactly how much of the area will be harvested and in what sequence. Regardless of the timing or the number of entries, it is very important to have suitable anchors and structures available for each entry. Intermediate supports and tailtrees are often used due to the long continuous slopes with limited deflection opportunities. The reserve areas are planned around the structures since the structures will likely be required for subsequent entries. The upper and lower edges and short sides of the "Wiener" openings are flagged and painted to insure clear boundaries for the falling phase to commence.

Any time a stand is opened up, there is a higher potential for blow-down to occur. The chance for blow-down can be minimized by keeping the openings narrow (within a tree length or two). Narrow openings minimize the wind from moving down into the stand.

Wind-firm edges are selected at the ends of the narrow strips to reduce the chance of blow-down in these areas. If a blow-down event does occur, the entire area will have been engineered with the roads located appropriately for the timber to be successfully salvaged.

HARVESTING

After the area is engineered and laid out, the falling crew falls the timber across the hill, keeping the timber within the narrow openings, similar to falling a road right-of-way. Lead is across the hill, within the openings, for the lateral yarding carriages employed. Corridor trees are felled down the hill within the narrow three- to four-meter-wide corridor. A slight widening of the corridor near the upper edge of the contoured openings allows the turn of logs to swing into the corridor. This slight widening also provides room to change the direction of the felled timber from down the hill in the corridor to across the hill in the contoured openings. Trees along the upper edge of the "Wiener" opening can be felled slightly downhill, away from the upper edge, to help the turns to swing into the corridor. Timber is bucked or left tree-length depending upon available landing space and desired loads for the equipment being used.

Pre-rigging of structures ahead of yarding is necessary, since there is more setup time per volume of timber yarded per skyline road. If the structures are needed for subsequent passes, they can be protected with tree plates, or new corridors may need to be selected to line up other structure combinations when the reserve areas are harvested.

Various yarders and carriages can be utilized with this technique. Carriages which have lateral yarding capabilities are required to yard sideways between the corridors. Radio-controlled, motorized slackpulling carriages capable of going over an intermediate support are often used. Choker setting production is similar to clearcut harvesting since logs are still being yarded from a clearcut. The main production loss is related to a larger proportion of time associated with setup. Quality engineering and layout, along with a hardworking and trained logging crew, have kept production at acceptable levels.

TRAINING

Successful implementation of new techniques requires an understanding of the concepts as well as support from management. Engineering technologies need to be transferred to the people implementing the layout. Harvesting technologies need to be developed within the logging contractor community to perform the subsequent harvesting. Management needs to weigh the costs and benefits of the new technologies and provide time and resources to implement any necessary changes.

Weyerhaeuser Vavenby has invested in the training of their forestry staff and logging contractors. Company management has seen the tangible and intangible benefits of the new technologies and understands the effort to train both forestry and logging staff in new harvesting and engineering technologies. "Wiener" logging is just one of many techniques being introduced and implemented. The forestry staff and logging contractors have received classroom training and hands-on training in the field. The training has allowed the forestry staff to develop a wide variety of important engineering skills necessary to implement operationally feasible strategic and tactical plans incorporating the new techniques. Logging contractor training has provided the knowledge for the contractor to harvest the areas efficiently and safely.

SUMMARY

Within a fairly short time of 3 years the Vavenby forestry staff has successfully field-implemented detailed engineering plans in highly visible, steep, mountainous terrain utilizing the "Wiener" logging concept. Some of the areas engineered in the field are currently being harvested by contract loggers embracing the new technologies. "Wiener" logging maintains many of the advantages of harvesting within a clearcut while providing a screen to reduce visual impacts. The ability to operate successfully on steep, mountainous slopes is based upon the detailed, operationally focused engineering being done. The new technologies being applied allow areas which were avoided in the past to be considered economically and environmentally feasible.

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Skyline Grapple Yarding

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ABSTRACT: A logging contractor and equipment manufacturer in northern Idaho have teamed up to develop a fully mechanized skyline logging system. The felling is completed with a steep-slope feller/buncher. The yarding is accomplished using a skyline yarder with at least two drums and a prototype radio-controlled, hydraulic grapple carriage. Once the trees reach the landing a stroke-boom processor is utilized to limb, top, and buck the logs. On moderately steep ground (35-55%) this system promises to increase the economic feasibility of harvesting small wood.

KEYWORDS: skyline, logging, grapple, carriage, steep-slope, mechanized

INTRODUCTION

As the size of trees available to logging contractors decreases, the efficiency inherent with mechanized equipment has kept operations economically feasible. This trend has been limited primarily to ground-based operations and practiced on more gentle terrain (0-35%). Two equipment developments have allowed a northern Idaho logging contractor to use mechanization to fell, process, and load trees up to 55.9 cm (22 inches) in diameter on steep slopes.

This mechanized skyline system consists of a steep-slope feller/buncher, skyline yarder equipped with a recently developed grapple carriage, a stroke boom delimber, and a log loader.

A complete description of the entire system is presented in this paper. However, it is recommended your focus be on the recent skyline carriage development and how it provides the opportunity to merge other mechanized developments into a physical and economically feasible mechanized skyline yarding alternative.

SYSTEM DESCRIPTION

Felling

In preparation for use of the grapple carriage, felling of timber is completed using a steep-slope feller/buncher. This track-mounted machine mechanically fells all trees within a skyline corridor by beginning at the road and working down to the unit boundary. Trees felled in the downhill pass are placed along one side of the corridor. Once at the bottom of the unit, the feller/buncher begins its return to the landing by felling trees to either side of the corridor and placing them behind the machine. This in effect prebunches an area 15-17 meters (50-56 feet) in width by the length of the skyline corridor. Within this total felling width, felled timber is concentrated in a strip 3-3.5 meters (10-12 feet) in preparation for the yarding phase. Trees are felled and bunched as a whole-tree operation.

Yarding

This phase of the operation is completed through use of a skyline yarder equipped with at least two drums. A live skyline configuration is utilized to support the weight of the carriage and turn while allowing the carriage to be raised and lowered when necessary. A mainline is attached to the grapple carriage and serves to return the carriage to the landing.

A complete cycle of this skyline yarding system would be described as: 1) carriage outhaul under the control of the yarder engineer, 2) grasping (hook) of a turn through radio controls operated by a person in the woods. This person has a set of joy sticks for controlling the grapple arm and grapple, 3) inhaul of the turn, where control of the carriage has been returned to the yarder engineer, and 4) release (unhooking) of the logs at the landing, where the yarder engineer has control of the grapple carriage.

Processing

Once the trees have been yarded to the roadside, a stroke boom delimber is utilized to limb, top, and buck material into desired log lengths. Slash generated by this operation is thus retained in a pile at the roadside for later disposal. Logs are decked along the roadside by the delimber for later loading.

CARRIAGE

The prototype carriage utilized by this system was designed and built by Bill Maki of Maki Carriages, and Steve Henderson of Henderson Logging. It is equipped with a hydraulic arm and grapple. The arm is mounted on the bottom of the carriage, can be remotely swiveled to assist in placement of the grapple, and has a reach of 1.83 meters (6 feet) to either side of the carriage. The grapple is mounted on the end of the boom arm and can be opened to a width of 1.83 meters (72 inches).

The carriage rides on a skyline cable under gravity during the yarding operation. Once the person in the cutting unit signals the yarder engineer to stop the carriage, control of the carriage is turned over to that person. This individual is outfitted with two joy stick remote controls mounted on a belt and worn around the waist. These joysticks control the grapple arm and the grapple from a safe distance during the process of acquiring a turn. Once a turn has been secured in the grapple that person signals the yarder engineer to begin the inhaul phase. At the landing, the yarder engineer releases the turn from the grapple and returns the carriage to the cutting unit.

Turn time is much faster with this carriage in comparison to a carriage equipped with chokers. This is due to a shift from labor intensive cycle elements, hook and unhook, to an operation that is fully mechanized. The speeds of cycle times are more dependent upon line speed capability of the yarder than before. Use of yarders which are equipped with two or more drums that can achieve high line speeds is a good match for this carriage.

DISCUSSION

The use of this system has several advantages to the equipment owner. First, crew size and workman's compensation costs can be reduced. These reductions result from moving the felling operation from a manual, high manpower work force to that of a single individual operating inside an enclosed cab. These costs are further reduced by an operation that requires only one person in the cutting unit during the yarding operation. The owner can see a potential workforce reduction of 3-5 people with these changes.

Total yarding time can be reduced per cutting unit by prebunching whole trees into corridors. This eliminates the lateral yarding element of the cycle time. By eliminating this element, maximum efficiency of a grapple carriage over a choker setting system can be realized. The ability to release logs at the landing without having to remove chokers further reduces cycle time.

Previous studies on skyline yarding established that lateral yarding consumes approximately 50% of the cycle time. In addition, unhooking time consumes another 20-25% of the cycle time. By investing in a machine to complete the felling and prebunching, yarding time can be cut approximately in half. Utilizing this grapple carriage can further reduce cycle times.

Utilizing a process of mechanized felling to prebunch trees can result in turns that more closely approximate desired skyline loads. As silvicultural prescriptions are implemented that direct industry toward ever decreasing wood size, this aspect will allow the equipment owner an opportunity to reduce yarding costs in smaller timber.

Hurricane Fran Helicopter Salvage Case Study

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ABSTRACT: Three harvesting alternatives were considered to salvage Appalachian hardwoods blown down by Hurricane Fran 9/96. Helicopter logging was the chosen alternative, being the least costly, least impacting, and allowing salvage of the most timber. A case study of the KMAX helicopter production and costs for the project indicate a production average 10.7 mbf/hr at a cost of $209/mbf International. Comparison of case study results to estimates by HELIPACE, a PC program to simulate helicopter production and costs, indicates estimates for the KMAX may need refining.

Key Words: helicopter, logging, Helipace, KMAX

INTRODUCTION

On September 6, 1996, Hurricane Fran impacted the Dismal Mountain area on the Pedlar Ranger District approximately 5 miles west of Lowesville, Va. The damage to the forest consisted mainly of blown down trees and broken tops in a variety of intensities ranging from scattered individual trees to areas of complete collapse of the dominant forest. This paper looks at the alternative methods of harvest which were considered, presents a case study of helicopter logging, and reviews the effectiveness of the computer program Helipace (Aerial Forest Management Foundation 1996) to predict costs based upon the case study results.

ALTERNATIVES CONSIDERED

The sawtimber that blew down was subject to rapid deterioration in the 1997 growing season due to staining. Species composition was 80% yellow poplar, 20% northern red oak. The damaged sawtimber component would be characterized as high quality in a market where industrial demand is outstripping available supply (Sloan 1995). The damaged small roundwood component of this timber is very common in the market area and of little economic value, either in terms of stumpage receipts or in meeting industrial demands for forest products. Available supply of small roundwood exceeds industrial demand (Sloan 1995). The focus of this salvage effort was thus on the sawtimber.

The salvage area terrain is characterized as rocky with extensive steep slopes, >35%. The soils are shallow with bedrock surface exposure in several areas. The ownership pattern was such that some salvage areas could not be accessed by ground due to a lack of easement. These factors restrict the operability of logging systems.

Three harvesting alternatives for salvage of the blown down timber were considered: 1) conventional cable skidder with forwarder swing, 2) downhill skyline with cable skidder bunching, and 3) helicopter logging.

Alt. 1: conventional logging with forwarder swing

Due to the steep ground, an extensive network of skid roads would be required in this alternative. Given the shallow soils and bedrock exposures, this alternative also presented some risk associated with the ability to build skid roads without blasting. These same factors also limit the ability to build truck road in the area. In lieu of building truck road, a forwarder road was considered more feasible, utilizing forwarding to a full service landing at an existing truck road. The forwarder road would require the construction of a temporary bridge to cross Kings Creek, a trout fishery.

This logging system alternative is the closest match to the area's conventional systems and, being common, would theoretically give the timber sale offering the greatest market exposure. However, the difficult terrain and the availability of forwarders would limit significantly this alternative's marketability. The timber that was blocked by lack of easement would not be salvaged. This alternative's projected sale volume was 621 mbf (International 1/4-inch). Given the midwinter sale date, it is likely that harvest operations under this alternative would be delayed until early spring and production would be limited by the forwarding swing to the truck road.

Given the average skid of 800 ft combined with a 2400 ft average forward, the logging system production is estimated at 9-10 mbf/day. At this rate of logging production the harvest would conclude in late summer/early fall of 1997. The staining of the sawtimber would begin to occur in late spring and by harvest end would be quite heavy. The value loss due to stain degrade would be high.

Alt. 2: downhill skyline with cable skidder bunching

To reduce ground impacts and risks associated with road building, an alternative using a downhill skyline system was developed. In areas where there was insufficient deflection for skylining, a cable skidder would be used to bunch the timber under a skyline corridor. The timber that was blocked by lack of easement would not be salvaged. Approximately half of the estimated 621 mbf in this alternative would need to be both skidded and yarded. The cable skidder would need to have a system of roads built, although this alternative would reduce the roading required by approximately 40%. Harvesting could begin without delay in the half of the area to be yarded directly, delaying skid road building until seasonal weather permitted.

The logging system production for this alternative is estimated to be 12-15 mbf/day. At this rate of logging the harvest would conclude in mid summer, and by harvest end value loss due to stain degrade would be moderate.

Alt. 3: helicopter

Given the rough terrain, the trout fisheries, inaccessible timber, and the fairly intense amount of development required in the first two alternatives a helicopter alternative was planned. The timber that was land locked to ground based systems could be harvested, and this alternative's projected sale volume was 925 mbf. Estimated volumes of removal in the 10+ mbf/ac range provided the opportunity to hook full turns and minimize helicopter costs.

Initially, it was thought that an optimal number and spacing of landings could be selected to minimize helicopter costs. The environmental analysis process, however eliminated all landing opportunities except one, due to cultural resource protection or Land Management Planning allocations. Fortunately this landing location was fairly central to the timber to be salvaged.

Production for this alternative was estimated to be 80-100 mbf/day, and logging production could begin without delay. At this rate of logging the harvest would conclude in late winter, prior to any loss due to stain degrade. See Figure 1. for a map of this alternative.

DECISION FOR HELICOPTER LOGGING

The decision to use the helicopter alternative was based upon these factors:

1. It salvaged the most timber.
2. It was estimated to be the most cost effective.
3. It was estimated to have the least soil, water, fisheries, and visual impacts.
4. It minimized the risk of developments in rugged terrain.
5. It minimized loss in value due to stain degrade.

Helicopter logging is normally thought of as the most expensive logging method. This is not always the case. There are no "rules of thumb" which can be applied to logging system selections. A comparison of typical unit rates for logging systems is not sufficient to portray enough information to base a reliable decision. Each alternative must be developed in sufficient project detail to allow for specific cost estimates, environmental impacts, and risk assessment.

It is possible to identify when helicopter logging should be considered as an alternative. These factors are when:

1. Conventional logging costs are higher than normal and particularly when swing systems are needed.
2. When conventional logging systems can not access all timber, either through operability limitations or ROW easement limitations.
3. When environmental impacts from conventional logging are heavy or unlawful. This includes timber with BMP restrictions such that it either eliminates harvest conventionally or forces BMP variance to harvest conventionally.
4. When road costs are higher than normal, or when permanent access is not needed for future management.
5. When quick salvage is necessary over large areas due to substantial risk of degrade, particularly during weather related inoperable seasons.

KMAX CASE STUDY

The Dismal Salvage Helicopter sale was prepared under the Recission Act legislation (Salvage Rider, Section 2001 (f((1) Public Law 104-19) which made the environmental decision to harvest not subject to administrative appeal. This act expired December 31, 1996, and, due to administrative limitations late in the year, any timber sale under this legislation needed to be awarded by year end. If not awarded by year end the decisions to make the sale would need to revert to a "normal" environmental analysis process lasting at best 6 months. This would effectively eliminate the need to salvage, as the timber would be wasted due to deterioration and be of little remaining value.

This timber sale was a "fast track" project with the time of awareness of the salvage opportunity to time of bidding less than 3 months. Glenwood Ranger District Timber Management Assistant Glenn Szarzynski is credited with providing the leadership and coordination that made this project a timely and successful salvage operation. The sale was formally advertised December 12, bids opened December 30, and award was made on December 31, 1996.

The advertised minimum acceptable price for the 936 mbf was $41,000. Two bids were received, one of $55,567 and the high bid of $102,003. Kachina Forest Products, Boise, Idaho, was the successful bidder.

Kachina Forest Products was formed as a partnership between Kachina Aviation and George Jenson Logging in 1996, combining over 50 years of aviation and logging expertise to focus on the business of heli-logging. Kachina Forest Products is interested in contract heli-logging opportunities with their KMAX helicopter. They may be contacted by calling Keith Watson, (208) 343-8749.

Equipment Utilized:

Helicopter: KMAX, 6000# lift capacity, Cost $3,500,000

Other: 1400 gallon Jet A fuel truck, aircraft maintenance trailer, dozer (Landing Construction, CAT D5C), front end loader (CAT IT28F), Knuckleboom loader with buck saw (Prentice 180), skidder (Landing Clearing, Timberjack 380B), four subcontract log trucks.

The contract was executed and paid for January 8, 1997, and cutting began January 10, 1997. Timber falling conditions were extremely difficult due to Hurricane Fran's fury. The timber was, in places, blown down in jackstrawed layers 4 deep, root wads, broken boles and tops, on very steep (65%+) ground. The cutting job was subcontracted to Ross Hojem, Hojem Logging, out of Chehalis, Wash.

Ross and crew did an excellent job in dealing with these dangerous cutting conditions. Ross had never cut

Table 1. Harvest alternative comparison.

	Alternative 1 Cable Skid Forwarder Swing #	 Total Cost	Alternative 2 Skyline with Cable Skid Bunch #	 Total Cost	Alternative 3 Helicopter #	 Total Cost
Landings	2 ea	$1200	4 ea	$2000	1 ea	$6000
Swing Landing	1 ea	600				
Forwarder Road	2400 ft	3000				
Forwarder Bridge	1 ea	4200				
Skid Road	8000 ft	7000	4600 ft	4000		
Swing Vol.	544 mbf	24480	345 mbf	17250		
Logging Costs [1]	621 mbf	62100	621 mbf	74250	925 mbf	130425
Total Vol.	621 mbf		621 mbf		925 mbf	
Total Costs		102580		97770		136425
Unit Rate [2]	$165.20/ mbf		$157.40/ mbf		$147.50/ mbf	
Estimated time to harvest	7 months		5 months		1 month	
Potential Deterioration	High		Medium		None	

[1] Fell and Skid/Yard Rates estimated by Alt are: Alt 1. $100/mbf; Alt 2. $120/mbf; Alt 3. $141/mbf

[2] Costs are stump to landing

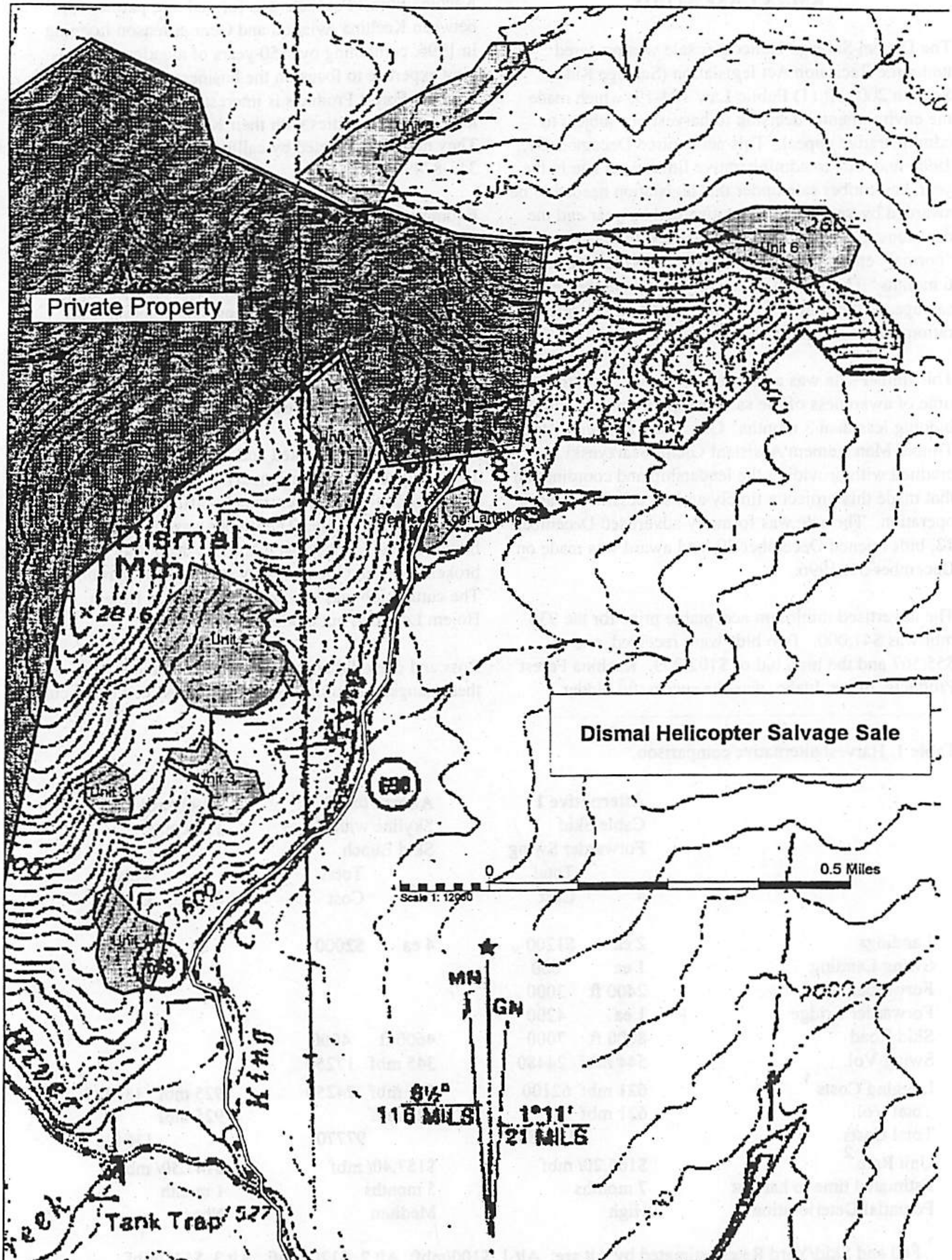

Figure 1. Dismal Helicopter Salvage Sale Map

for a helicopter job, but he has worked extensively with a wide range of logging systems on steep ground. He also had valuable experience cutting Appalachian Hardwoods (Sloan 1992), something that Kachina Forest Products lacked.

Timber cutting production average 10mbf/man-day, and was done with safety in operations as first priority. No cutting occurred on windy days, length of work day was controlled to minimize fatigue, and communication was maintained between the cutting crew members. The cutting contract rate was $22/mbf International.

Both the service and log landing construction was accomplished with a rented Caterpillar D5C dozer. Along with some minor road widening, the landing clearing and construction process took a full week. In order to armor the landing for winter season work, 400 tons of Va #2 stone (3-4"/dia) was placed. The cost of these landings were $2100 D5C, $4800 stone, $1500 labor for a total cost of $8400.

Flying of the timber began on January 23 with a schedule of working Monday through Saturday when not limited by visibility or wind (>35mph). Table 2 represents a summary of the production data recorded during the project.

Total timber sale cruised volume to be flown was 925 mbf International broken down as follows:

Species Group	MBF International
Yellow Poplar	743
Red Oak	174
Misc HWD	8

Based upon the cruised volume and the actual flight records, production for the KMAX was 10.7 mbf/hr International.

Total timber sale delivered volume as recorded from mill receipts was 754 mbf Doyle broken down as follows:

Species	MBF Doyle
Yellow Poplar	595
Red Oak	109
Chestnut Oak	27
Ash	7
Hickory	6
Hard Maple	3
Basswood	3
Soft Maple	2
Misc	2

Based upon the delivered volume and the actual flight records, production for the KMAX was 8.73 mbf/hr Doyle.

One of the most critical factors in determining aircraft costs is the utilization rate of the aircraft. Annual utilization can be projected from this project, based upon the availability of the aircraft to fly with weather

Table 2. KMAX production data record

Date	Total Pounds	Total Turns	Aborts #	Flights Hours	Turns/ Hour	Pounds/ Turn
1/23/97	382380	81	4	3.6	22.5	4721
1/24/97	333590	70	6	3.6	19.4	4766
1/27/97	699890	146	7	6.5	22.5	4794
1/29/97	706750	151	12	6.9	21.9	4680
1/30/97	778390	172	6	6.9	24.9	4526
1/31/97	748690	164	7	7.0	23.4	4565
2/1/97	699010	156	5	6.6	23.6	4481
2/3/97	826420	189		6.7	28.2	4373
2/4/97	751200	162		6.3	25.7	4637
2/5/97	867500	193		6.3	30.6	4495
2/7/97	795200	186		5.5	33.8	4275
2/10/97	152360	37		1.2	30.8	4118
2/11/97	461720	104		3.6	28.9	4440
2/15/97	609620	140		4.9	28.6	4354
2/18/97	897310	198		7.3	27.1	4532
2/19/97	402070	94		3.5	26.9	4277
Totals	10112100	2243	47	86.4	26.0	4508

delays and scheduling conflicts. On this project 86.4 flight hours were recorded with 23 scheduled days. The projected utilization rate is (86.4/23)* 300 scheduled days/year =1127 hours/year. Based upon this annual utilization rate, the projected cost for the KMAX is estimated as $1615/flight hour (Sloan 1994).

The unit rate for the KMAX flight operations only would be:

$1615/10.7 = $151/mbf International
$1615/8.73 = $185/mbf Doyle

In addition to flight costs, there were 4 hookers, 2 chasers, and 1 loader with operator to support the job. Estimated cost for this is $150/man-day average plus $500/day for the loader. The number of days worked was 16 days.

The unit rate for hooking, chasing, and clearing the chute would be:

($150*7*16)+($500*16)/ 925 MBF = $27/mbf International

($150*7*16)+($500*16)/ 754 MBF = $33/mbf Doyle

Table 3. Total unit rate cost[2] for KMAX helicopter salvage

	$/MBF International	*$/MBF Doyle*
Felling	22	27
Flying	151	185
Hooking, Chasing, Clearing	27	33
Landing Construction	9	11
Total Stump to Landing	209	256

[1] These costs exclude mobilization, travel, and profit

During the operation, there were some observations where improvements in productivity might be possible. There was not enough lead time between cutting and yarding. This resulted in an approximate 4-day delay in the yarding when the KMAX could have flown, but there was no timber cut to be flown. By planning helicopter operations and scheduling enough lead time, this delay could be avoided. The lack of Kachina Forest Products experience in Appalachian hardwood timber, combined with extremely difficult cutting conditions, undoubtedly contributed to this delay.

Load factors, actual turn weight/available turn weight, could be improved. With the average cut per acre of 13.2 mbf Int. or 10.8 mbf Doyle, there was ample opportunity to hook full turns. The average load factor was 4508#/6000# = 75%. The target load was 5000#, or a load factor of 5000#/6000# = 83%. By utilizing different techniques (Sloan 1994) it is felt that this can be improved. The variability in density in Appalachian hardwoods needs to be accounted for in the process of turn building. Kachina Forest Products has reported average loads of 5200# on western projects, indicating that inexperience in Appalachian hardwoods contributed to the below average load factor on this project.

The yarding distance on this sale averaged 2700 ft, with the closest unit 1300 ft and the longest 4300 ft. In analyzing the turns per hour the average was 26 with the fastest being 33.8 and the slowest of 19.4. An equation set for turns per hour, tons/hr, mbf/hr, and $/mbf based upon this projects logging conditions and flight distance would be approximately

Turns/flight hour = 33.8 - .0048*(flight dist., ft - 1300)

Tons/flight hour = 76.2 - .0108*(flight dist.,ft. - 1300)

MBF Int/hr = 13.9 - .00198*(flight dist.,ft - 1300)

MBF Doyle/hr = 11.4 - .00161*(flight dist., ft - 1300)

$/MBF Int. = 1000/(6.52 - .000926(flight dist., ft - 1300)

$/MBF Doyle = 1000/(5.31 - .000755(flight dist., ft - 1300)

Both $/MBF equations do not include landing cost, mobilization, or profit.

CASE STUDY COMPARISON WITH HELIPACE 2.71

To effectively plan and appraise timber value in helicopter timber sales, the USFS in concert with the Aerial Forest Management Foundation developed a PC based computer simulation program to model production and costs for heli-logging called Helipace (Aerial Forest Management Foundation 1996). The program was introduced in 1990 and has gone through numerous updates, with the latest version being 2.71 (1997) and including the KMAX helicopter. To test the effectiveness of the program to predict production and costs, a comparison of this case study results to that predicted by Helipace is made.

To make the comparison, the actual values for pounds per board foot and pounds per turn from this case study were input along with all the other data required.

Table 4. A comparison between the production estimated by Helipace and the case study results

		Helipace 2.71		*Case Study*	
Unit	*Flight dist Feet*	*Turns/ hr*	*Int. mbf/ hr*	*Turns/ hr*	*Int. mbf/ hr*
1	1346	25.6	10.6	33.6	13.8
2	2214	23.5	9.6	29.4	12.1
3	3204	21.4	8.9	24.6	10.1
4	4307	19.4	8.0	19.4	7.9
5	3004	23.9	9.9	25.6	10.5
6	3043	21.7	9.0	25.4	10.4

It appears from the above case study comparison table that Helipace as an estimator for the KMAX tends to underestimate productivity at shorter average yarding distances. In viewing the aircraft coefficients used in Helipace, the same base times and coefficients are used for the KMAX as that for much larger ships. It appears that coefficients specific for the KMAX need to be developed to increase the accuracy of the productivity estimates.

A comparison between the costs estimated by Helipace and the case study results are shown in the following table.

Table 5. Comparison betweeen the costs estimated in Helipace and case study.

		Helipace 2.71	*Case Study*
Unit	*Flight dist*	*$/MBF Int*	*$/MBF Int*
1	1346	163	154
2	2214	183	177
3	3204	201	210
4	4307	221	268
5	3004	180	202
6	3043	198	204

It appears that from the above case study comparison table that Helipace tends to overestimate costs at shorter yarding distances and underestimate costs at longer yarding distances. This variance can, in part, be explained by the difference in the productivity previously outlined. Further explanation can be made by examining the costs in the program for the KMAX. The total cost in the program is $1311.50/hr, which is considerably less than the $1615/hr used in this case study. This difference could be in the annual utilization rate. If the annual utilization of the KMAX were 1500 hr/yr the costs for the KMAX are estimated at $1324.07/hr (Sloan 1994). This rate of utilization would yield costs which are in closer alignment with the costs included in Helipace.

If the delays due to poor scheduling of lead time for timber falling are taken out from this study's estimate of annual utilization, the predicted utilization would change to 1364 hr/yr. These estimates of utilization do not include move time. It is unlikely that for a contract heli-logging company, moving around the country for work, would get annual utilization of much greater than 1200-1400 hrs/yr. Helipace does not include information on the annual utilization rate used in costing, nor the ability to adjust it, or any other cost variables for specific situations.

Additional concerns for predicting KMAX costs using HELIPACE are mobilization. The program does not allow the user to modify the equipment spread and people that must be mobilized, and is fixed on the mobilization needs of a larger aircraft.

The Helipace program is an excellent tool to become aquatinted with the variables associated with helicopter logging. Hopefully, there will be continuing support which will keep it current as the technology of heli-logging changes.

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Automatic Foam Fire Suppression for Mobile Equipment

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ABSTRACT: Automatic dry chemical fire suppression systems have been used on mobile logging and road construction equipment for over 10 years by MacMillan Bloedel (MB) to reduce the costs associated with equipment fires and to increase employee safety. Undesirable features discovered include: dry chemical suppressant's corrosiveness causes electrical problems, dry chemical provides no cooling effect which increases the chance of rekindle, and dry chemical can not penetrate accumulations of twigs, needles, and duff to extinguish deep seated, smoldering fires. To overcome these concerns, a foam fire suppression system utilizing an Aqueous Film Forming Foam (AFFF) and antifreeze was proposed by MB. FERIC and MB designed and installed a prototype system. This system design was developed and fire tested by Firetech Engineering Inc., Fleck Brothers, and MB. Six of these foam fire suppression systems were installed in 1996, with more installations planned for 1997. This paper describes the benefits, the development ,and final configurations of this foam fire suppression system.

OBJECTIVES

The objective of this project is to develop an automatic fire suppression system for large mobile logging equipment with the following qualities. This fire suppression system is to be at least as effective as dry chemical fire suppression systems, typically used for knockdown of the fire and is to be superior at preventing rekindling of the fire. This suppression system should reduce potential hazards to people and the surrounding environment. This system must be cost competitive with presently available systems. It must not damage logging equipment and must require only minimal cleanup following a discharge. Providing protection for the adjacent vegetation is also desirable. General design should be kept simple so that refilling, maintenance, and repairs are easy.

BACKGROUND

Since 1985, MacMillan Bloedel has required that all new purchases of large mobile logging equipment include an automatic fire suppression system. Dry chemical fire suppression systems were the best alternative at the time. These systems are very effective in knocking down fires but they have some problems.

Dry chemical is corrosive. When a dry chemical system is discharged in mobile equipment it can cause electrical faults. Often, following a discharge, the alternator and regulator require replacement and sometime the engine starter motor also must be replaced. As mobile equipment uses additional electrical and electronic system, such as electric solenoid valves and electronic engine controllers, this issue becomes increasingly important. Also following a discharge, the mobile equipment must be immediately shutdown and thoroughly washed down. If engines and compressors are run prior to wash down, the dry chemical may be sucked in through the air intake and ultimately may cause extensive damage.

Dry chemical has no cooling effect on a fire. Although dry chemical has excellent knockdown capabilities and does form a coating to reduce combustion, dry chemical does not cool the affected area. Many mobile equipment fires start from a spark or hot piece of metal landing in a mixture of oil, fuel, grease, rubber, and duff. This fire may smolder unnoticed for hours before it flares up. This means the machine may be unattended at the time and that the fire is deep seated in the petroleum products and the duff. The consequence of this is that there is no one immediately available to mop up after the fire has been knocked down and that the fire may continue to smolder after the dry chemical suppression system has knocked the fire down. Following detection of the fire and discharge of the dry chemical suppressant, fires have rekindled on mobile equipment, causing extensive damage and costly repairs or equipment replacement.

Dry chemical does not flow after application. Generally, dry chemical suppressant will remain where it has been applied. Although this sounds positive at first, when considering the complex shapes on mobile equipment, this can be a disadvantage. Designing a system to direct suppressant at all possible fire hazards would be extremely costly to design, build, install, and maintain. It also would require many machine, model, and even option specific designs. Furthermore, if the fire has initiated from below the equipment or has carried on down to below the equipment, automatic dry chemical suppression systems are unlikely to extinguish any significant fire. Reignition is possible.

In 1989, MacMillan Bloedel decided that an automatic fire suppression system that utilized an AFFF (aqueous fluid forming foam) foam could be developed to reduce or eliminate these problems. A development team including Fleck Brothers, Firetech Engineering, FERIC (Forest Engineering Research Institute of Canada), and MacMillan Bloedel was formed to design an automatic foam fire suppression system.

INITIAL PROTOTYPE

In 1990, FERIC developed an experimental foam fire suppression system. FERIC investigated potential fire suppressants which confirmed foam to be the best choice of suppressant. Factors in this choice included heat absorption, ability to penetrate, blanket forming ability, and post discharge cleanup. Class A and B foams were compared, and Class B foam was found to be superior in forming and maintaining a blanket of suppressant to seal the surface of petroleum products. With no significant benefit using Class A foam, Class B foam was chosen.

Initially FERIC constructed a small single nozzle system for bench tests. This system assisted in defining the optimal operating pressures and hose sizes considering other design constraints. Small test fires were used to compare class A and B foams. A class B foam, Petroseal, was chosen as the superior foam in this application as a result of its rekindle or burn back resistance on hydrocarbons. Petroseal is an FFFP (film forming fluoro protein) foam that also performs as an AFFF but with reduced corrosive and environmental impacts. This test system was also used to ensure that adding a nontoxic antifreeze to the foam solution would not reduce fire suppressing effects.

Having chosen foam as the suppressant, other design objectives were reviewed. These objectives included quick response, effective coverage, minimal dependence on other machine systems, effective operation through expected ambient and operating temperatures, both manual and automatic actuation, and, a simple design to facilitate installation and simplify cleanup.

Following the above bench tests, FERIC designed an experimental foam suppression system for MacMillan Bloedel's Kelsey Bay Division on a Thunderbird 1146B hydraulic log loader. This prototype included a nitrogen cylinder, a regulator, a 60 US gal foam solution tank, four Angus K40 foam nozzles, a Ropec R777 control system, three Fenwall heat detectors, a 1 1/2-inch normally closed (NC) zero leak solenoid valve, and some hardware and wiring.

The nitrogen cylinder, through the regulator, maintains pressure in the solution tank and the solenoid valve mounted to the bottom of the solution tank keeps the solution in the tank until the valve is opened by the monitor. The monitor may be set into alarm by either the fenwall detectors (automatically) or a switch on the monitor (manual). The monitor will keep the solenoid valve open even if neither the detectors nor the manual switch remain closed to prevent partial discharges. A reset button is used to override this function and close the solenoid valve.

The monitor includes an auto shut down 15 seconds after the monitor receives signal of a fire. There is also a button to override this function and provide the operator more time to safely shut down the machine if required.

Installation and testing of this foam suppression system were completed in early 1991. Testing included a wet test, that is discharging the system as it would occur in case of a fire. The test results appeared favorable with a total discharge time of 55 seconds. Excess foam flowed through the machine and onto the ground below, providing protection for the surrounding vegetation. Although this system appeared to operate effectively, no full scale burn tests had been performed to this date.

POTENTIAL IMPROVEMENTS

The main concern with this prototype was that it had not been tested in full-scale fire conditions. There was also a need to reduce the size and weight of the solution and tank while improving the coverage on equipment with more obstructions that could prevent suppressant from reaching all locations.

To reduce the size and weight of the solution and tank, the suppressant must be applied more effectively. A greater number of lower flow nozzles carefully located was thought to be the best method of achieving these objectives. Improving the detection of fire also reduces the suppressant required, and although improvements were made with fire detection, it was decided that the minimum volume of suppressant must be sufficient to extinguish the largest realistic fire. Consequently more research was dedicated to effective use of suppressant than fire detection.

Other potential improvements include reducing the parts of the system under pressure to reduce the potential for leaks and ensuring the system design is adaptable to various sizes and shapes of machines. The prototype system used the nitrogen cylinder to pressurize the foam solution in the tank, using the 1 1/2-inch zero leak valve to control the flow. Keeping the hose from the nitrogen regulator (which is connected directly to the nitrogen cylinder) relatively short and sufficiently large in diameter, a control valve may be placed directly following the nitrogen regulator without significantly affecting the period from fire detection to suppressant application.

NOZZLE TESTS

The foam nozzle used in the prototype was an Angus K40. This nozzle tends to form an umbrella shaped spray pattern where most of the foam is distributed about the perimeter of the spray area. A full cone type spray pattern is preferred in this application.

In 1993, Firetech Engineering was contracted to evaluate foam nozzles and develop a practical system proven by full scale fire tests.

Nozzles tested were 5 feet above the ground and pointing directly down. The foam was supplied from a 60-gal solution tank pressurized by an air compressor. The hose connecting the solution tank outlet and the nozzle was 1 1/4 inch inside diameter, large enough to minimize any delivery system restrictions. Four 2x2s were laid horizontally, at ground level, perpendicular to each other, so that one end of each 2x2 met directly below the test nozzle. Each 2x2 was clearly marked in 1-foot graduations. Two 2x2s were placed vertically and were also marked in 1-foot graduations. These markers were used to assist in defining spray patterns from the test nozzles. Three video cameras were used to document the tests.

Firetech Engineering's evaluation of foam nozzle to date includes the Angus K40, Angus 361A, Angus B, Grinnell B, and Kidde ZBHM nozzles. Both the Angus B and the Kidde nozzles provided a consistent full cone spray pattern such that foam is evenly distributed throughout the cone. The flow rate of the Angus B nozzle (approx. 12 gpm @ 100psi) is approximately 4 times greater than the Kidde nozzle (approx. 3 gpm @ 100psi). Together these nozzles will protect a wide range of machine configurations and fire hazards. Consequently, these two types of nozzles were chosen to be used in our foam fire suppression system.

SYSTEM FIRE TESTS

System development and fire tests were conducted at Firetech's burn facility near Vernon in British Columbia, Canada. The site was chosen because the summer weather is warm and has minimal wind with a relatively predictable pattern for approximately 4 months a year. Consistent weather conditions are critical to produce comparable results when conducting burn tests. Wind can affect results significantly, so the burn site was surrounded with a 130 foot diameter, 12 foot high porous wind shelter. A standard 10 meter weather station is next to the burn site. A low threshold wind monitor is located so that it detects and records wind velocity as it reaches the burn site. Choosing periods of similar calm warm conditions helped to ensure that results are comparable.

Since Madill 044 grapple yarders were our target logging equipment, a mockup was built of 1/4 x 2 inch angle and 1/8-inch steel plate to represent the major areas to be protected on this machine. Components were added, such as a GM diesel engine when representing the engine compartment. Each compartment was equipped with thermocouples connected to a data acquisition system. Also connected to the data acquisition system were three video cameras recording the tests from different perspectives.

A standard fire was defined so that results could be compared. Standard fire requirements included that, each compartment was preheated to 212 degrees Fahrenheit and diesel fuel was poured into pans of water in the compartment to ensure an even thickness of fuel. The fuel was ignited, and in the engine compartment two jets of diesel fuel were also ignited to simulate a broken hydraulic hose. The fuel was allowed to burn for 30 seconds before suppressant was applied to the fire. This produced a large fire which represented the largest fire the suppression system could reasonably be expected to extinguish.

Approximately 25 standard test fires were conducted to test various nozzle locations and to estimate the optimum flow rate of suppressant. A dry chemical system was installed by Fleck Brothers as directed by the manufacturer and applied to the standard fire to evaluate the performance of the foam system compared to dry chemical.

TEST RESULTS

The test criteria was to achieve fire knockdown in 2 seconds or less, without rekindle. In the standard fire, optimal flow rates were determined for each of the following compartments of a Madill 044 grapple yarder, the engine, the brakes, the clutches, and the drums. Optimal nozzle locations were determined. Dry chemical suppressant was also tested in the standard fire to compare it to foam suppressant.

The optimal flow rate for the engine compartment is 73 gpm at 160 psi, for the brake compartment 35 gpm at 160 psi, for the clutch compartment 32 gpm at 160 psi, and for the drum compartment 40 gpm at 160 psi. Six nozzles are located in the engine compartment, seven are in the brake compartment, four are in the clutch compartment, and eight are in the drum compartment.

Firetech Engineering found that locating the nozzles so that the incoming combustion air is entrained with foam provides an effective suppression system. This helps draw the foam into the areas where the fire is located. Firetech also found that opposing nozzles can reduce the speed of the foam and create a foam that is more easily entrained into the combustion air. These benefits have been implemented. However, caution must be taken to ensure that non-opposing nozzles do not create air turbulence that may fan the fire by increasing the combustion air.

Validation tests were also conducted in the engine compartment for demonstration purposes. In addition to the fuel loading of the standard fire, rubber was added to simulate the effect of pneumatic and hydraulic hoses. In each dry chemical test, 21 pounds of dry chemical suppressant was used, whereas in foam tests the flow rate was 1 gallon per second with the foam suppressant flow being shut off as soon as knockdown was realized.

The time to knockdown for dry chemical was 2 to 8 seconds and for the foam suppressant 1 to 4 seconds. No rekindle occurred when using foam suppressant; however, rekindle of the rubber occurred after 6 minutes during a dry chemical test.

IMPLEMENTATION

In 1996, six foam systems were installed by Fleck Brothers and in 1997 two more were installed. The first system was installed in February on a Madill 044 grapple yarder. The second system was installed in March on a Hitachi EX400 excavator. The third foam suppression system was installed on a Linkbelt 5800 Quantum Road Builder in June. In September the fourth and fifth systems were installed on a TMM850 line loader; one on the loader and one on the carrier. The sixth system was installed on a Kobelco 350 log loader. In February of 1997 foam systems were installed on two 4300 Linkbelt machines—a hydraulic log loader and an excavator. Installation time and system cost for a foam suppression system are similar to a dry chemical system of comparable size.

CONCLUSIONS

This foam system is believed to be superior to dry chemical systems typically used on mobile forestry equipment and will continue to be implemented in our equipment.

For fire knockdown, this foam suppression system is at least as effective as a dry chemical system. Foam suppressant provides significant cooling to reduce rekindle whereas dry chemical suppressant does not. Foam suppressant is more environmentally friendly and less corrosive than dry chemical suppressant. Cleanup is easy, and recharging this foam system can be easily achieved in the field, minimizing equipment down time.

The Plastic Road

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ABSTRACT: The Plastic Road was designed for short-term access of vehicles and equipment over environmentally sensitive sites or soils with low bearing capacity. The system is lightweight, portable, inexpensive, easily constructed of readily available materials, and temporary. Material lists and tools, plus step-by-step instructions are included in this report. The road was tested on the Osceola Ranger District in Florida.

Key Words: environment; low bearing capacity soils; plastic road; geotextile; portable crossing

INTRODUCTION

Many forest activities require short-term access for vehicles and equipment over sensitive sites or soils with low bearing capacity. Likewise, many projects in the forest benefit from work schedule extensions or seasonal adjustments that allow increased sensitivity to wildlife. Temporary access over environmentally sensitive sites is facilitated by effective crossing systems that are economical as well as easily installed, moved within project, and removed. The plastic road is one such system (Figure 1).

This system is lightweight, portable, reusable, inexpensive, and easily constructed of readily available materials. The plastic road was conceived with use on temporary roads in mind.

This report describes site conditions and operational requirements under which the plastic road may be used for short-term access into the forest. System limitations are discussed, as are areas for improvement. Using, moving, disassembling, and transporting are also described. Materials and tools required to fabricate the plastic road are listed, and step-by-step instructions for assembly and installation of the system are included.

THE PLASTIC ROAD FOR SHORT-TERM ACCESS

The plastic road spreads wheel loads over an increased subgrade area, reducing rutting and disturbance to soils and vegetation (Figure 2). This helps reduce water concentrations, channeling, erosion, and the potential for damage to fish and wildlife habitat. A geotextile underlayment (Figure 3) to the plastic road further increases environmental sensitivity by separating the crossing from soil and allows water to filter through. Geotextile helps spread load, may increase soil bearing capacity, and facilitates removal of the crossing after use. Removal is quick and easy compared to that of conventional techniques for crossing soft spots and can aid in closure and obliteration of the temporary road.

The plastic road is lightweight, portable, reusable, and inexpensive when amortized over system life. Its length is tailored to site conditions in 10 foot (3 meter) increments. Plastic road panels and required accessories for 40 linear feet (12 linear meters) of crossing may be transported in a 3/4 ton pickup and assembled on a typical site by a two-person crew (Figure 4) in approximately 1 hour. This length of plastic road may be moved from site to site by chaining-to and towing with a pickup truck or logging equipment. Worn or broken PVC pipe members are easily replaced, facilitating maintenance and reuse of the system. Materials cost including geotextile and transition mats (Figure 1) for this length of plastic road is approximately $2000. Adding labor to fabricate increases the cost to approximately $2500. Materials are readily available through major hardware distributors.

Transition Mats

Transition mats composed of successively larger pipe (2-inch to 3-inch up to the 4-inch standard panel pipe size) ease the transition of tires from the approach onto the plastic road. Making the first 2-inch pipe in the mat to support wheel loads of Schedule 80 increases mat durability. The transition mats increase environmental sensitivity by eliminating the need for ramping up to the plastic road with soil, which usually has to be borrowed from somewhere (Figure 5). Transition mats also reduce the forces applied to the plastic road as tires roll onto it. Longitudinal forces tend to displace the plastic road in the direction the vehicle is moving, discouraging it from gaining a set in the soil. Absence of this set can lead to soil kneading and increased rutting as the plastic road creeps and point loads from individual pipe vary in location on the soil. Forces abruptly applied by tires to the 4-inch pipe as in use of the plastic road without ramping or transition mats can result in pipe shattering, especially in very cold environments.

Use of The Plastic Road

Vehicles negotiating the plastic road should travel at a constant 5 mph (8 kph); sudden acceleration or deceleration may cause loss of traction, especially if the plastic is wet. The system has successfully supported 18-wheel on-highway (80,000 lbs GVW, or 36,400 kg) log trucks (and other forest traffic and logging equipment) on straight alignments with grades up to 4% with no cross-slope. Steeper grades or the existence of cross-slope or horizontal curvature may also result in loss of traction. Traction loss may occur between tires and the PVC, or slippage may occur between the PVC and the soil or geotextile, causing it to work out of the soil ramp if so installed (Figure 6). In these latter cases a wave may form in the crossing system which can lead to failure if the system folds over on itself.

Experimentation with tractive surfaces applied to the PVC pipe was conducted in an attempt to reduce the potential for traction problems. Epoxy and sand was tried, as was attaching sheet grating with machine-screws to individual pipe and to a series of pipes. The epoxy/sand application did not exhibit required durability, as the sand grains rolled out or were sheared out of the epoxy when subjected to wheel loads. Attaching grating was labor- and time-intensive and did not appear to greatly increase traction; the coefficient of friction between rubber and steel is low, causing a reliance on interlock between tire tread and grating openings for any traction increase. Successfully increasing traction between tires and plastic without anchoring the plastic road may result in displacement of the system or in a wave buildup.

Plastic Road Field Tests

A PVC pipe mat used and removed at scores of sites on the Osceola Ranger District in Florida remains serviceable after several hundred log truck passes and other heavy and light vehicle traffic. A prototype plastic road installation tested by San Dimas Technology and Development Center has supported over 400 loaded 18-wheel log truck passes at two sites. Testing included several relatively high-speed passes (in excess of 10 mph, or 16 km/h), the negotiation of several passes with driver and trailer tires only partially on the plastic road, and hard braking. Several passes were made with the plastic road located on a dry, hard, rocky subgrade, which resulted in point-loading and breakage of several 4-inch pipe.

Areas for Improvement

Areas for improvement and further testing include anchoring systems, alternative transition mats, alternative materials to resist pipe breakage (use of Schedule 80 PVC or ABS, for example), use on grades steeper than 4% or on cross slope, further investigation into tractive surfaces, and use on curves.

Use on curves may require anchoring, tractive surfaces, and a wider plastic road to compensate for off-tracking and curve widening. A design conforming panels to curvature and specific configurations for inside and outside panels may also be required.

Use of the plastic road to provide access across gullies or drainages merits experimentation. Loose or bundled pipe placed in the low spots might possibly provide the smooth subgrade required for subsequent installation of the plastic road. Investigation into use on skid trails as well as long term use is also warranted.

MOVING AND DISASSEMBLY

Up to 40 linear feet (12 linear meters) of plastic road can be moved from site to site by attaching a chain to the transition mat cable loops (Figure 1) or around the panel spacer. Washers and double clips are installed on the loops to provide strength expressly for this purpose. A pickup truck or logging equipment may be used to drag the plastic road to the new site. Care should be taken in tugging the plastic road out of its set, especially if it is deeply sunk into the soil and/or if soil has migrated into the pipe ends. Well-set plastic road installations may require disassembly prior to moving to prevent damage or breakage. The distance and surface over which the plastic road is dragged should also be evaluated to avoid excessive wear or breakage.

Disassembly of the plastic road after use or for transport to another site is easily accomplished by pulling quick pins in the panel connectors. This reduces the assembly into its component parts: panels, panel connectors, and transition mats. Forty linear feet (12 linear meters) of plastic road components fit into a 3/4 ton pickup truck or on a flatbed. The geotextile material is removed unless a biodegradable type was used allowing it to remain in place. Shaping of the site may be required if the set resulted in depressions which might lead to channeling or concentration of water.

CONCLUSIONS

The plastic road is available to aid short term access for vehicles and equipment into forest. This system is lightweight, portable, reusable, inexpensive, and constructed of readily available materials. The plastic road reduces rut depth and has provided satisfactory service over sensitive sites and soils of low bearing capacity on relatively flat road grades free of cross slope and horizontal curvature. Testing usage outside these constraints and further development effort to optimize performance is warranted.

MATERIALS AND TOOLS REQUIRED FOR THE PLASTIC ROAD

Plastic road fabrication requires the following parts (Figure 7):

- 4-inch PVC Schedule 40, four foot lengths
- 3-inch PVC Schedule 40, four and three foot lengths
- 2-inch PVC Schedule 40, four foot lengths
- 1-inch PVC Schedule 80, ten foot lengths
- 1-inch PVC Schedule 80, eight inch lengths
- 3/8-inch diameter quick pins
- 3/8-inch cable Cable clips for 3/8-inch cable
- 3/8-inch washers

Nonwoven, needle-punched polypropylene or HDPE geotextile materials of low (3 oz./sq. yd, or 100 gm/sq. meter) to medium weight (6 oz./sq. yd, or 200 gm/sq. meter) have performed adequately, as have biodegradable poly-jute materials. To fabricate the plastic road you will need the following tools:

- Drill press
- 13/32-inch drill bit
- 1 3/8-inch drill bit
- Power saw (abrasive, table, or radial arm)
- Hammer
- Pry-bar to fit 13/32-inch hole
- Sander

Use of geotextile is optional and dependent on the soil and site conditions.

FABRICATION OF THE PLASTIC ROAD

To produce parts A,B,C,D,E, and F, cut PVC stock into the specified lengths and drill appropriate hole sizes into the pipe as specified in Table 1. Bevel ends of parts E and F to enable easy installation into part A.

Assembly of Panels
(2 each required per 10 LF of plastic road)

Materials needed for each panel:

27 A
2 E
4 Quick Pins

Steps:

1. Lay 2 Es parallel to each other, approximately 42" apart.
2. Slip-fit an A onto the two Es, see figure 8(a).
3. Repeat step 2 until 27 As are on the 2 Es, see figure 8(b).
4. Arrange the As on each end such that the E protrudes only halfway through as shown in figure 8(c).
5. Insert quick pins in the holes in the ends of each E as shown in figure 8(c). This requires sticking your hand into each end A, and results in an open hole to accept the F part of panel connector (Figure 9). The Es have extra holes at 108-inches on center for prying, if required.
6. Repeat steps 1 through 5 for the other panel.

Assembly of Panel Connectors (2 each required)

Materials needed for each panel connector:

2 A
1 D
4 F
8 quick pins

Steps:

1. Arrange the parts A and D side by side, A-D-A as shown in figure 10(a).
2. Slide the end of D into the end of an A.
3. Line up the holes and slide an F into the holes to secure the pipes in place.
4. Quick pin the stubbies in place.
5. Repeat steps 3 & 4 for the opposite end of D and the remaining A.
6. Repeat steps 1 through 5 for the other panel connector.

Assembly of Transition Mats (4 required)

Materials needed for each transition mat:

1 A*
5 B
6 C
2 H
8 I
4 J

Steps:

1. Form a 4-inch loop in the end of the cable and secure with 2 cable clips.
2. Slide a washer on the cable.
3. Insert the free end of the cable into the 13/32-inch hole in the A from the inside (see figure 11(a) and pull tight.
4. Repeat steps 1-3 for the other cable.
5. Slide the Bs onto the cables, see figure 11 (b).
6. Slide the Cs onto the cables**, see figure 11(b)
7. Slide a washer on each of the two cables.
8. Form loops in each cable end (removing slack in the cable in the process) and secure with 2 I, see figure 11(c).
9. Repeat steps 1 through 8 for the other three mats.

Assembly of 10 LF of Plastic Road with Transition Mats

Materials needed:

2 panels
2 panel connectors
4 transition mats

Steps:

1. Arrange the two panels at the needed crossing location with a gap of approximately 2 feet, see figure 12(a).
2. Place the 2 panel connectors as shown in figure 12(a). Remove the quick pins, allowing the stubbies to fit into the corresponding holes in the As in the panel ends.
3. Quick pin the panel connectors in place. This requires you to stick your hand into the last A at the end of each panel. Watch out for snakes!!
4. Arrange the transition mats as shown in figure 12(a) and quick pin as described above for the panels.

The length of plastic road can be easily increased by 10 foot increments. Required parts for each 10 foot increment are shown in Table 3. Two panels and 1 panel connector are installed for each additional 10 LF increment as described in the Section entitled "Assembly of 10 LF of Plastic Road with Transition Mats." Transition mats are installed at each end of the plastic road as described in the same Section.

Table 1. Parts Specifications

Part	Name	Description	O.D.	Length	Drilled Hole Dia.	X-X on Center
A	Panel Member	4" PVC Sch. 40	4.5"	48" (-)	1.375"	42"
B	Mat Member	3" PVC Sch. 40	3.5"	48" (-)	13/32"	32"
C	Mat Member	2" PVC Sch. 40	2.375"	48" (-)	13/32"	32"
D	Panel Spacer	3" PVC Sch. 40	3.5"	36"	1.375"	30"
E	Stringer	1" PVC Sch. 80	1.315"	120" (-)	13/32"	108, 117"
F	Stubbie	1" PVC Sch. 80	1.315"	8"	13/32"	5.5"
G	Quick Pin	Steel Pins	3/8"	3"	--	--
H	Cable	Cable	3/8"	5'	--	--
I	Cable Clip	Cable Clip	--	--	--	--
J	Washer	Washer	--	--	--	--
K	Geotextile	Geotextile	--	--	--	--

(-) indicates true length will be less than that tabulated due to saw blade width loss

hole location:

The number of parts and stock items necessary for 10 LF of plastic road with transition mats are displayed in table 2.

Table 2. Parts for 10 LF of Plastic Road with Transition Mats

	# of Parts necessary for the:			Total	Stock
Part	Panels	Connectors	Transition Mats	Quantity	Items
A	54	4	4	62	13 @ 20' Joint (+) 4" Sch 40
B	0	0	20	20	4 @ 20' Joint (-) 3" Sch 40
C	0	0	24	24	5 @ 20' Joint (+) 2" Sch 40
D	0	2	0	2	1 @ 6' 3" Sch 40
E	4	0	0	4	2 @ 20' Joint (-) 1" Sch 80
F	0	8	0	8	1 @ 6' 1" Sch 80
G	8	16	0	24	24 @ quick pins
H	0	0	8	8	8 @ 5 ft length of cable
I	0	0	32	32	32 @ 3/8-inch cable clips
J	0	0	16	16	16 @ 3/8-inch heavy duty washers

(-) indicates true length will be less than that tabulated due to saw blade width loss
(+) indicates some materials will be left over.

Table 3. Parts for Each 10 foot Incremental Increase.

Part	# of Parts needed for: Panels	Connectors	Total Quantity	Stock Items
A	54	2	56	12 @ 20' (+) 4" Sch 40
B	0	0	0	—
C	0	0	0	—
D	0	1	1	1 @ 3' 3" Sch 40
E	4	0	4	2 @ 20' (-) 1" Sch 40
F	0	4	4	1 @ 3' 1" Sch 40
G	8	8	16	16 Quick Pins
H	0	0	0	—
I	0	0	0	—
J	0	0	0	—

(-) indicates true length will be less than that tabulated due to saw blade width loss
(+) indicates some materials will be left over

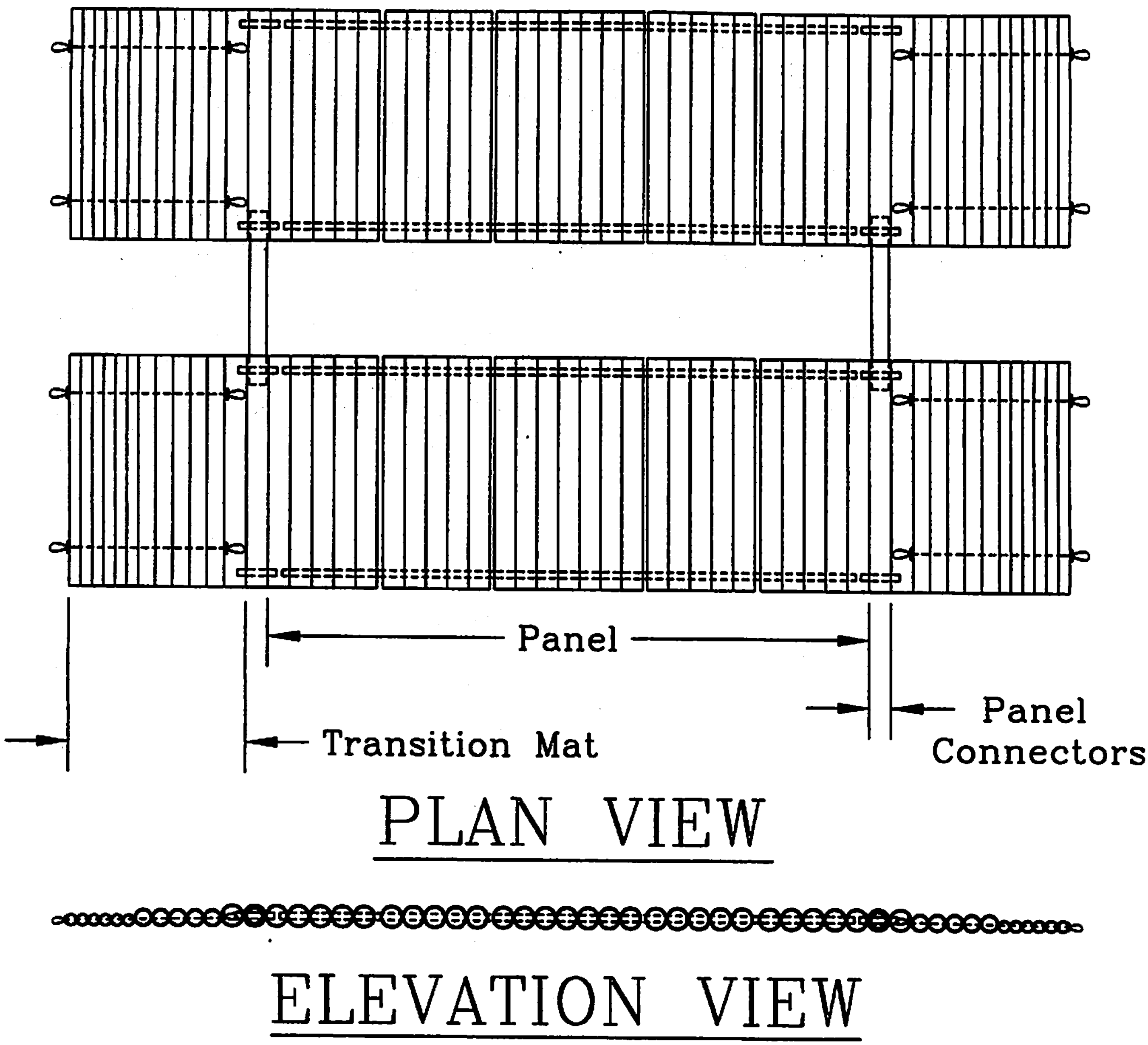


Figure 1. Plastic road with transition mat.

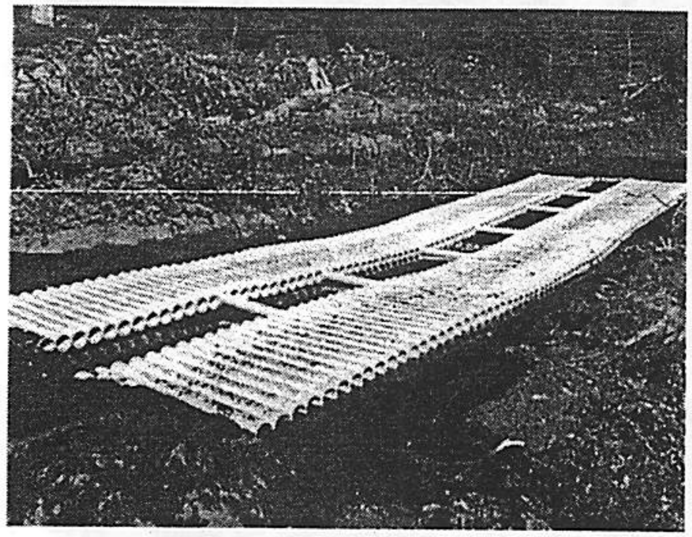


Figure 2. 40 linear foot plastic road installation.

Figure 3. Geotextile underlayment to the plastic road.

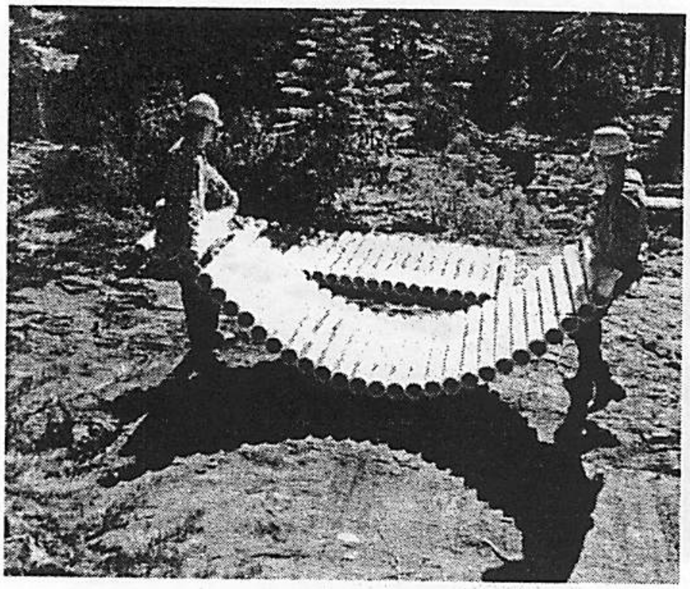


Figure 4. Two-person crew installing the plastic road.

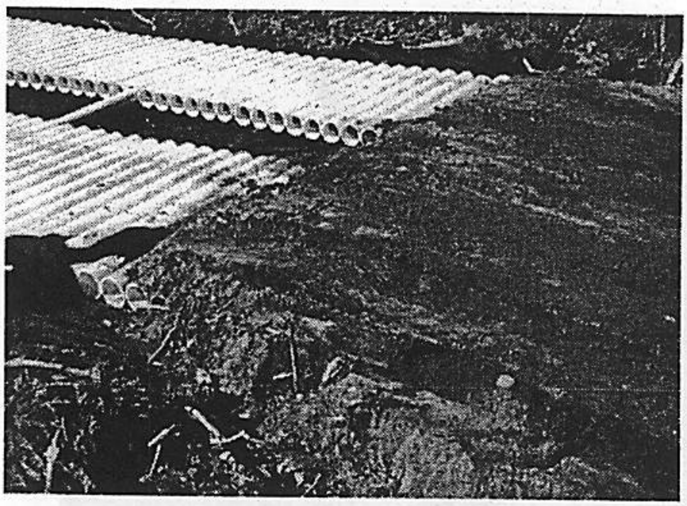


Figure 5. Borrowed soil ramps to the plastic road.

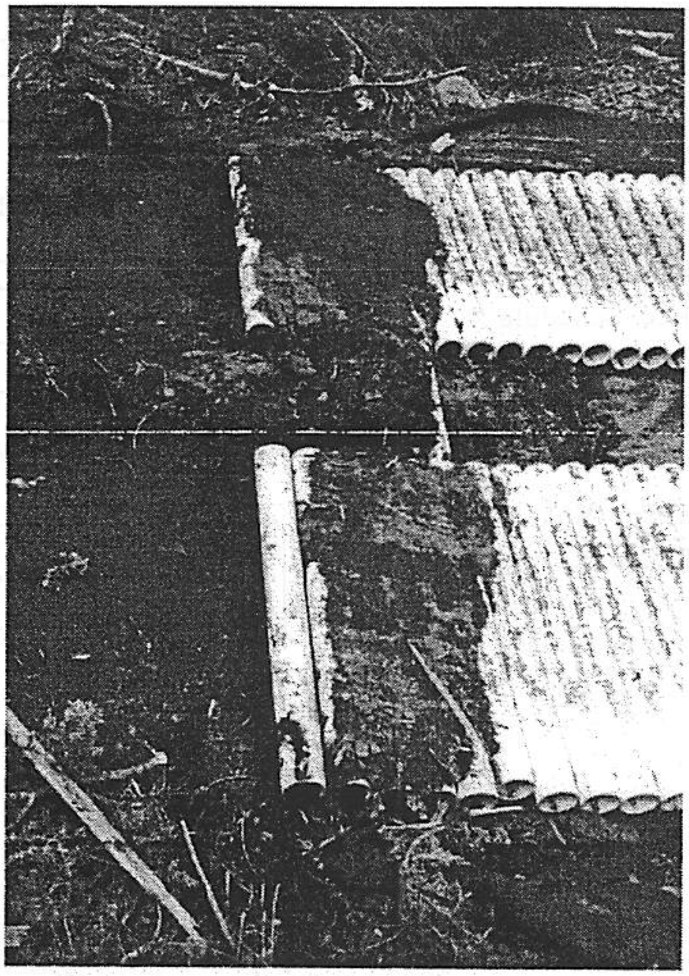


Figure 6. Plastic road worked out of the soil ramp.

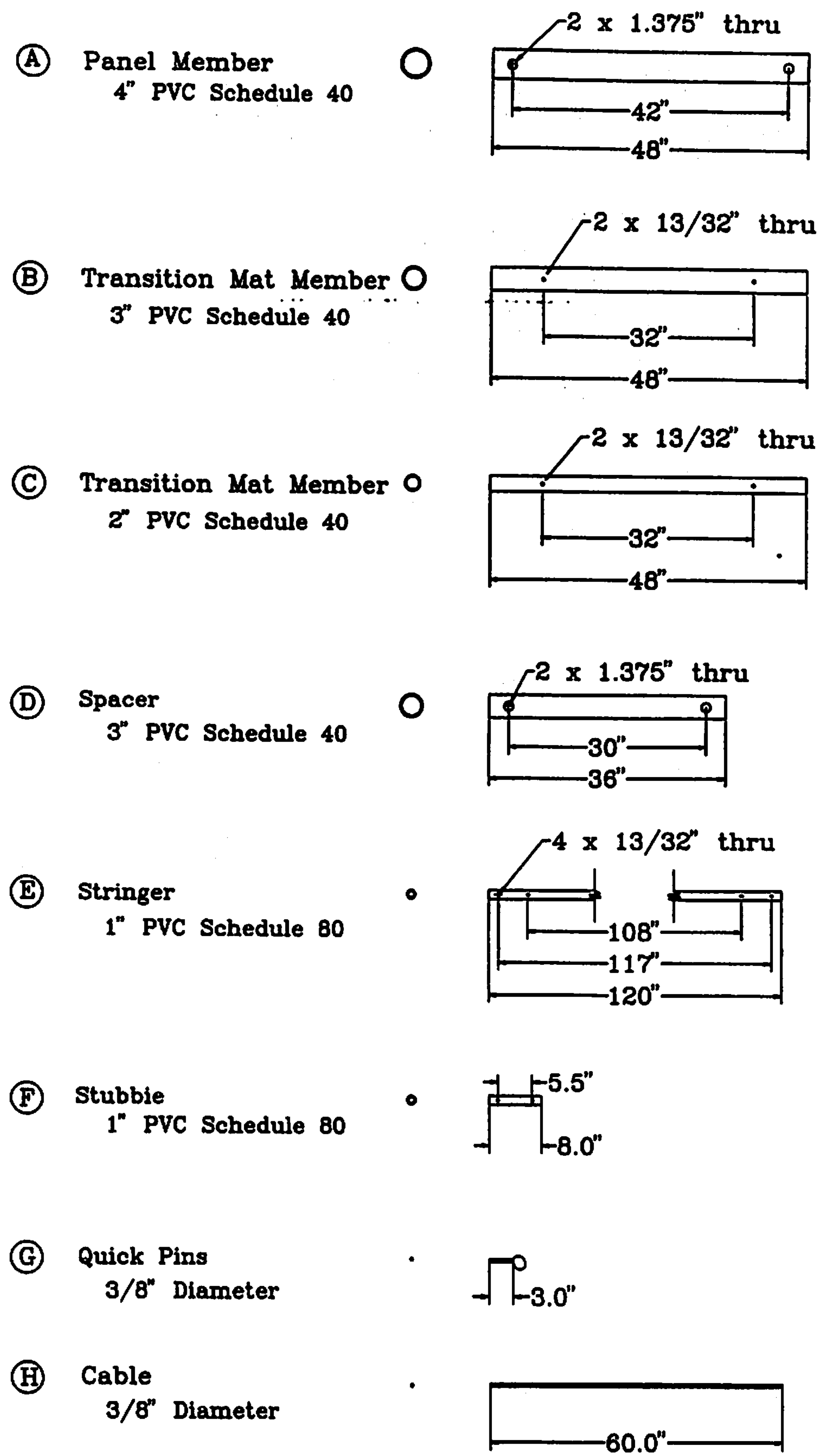


Figure 7. Parts of the plastic road.

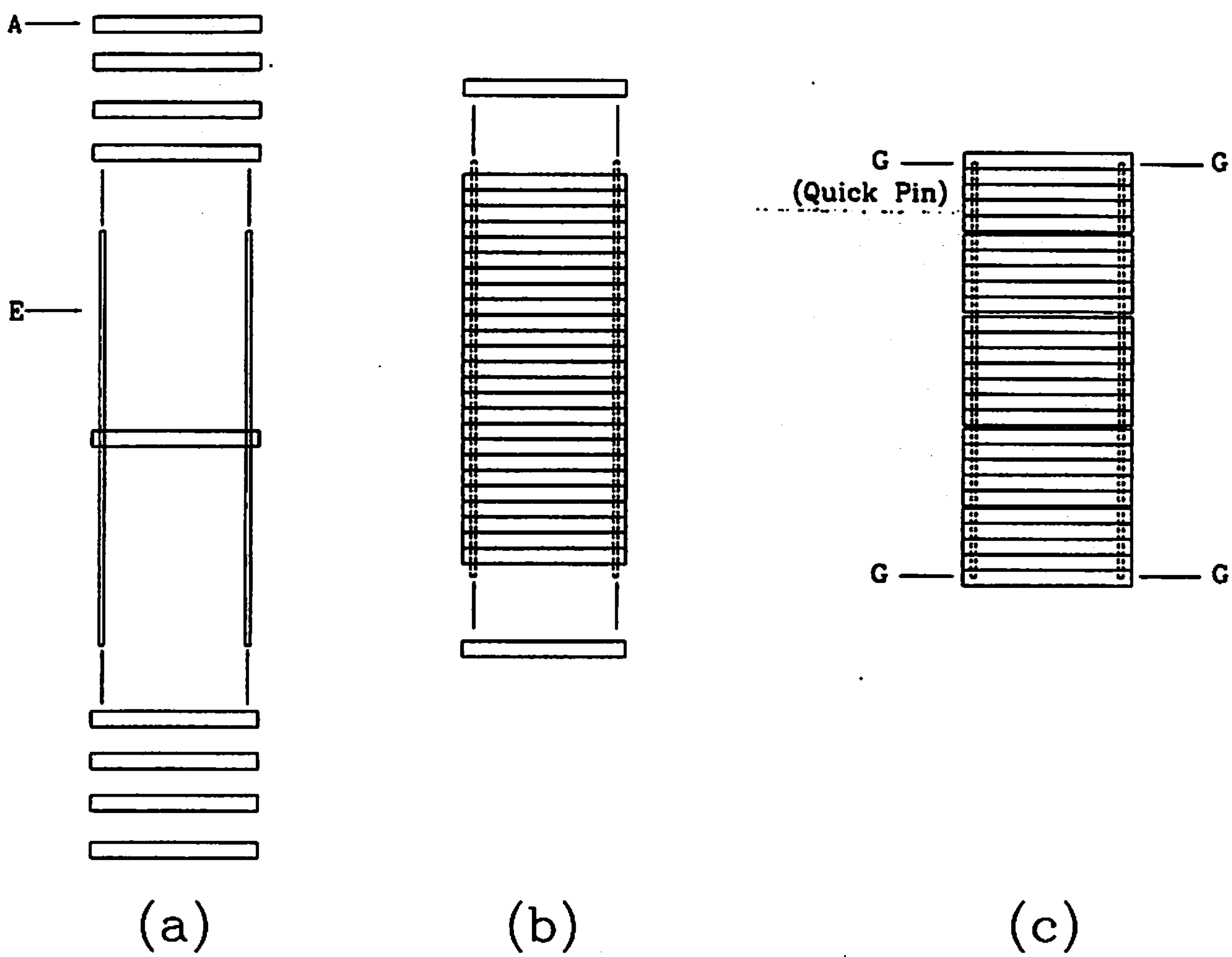


Figure 8. Assembly of panels.

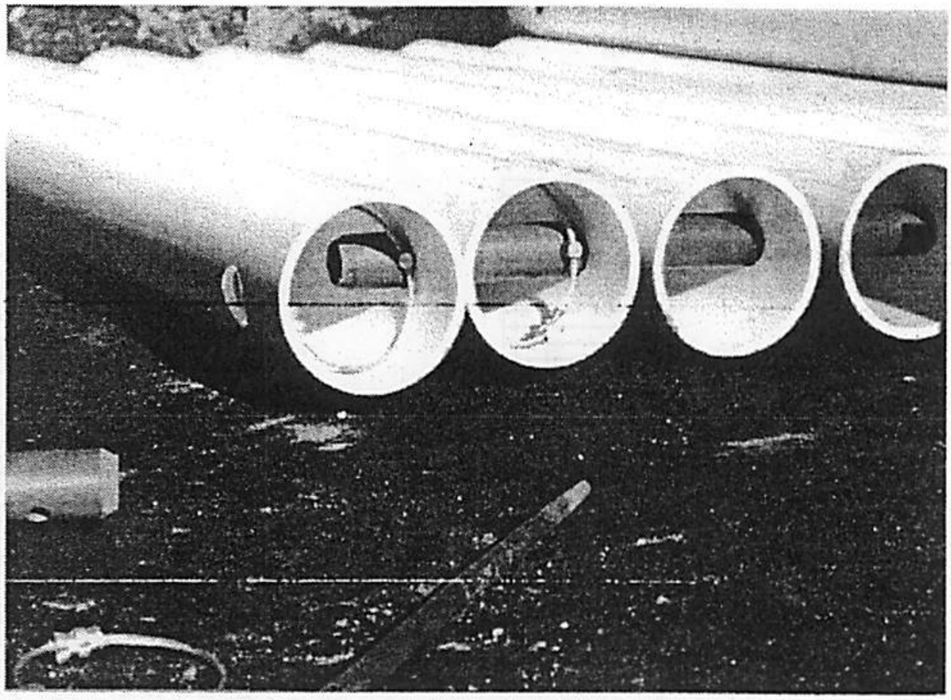


Figure 9. Open hole to accept F part of panel connector.

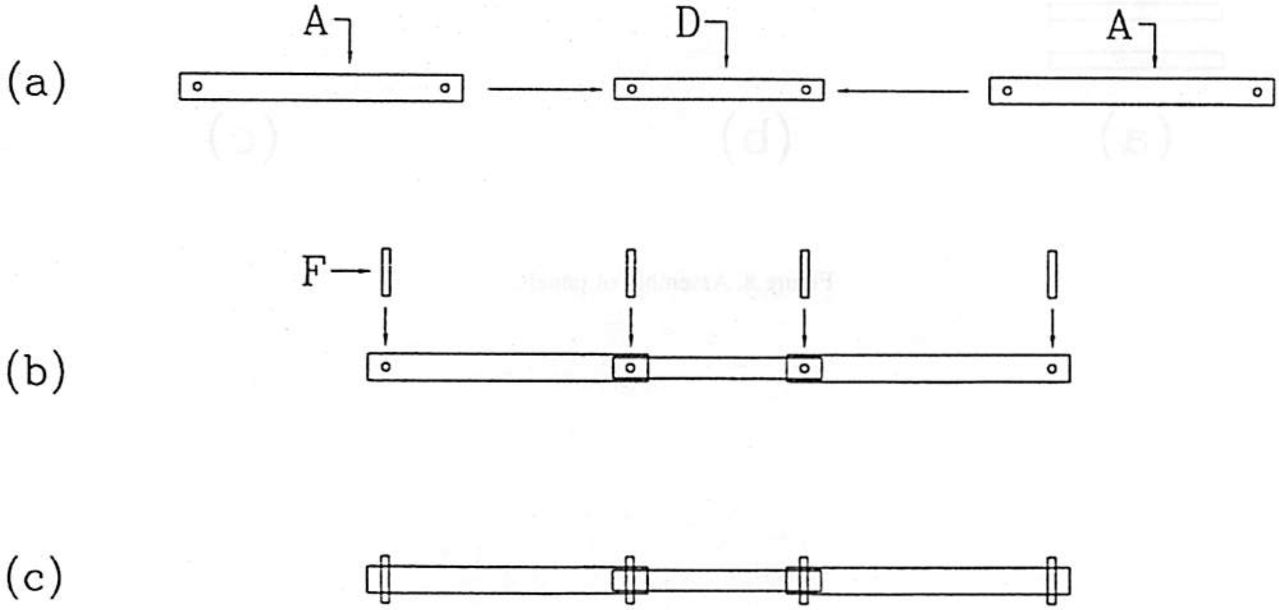


Figure 10. Assembly of panel connectors.

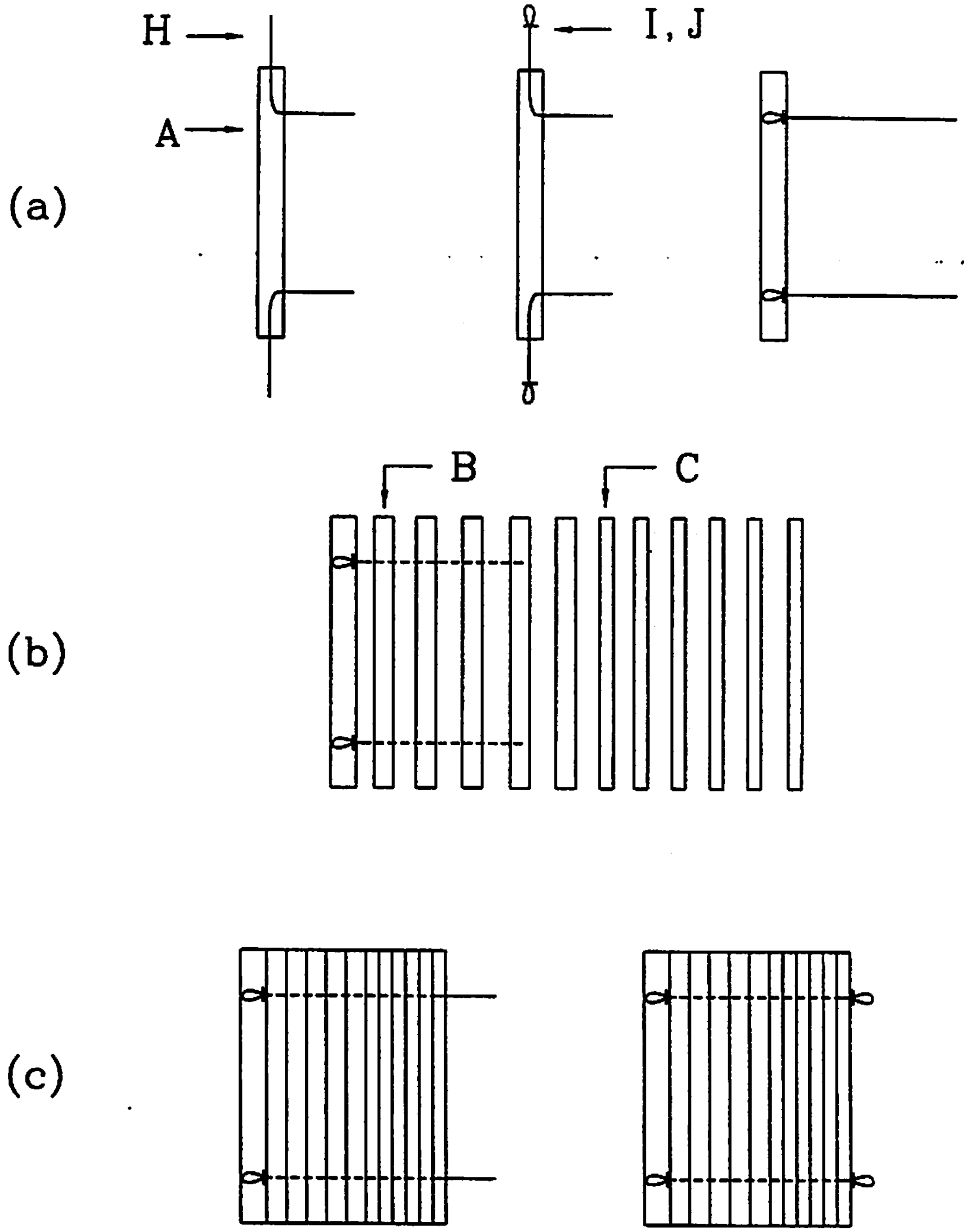
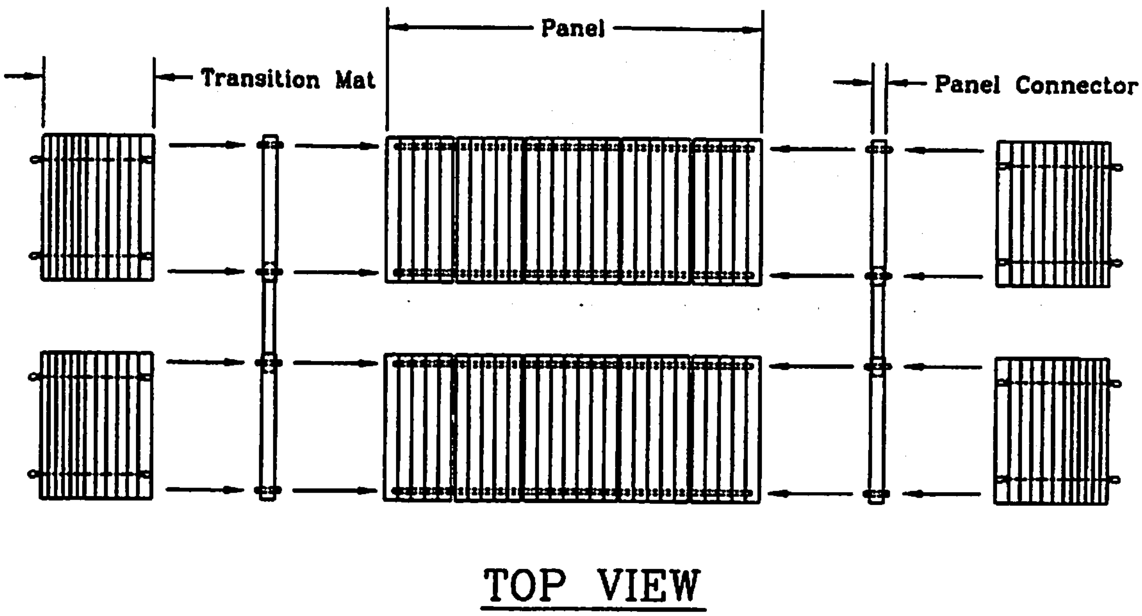


Figure 11. Assembly oftransition mats.

(a)



(b)

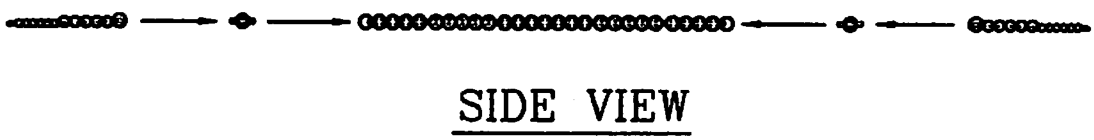


Figure 12. Assembly of plastic road with transition mats.

An Earthwork Calculator Program For Your Personal Computer

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ABSTRACT: The calculation of earthworks by hand is an arduous task fraught with error. On most forest roads, particularly on private lands, there is rarely a need for the calculation of earthworks to assess the estimated cost of a road. However, the availability of earthwork data is helpful in deciding whether sections of gradient should be modified to achieve a more efficient use of construction equipment. In certain circumstances, such as steep terrain, these earthwork calculations can result in recognition of excessive cuts or fills and point out the need for the vertical adjustment of the gradeline to minimize erosion,trafficability concerns, and road costs.

Key Words: forest roads, gradients, alignment, excavation, embankments

INTRODUCTION

Direct location of forest roads involves the installation of road tangents and curves directly in the field along a gradeline. This technique works well for most temporary and perhaps secondary forest roads, but does not allow for the best alignment, final grade, and calculation of construction costs. Paper location involves the establishment of a preliminary line on a gradeline in the field. This preliminary line is used as the basis for subsequent office development of the final centerline, road grade, vertical adjustments, and finally, earthwork calculations. These earthwork calculations can be used to estimate the machine hours needed for excavation and embankment, to estimate the total yardages of cuts and fills, and estimation of road construction costs.

The "Earthwork Calculator" is a modification and upgrading of the original "End Area Calculator" designed by Rick Hokens in 1985 when he was on the faculty at Virginia Tech. The program allows the calculation of earthworks from field data which includes the cut and fill at centerline, and the percent of the side slope to the right and left of centerline at each station. Yardages of excavation and embankment depend on the distance between stations (Figure 1).

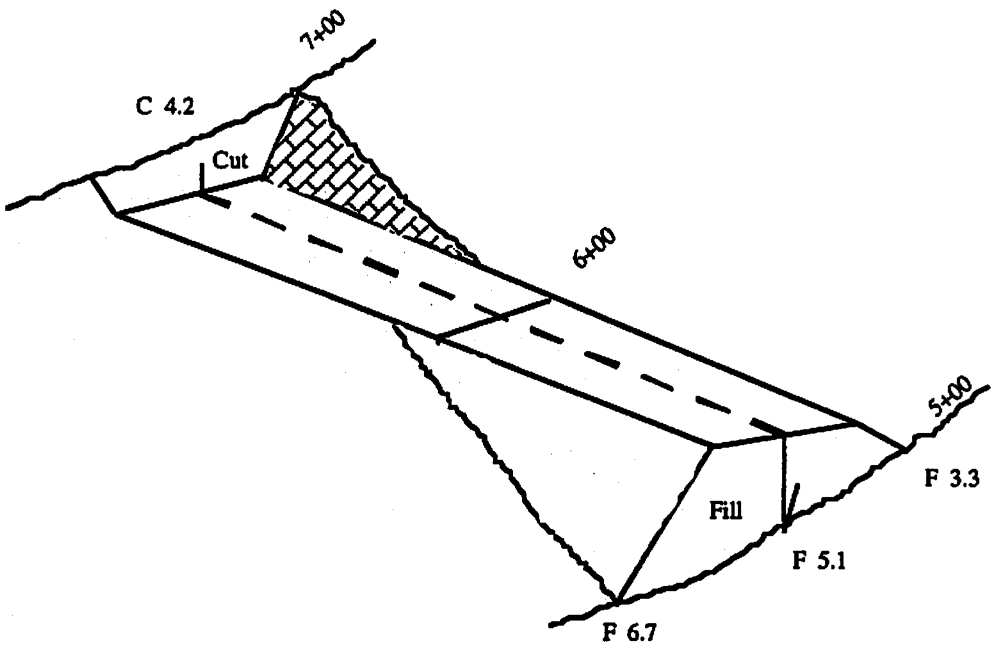

Figure 1. Schematic of earthworks (addapted from Walbridge et al. 1984)

PROGRAM CALCULATIONS

The program calculations use the "average end-area method" to produce the cubic yards of excavation and embankment, where there are end areas (EA) of cut and fill (ft^2) at both stations:

$$\frac{EA1+EA2}{2} \times \frac{\text{Distance between Stations}}{27} = \text{Cubic Yards}$$

In the case where there is no matching end area, such as a through fill at station 1, and a through cut at station 2, the length of runout for fill and cut is calculated based on the cut and fill at centerline. Yardages are then calculated as separate prisms (Figure 2), where:

$$\frac{EA(cut) \text{ or } EA(fill)}{2} \times \frac{\text{Length of Runout (cut or fill)}}{27} = \text{Cubic yards}$$

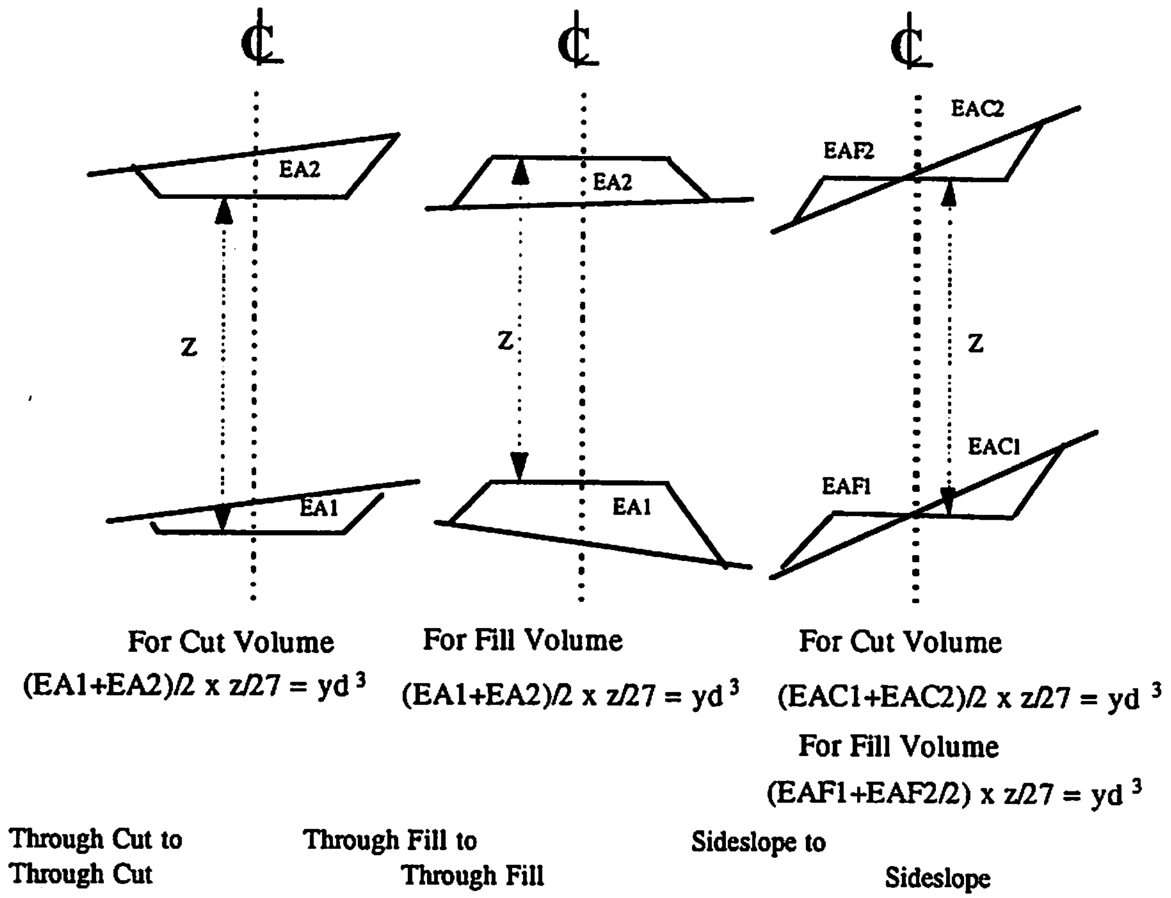

Figure 2. Examples of earthwork calculations with matching end areas (adapted from Walbridge, 1991).

When the end area of station one is a through cut or a through fill, and the end area of station two is a sidehill section with cut and fill, the length of runout is calculated based on the height at the shoulder of the road (Figure 3). Yardages are then calculated as separate pyramids, where:

$$\frac{\text{EA(cut) or EA(fill)}}{3} \times \frac{\text{Length of Runout (cut or fill)}}{27} = \text{Cubic yards}$$

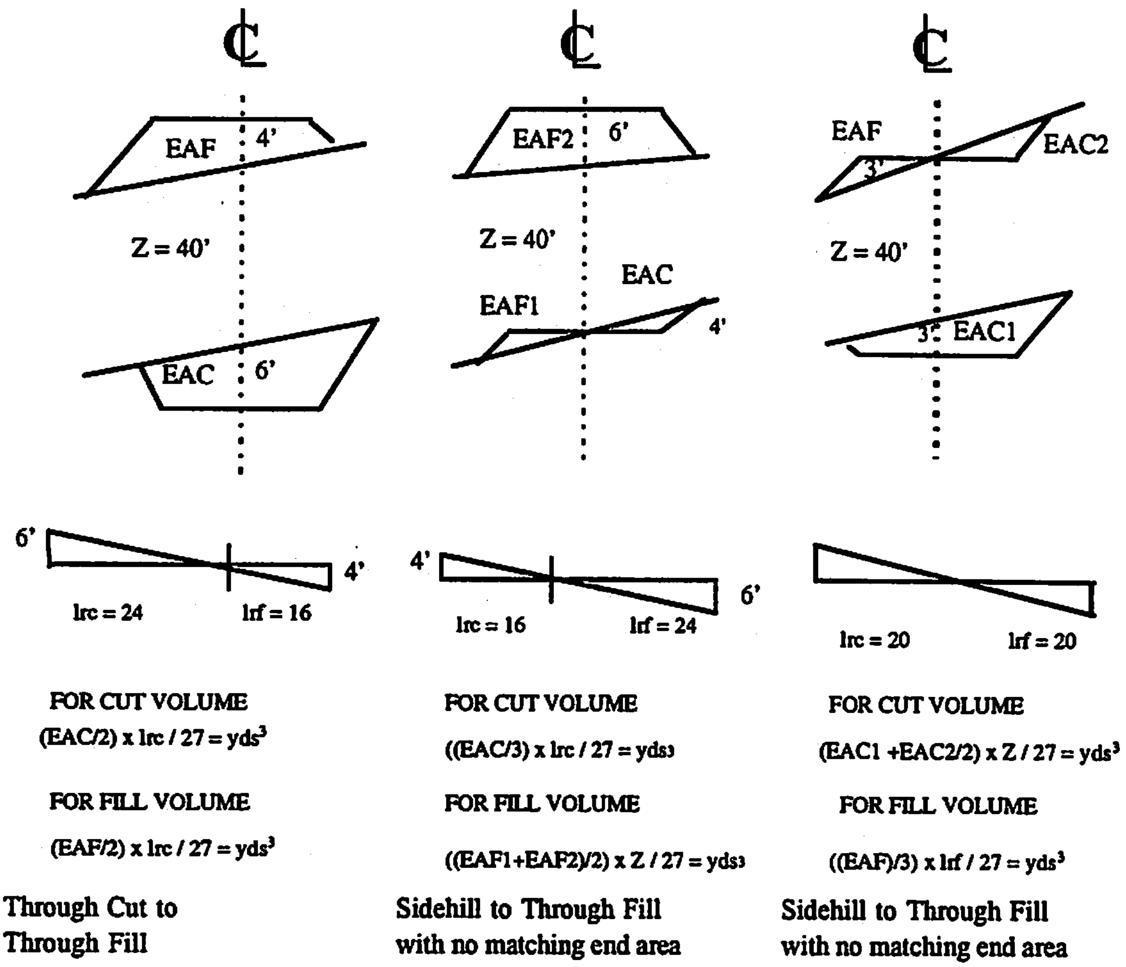

Figure 3. Example of earthwork calculations without matching end areas (adapted from Walbridge, 1991).

The new program, known as the EarthWorks Calculator, is straightforward and very user friendly. All that is required of the operator is to modify road standard defaults if desired, and enter the cut or fill at centerline, and the percent of sideslope to the right and left of the centerline at each station on the road centerline.

The road standard defaults are: subgrade width 20 feet; ditch width 3; cut slope ratio 1:1: fill slope ratio 1.5 :1; and a soil shrinkage percentage of 20%. Any or all of the defaults may be changed to suit a different road standard. The input format is depicted in Table 1.

Table 1. Defaults and inputs for Earthworks Calculator. Underlined sections must use default value or have data input.

Project data					
Project name:	Class demo				
File name:	demo.dat				
Road Standard Inputs					
Road width	20	units	feet		
Ditch width	3	units	feet		
Cut slope	1	run	1	rise	= 100 %
Fill slope	1.5	run	1	rise	= 67 %
Soil shrinkage	20	%			
Station Inputs					
Station Number			1		
Cut (+) or Fill (-) @CL			-1	units	feet
Right side slope			30 %		
Left side slope			-20 %		
Between Station Inputs for Volume					
Distance from last station			50	units	feet

The station inputs are cut or fill at centerline, percent sideslope to the right of the centerline, and percent sideslope to the left of the centerline. In steep to moderate terrain the most common road prism is the sidehill cross section. Through cuts and fills usually occur when crossing hollows or drains In relatively flat country shallow through cuts and through fills are used to form turnpike sections of road, as typified by the roads in the lower coastal plain region.

Cuts and fills at each station are taken from the plotted profile of the road centerline. The percent of sideslope to the right and to the left of the centerline must be taken at the time of staking the centerline, or during the profiling of the centerline. This is the one piece of data not normally taken in direct location that must be taken if the centerline is to be paper located.

PROGRAM OUTPUTS

Once the operator has entered the inputs described above, the program calculates the square footage of the end areas present at that station. Inputs of the station ahead are entered next, and cubic yard volumes of cut and fill are produced when the distance between stations is entered (Table 2).

Table 2. Examples of the outputs of Earthworks Calculator. Italic sections are calculated earthwork variables. Underlined sections are units that may be changed.

Station Outputs			
	Cut end area	*20.0*	square feet
	Fill end area	*31.0*	square feet
	Right shoulder height	*2.9*	feet
	Left shoulder height	*3.1*	feet
	Right slope distance	*16.7*	feet
	Left slope distance	*16.5*	feet
Volume Outputs			
	Cut volume	*37.1*	cubic yards
	Fill volume	*10.0*	cubic yards
	Accumulated volume	*27.1*	cubic yards
Options			
	Continue to next station		
	Back up 1 station		
	Bring accumulated volume to zero		
	Print results		

Yardages of cut and fill are kept separate, and the accumulated yardage is shown as a surplus of excavation or embankment. These surpluses indicate how well the earthworks are balanced and whether there should be adjustments to the gradeline in order to reduce construction costs (Table 2).

The earthworks Calculator, version 2 is a stand alone program written in Visual Basic, to run under Windows 95 or Windows NT.

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Laser Surveying

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ABSTRACT: The Laser Technology, Inc., Criterion 400 laser instrument makes and downloads 3-dimensional survey measurements in a few seconds and is eye safe. Accuracy for slope distance measurements is plus-or-minus 0.1 meter; for vertical inclination, plus-or-minus 0.2 degree; and for azimuth, plus-or-minus 0.5 degree. Survey management software, called LASERSOFT, compatible with PCs, laptops, pen computers, and many MS-DOS data recorders, is available from LTI. Standard traverse and cross section surveys are managed by LASERSOFT, as are repeating radial type surveys. Repeating radials are performed by surveying in a baseline traverse as in the standard, but allow side shots to be taken to any point of interest in any direction. Turning points can be used on any string of side shots. LASERSOFT converts survey data into input files for LUMBERJACK, FLRDS, RDS-PC, HANS-ON, Eaglepoint, and AUTOCAD, and contains a file transfer utility.

KEY WORDS: surveying, laser, design, traverse, side shot

INTRODUCTION

LASERSOFT and the Laser Technology, Inc. (LTI) Criterion 400 survey laser instrument constitute a virtual revolution in pre-design activities for many projects requiring field survey in the Forest Service. The instrument makes and downloads survey measurements in a couple of seconds; LASERSOFT is MS-DOS compatible software that provides a user-friendly platform for survey management and data conversion into formats required by several widely-used PC-based road and site design software systems. This article provides information specific to LASERSOFT V1.0 usage, in addition to brief overviews of laser instrument capabilities and and planned survey routines. "Reflector assemblies" and rods used during a laser survey are described, as are control and test surveys conducted to date. Step-by-step instructions for a simple survey are available from the San Dimas Technology and Development Center, including "quick key" help menus and options made possible by the LASERSOFT system.

LASERSOFT is an evolution of ROADSOFT, created by LTI software engineers primarily for low-volume road surveying and data conversion for import into LUMBERJACK and FLRDS road design systems. Incorporation of a conversion for ASCII three-dimensional coordinate files followed, as did conversions for RDSPC and ROADCALC, capable of performing higher-standard and geometric design. The 3-D information may be tailored for import not only to road design systems, but terrain modeling, site design, and CAD type software, making possible a host of survey applications useful in most resource areas of the Forest Service. Indeed, the name was changed so specialists in all disciplines would realize the system is not restricted to road-related or engineering surveys. LASERSOFT operates on several MS-DOS compatible data recorders and the PC.

LASERSOFT is much more sophisticated than previous laser survey management systems discussed by this author, although one—MC-TRAVERSE, which runs on the Corvallis Microtechnology, Inc. MC-V data recorder—has been refined by the Malheur National Forest and is being used by Forests in Region 6.

THE LTI CRITERION 400 SURVEY LASER INSTRUMENT

The instrument uses an infrared semi-conductor laser diode for slope distance (SD) measurement. A vertical tilt-sensing encoder provides vertical inclination (VI), while a fluxgate electronic compass measures magnetic azimuth (AZ), completing the data required to establish a point's three-dimensional location in space.

Manufacturer specifications give the instrument a slope distance measurement range of 1.5 to 9,150 meters (5 to 30,000 feet) when sighted on a retrodirective prism, and from 1.5 to 450 meters (5 to 1500 feet) when sighted on a "non-cooperative" target, such as a tree or the ground. A common 7.5 centimeter (3 inch) diameter plastic automotive reflector—with hundreds of tiny prisms—carried by a rodperson, is used in conjunction with a filter on the instrument to ensure measurement only to the desired point. With filter and reflector, the instrument will measure through heavy vegetation, reducing the amount of clearing required compared to existing survey methods.

Accuracy specified by LTI for slope distance measurements is plus-or-minus 0.1 meter (0.3 foot); for vertical inclination, plus-or-minus 0.2 degree (0.35 percent slope); and for azimuth, plus-or-minus 0.5 degree. Results of controlled tests performed by SDTDC show average error to be within these values.

Eye safety for the instrument meets FDA Class 1, (CFR 21), which means no measurable eye damage results after 3 hours of constant exposure to the laser beam. The laser beam contains only 5% of the energy of the average TV remote control. See Figure 1 for the survey laser field hardware configuration.

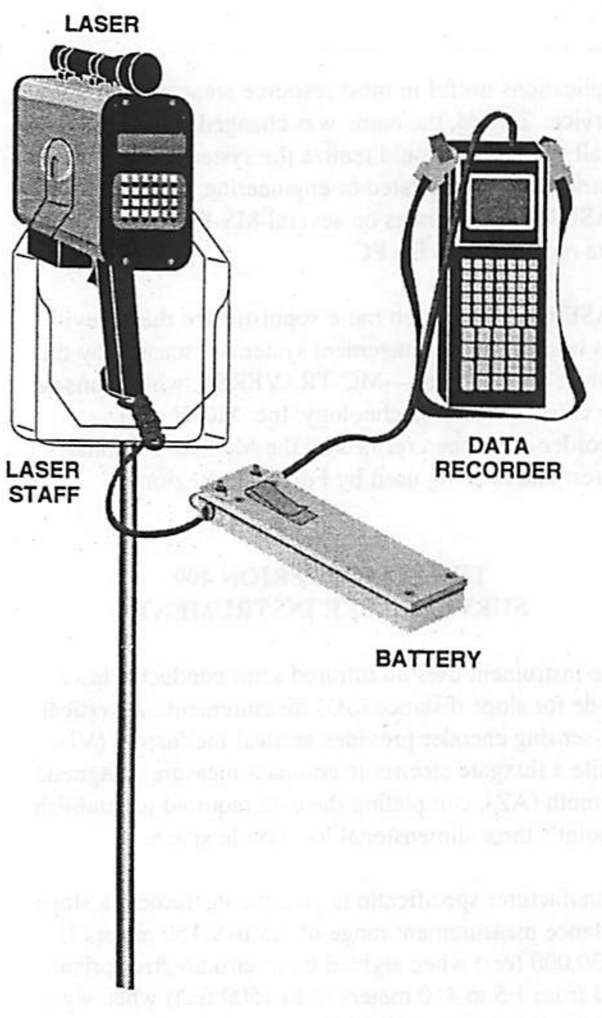

Figure 1. Survey laser field hardware configuration

SURVEYING ROUTINES

LASERSOFT duplicates standard traverse and cross sectioning and makes possible an economical, efficient "repeating radial." Standard methodology is potentially replaced, as the repeating radial makes full use of laser system utility in providing quick data collection to any point of interest. Gone are the instrument constraints that defined development of the standard method.

A traverse is simply a string of points—called Points-of-Intersection, or PIs—connected by survey measurements that establish each PI's 3-D location. Cross sections are also strings of points, referred to as side shots and associated with a particular PI. Thus, the traverse may be considered a base line, while side shots are made from the base line to points of interest. The cross section is generally made along the angle bisect in the traverse, allowing the assumption of horizontal angle; the surveyor need make only distance and vertical control measurements to determine the 3-D location of a side shot. PI #1 in Figure 2 shows a standard cross section, the horizontal angle in this case perpendicular to the traverse link between PI #1 and PI #2.

Radial side shots require collection of 3-D information, as they may be made in any direction. PI #2 shows simple radial side shots, while radial side shots associated with PI #3 illustrate use of turning points. The instrument must be set up on the turning point for measurement to subsequent side shots, generally due to a lack of sight distance to the side shot from the PI.

Multiple radial shots may be made from a turning point side shot as well as from a PI, and multiple side shot

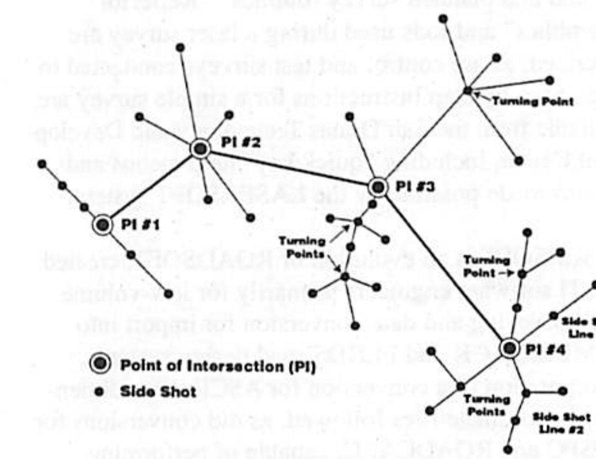

Figure 2. Plan view of traverse and side shots

lines may be built at a PI (see PI #4). Thus, the term "repeating radial" actually refers to three types of repeatability: these multiples, and their repeating nature at any PI. The repeating radial takes full advantage of laser functionality in that a commanding position—one with a good view—may be occupied by the instrument person to maximize the number of side shots possible at the PI or turning point; these positions need not lie within the project corridor. Road or site design software accepting stacks of three dimensional coordinates are used in conjunction with the repeating radial survey.

LASERSOFT operators have requested that algorithms be developed for an automated construction staking routine; the prototype planned will accept road design results from the LUMBERJACK Road Design System and provide measurements (to be made with the laser) for the iterative staking process. Additionally, an automated "GRID," systematically built of foresight and backsight traverse links, and with side shot capabilities, is under consideration for site surveys and mapping projects requiring higher precision.

THE INSTRUMENT ROD AND REFLECTOR ASSEMBLY

Some remarks concerning the instrument rod and "reflector assembly" are helpful in clarifying options available during surveying. The instrument rod used by SDTDC is a modified telescoping EDM prism staff, adjustable for Height of Instrument (HI) between approximately one and two meters (3 to 6 feet), and fitted with a bull's-eye bubble for maintaining plumb.

Additionally, SDTDC has designed and manufactured two prototype reflector assemblies, named in honor of the reflector that makes laser surveying applications possible, and at $0.79, the cheapest of the hardware componentry (Figure 3). One assembly has a Lietz orange-and-white paper target and a reflector attached to a plate. The other incorporates a flashlight into the target, useful for sighting-on in heavy brush. The reflector assemblies are adjustable to any height on the reflector rod, allowing management of Height of Reflector (HR) and "boot heights." The assembly with the flashlight also has a bull's-eye bubble that separates from the reflector/target portion for maintaining plumb even as the reflector is booted up the rod. Booting up or down is sometimes required to provide line-of-sight for the instrument person. Individual boot heights may be input into the Traverse Pt. and Side Shot Pt. Screens of LASERSOFT, and like HI and HR, are automatically reduced by the software.

The vertical distance between target and reflector centers is 8.9 centimeters (3.5 inches). This matches the distance between scope and receiving diode—at instrument center between yoke knobs and thus, also HI—in the laser instrument. HI should be set for comfort by the instrument person; HR (the center of the reflector) usually is set the same as HI. The laser scope is sighted on the target (flashlight); the instrument makes measurements between instrument center and reflector center.

A reflector assembly designed by LTI presents two targets, one situated as described above and the other centered 3 inches below the center of the reflector. The lower target is sighted-on by a transit that supplies higher precision horizontal and vertical angles. The transit is coupled with a laser diode for slope distance measurement. Refinement of this prototype instrument and the reflector assemblies is ongoing.

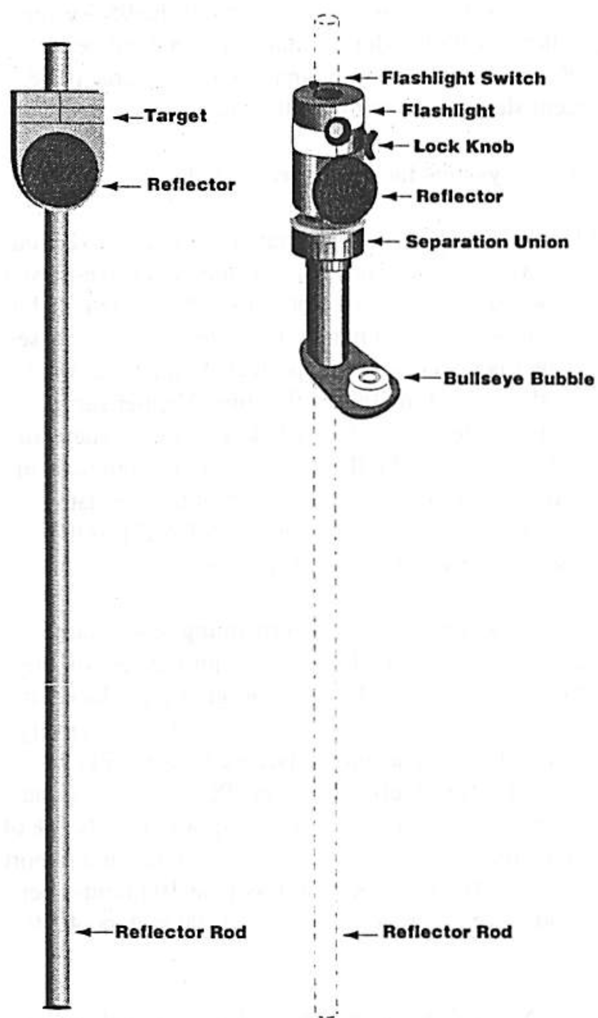

Figure 3. Reflector assemblies and rod

The horizontal distance (in inches) between the center of the reflector rod and the reflector surface is referred to as Prism Offset, and should be measured and input—along with HI and HR—into the Inst/Targ Height screen of LASERSOFT. These values remain in effect for all measurements until different values are keyed in; only one set of values may be input for a particular traverse point and the associated side shots.

CONTROL AND TEST SURVEYS

Several control and test surveys have been conducted to date. These include control surveys for investigation into instrument accuracy and precision, and various test surveys for troubleshooting survey management software, investigating instrument utility, and predicting economic benefits.

As noted above, control surveys indicate average sensor error is within LTI system specifications. Instrument precision is described in terms of the 95% error as follows: E95 for slope distance is 1.8 centimeters (0.06 foot); for vertical inclination, 0.05 degree (0.08 percent slope); and azimuth, 0.11 degree.

Test surveys thus far conducted include:

1) Duplication of a standard traverse and cross-section low-volume road survey performed by a five-person crew using a 100-foot cloth tape, 75-foot retractable logger's tapes, and hand clinometers and compasses. A two-person laser crew performed the same work on the ground in 80% of the time. Neither survey required clearing. Manually keypunching standard data into the LUMBERJACK Road Design System required 83 minutes, while electronic laser data transfer and related activities with LASERSOFT requires between 5 and 15 minutes.

2) A four-person laser crew performing low-volume road surveys in brushy, mountainous terrain on the Gunnison National Forest of Region 2 produced at the rate of one station, 30.5 meters (100 feet) every 2 minutes. The average distance between PIs was 15 meters (50 feet). Thus, one PI stake was pounded per minute on the average. Approximately 3% of shots required clearing. Data conversion and import into LUMBERJACK took less than 10 minutes per road. Average road length was 1200 meters (4000 feet).

3) The North Zone of the Black Hills National Forest, also in Region 2, hosted a test survey consisting of a 12 PI traverse with cross sections averaging 6 side shots each. The survey was performed by the standard method and duplicated first with an EDM for control, and then with the laser instrument. Many deviations from control by the standard are apparent when comparing traverse, profile, and cross section plots. Inspection reveals causes including low resolution of standard instruments, and human error in reading standard instruments and in recording and keypunching standard data. Comparisons of laser-derived versus EDM plots shows almost perfect overlay: only a couple of cross section plots are off by as much as the width of a plotted line. Heavy oak brush was manually pushed out of the way to provide sight distance on approximately 36 shots during the standard and EDM surveys. Similar clearing was required on only four shots during the laser survey.

4) Road obliteration surveys on the Six Rivers National Forest in Region 5 were performed by a four-person laser crew in which 4.5 meter (15 foot) deep by 30 meter (100 foot) embankments over 76 centimeter (30 inch) CMP were to be removed. Repeating radials were employed requiring an average of 45 minutes per site. An average of 60 shots—only a few of which needed clearing—were made at each site. The data were electronically imported into Design Cad software for contour map development. Templates can be fabricated in field design to model re-contouring, and earthwork quantities and construction staking notes can be generated after survey completion on a laptop computer at the site. Thus, all field work supporting preconstruction activities may be completed in a single trip.

5) A "GRID" prototype has been tested for higher precision survey requirements, with the points in the grid established by foresight/backsight traverse links. This routine allows data averaging, and thus increased accuracy; the duplication also feeds error tracking and correction algorithms. Results for a 20 point grid indicate raw closure ranges of 1:500 to 1:5000 horizontally and between 1:50 and 1:500 vertically, depending on site conditions. This particular grid was performed with the laser on a staff; tighter closures are possible when tripod-mounting the instrument.

6) Numerous other surveys have been conducted by SDTDC to test LASERSOFT algorithm outputs for the following options:

* Foresight/backsight averaging;
* Reduction of turning points on side shots;
* Reduction of boot height and HI and HR inputs;
* Reduction of side shot data to coordinates for extra side shot lines at a PI.

Step-by-step instructions for a simple survey, including quick key help menus and options made possible by LASERSOFT, are available by contacting J.Moll:w07a or (909) 599-1267x246.

Additional information on the LTI Criterion 400 survey laser and LASERSOFT program may be obtained from LTI at (303) 649-1000.

Surveying for National Forest Boundaries in the Rocky Mountain Region, USDA Forest Service

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Abstract: This paper discusses procedures for conducting an "Official U.S. Government" cadastral survey and the integration of the Global Positioning System (GPS) in delineating National Forest boundaries in the Rocky Mountain Region, USDA Forest Service. GPS technology is rapidly becoming one of the most important "tools" surveyors have in their "tool box."

INTRODUCTION

In the Rocky Mountain Region there are over 44,000 miles of property boundary line and many more countless miles of rights-of-ways and other land surveys which need to be surveyed. Property boundary lines must be marked and posted to show the forest land manager and the general public where National Forest System lands are located.

Historically, National Forest System lands were established by proclamation based on "aliquot parts" conforming to the U.S. Rectangular Survey System, aka Public Land Survey System (PLSS), or by metes and bounds descriptions.

The process of delineating property boundary lines usually requires the lines to be resurveyed or retraced to establish the lines on the ground. The resurvey or retracement of these lines is done in two ways: 1) in accordance with the rules and procedures set forth by the USDI Bureau of Land Management (BLM) for the survey of public lands and, 2) by state licensed surveyors in accordance with individual state regulations, for the resurvey or retracement of "reacquired lands" (private lands returned to federal ownership).
The modern U.S. government cadastral surveyor must follow in the **"footsteps of the original surveyor."**

This is accomplished by the following outlined (BLM 1991) procedure:

The need for a survey is determined

An official land survey is required for land actions involving U.S. Forest Service administered lands. Surveys are sometimes necessary to insure proper management of certain Resource Management actions.

These may include:

- Delineating areas of federal lands where, by law, stipulations on use are limited.
- Preventing and detecting trespass/encroachments
- Defining lease or resource boundaries
- Land exchanges and small tracts act

A request for survey is issued

Request for surveys are usually submitted by Forest Service land managers or private citizens.

Requests can also originate from other various sources:

- Congressional orders
- Court andexecutive orders
- Special and Congressional acts
- Cooperative surveys

Requests include the following information:

- Purpose and scope of the survey
- Detailed special requirements
- Source of funding and method of payment

The request is received and acted upon

The Forest Land Surveyor receives the request, which triggers some internal actions, including:

- Research of official public land records
- Research of other federal Agencies (BLM), state and local governments, and various nongovernmental sources

Evaluation of the information obtained to extract what is pertinent to the survey and using that information to prepare a plan of survey.

This step initiates the gathering and evaluation of evidence portion of the survey which continues until the survey is completed.

A surveyer is assigned to the project

Survey instructions are prepared and issued to the project surveyor. If BLM Special Instruc- tions are required, then these are prepared by the BLM and issued to the Forest Service Land Surveyor. These instructions are multi-functional and are essential documents.

Assignment of survey instructions include written authorization for the surveyor to execute and expend money to complete the survey.

Survey instructions include:

- Historical information relevant to the survey
- Proper authorization for the survey
- Limits and character of work for the survey
- Method and order of procedure to be utilized
- Supporting field data
  - Field notes
  - Plats
  - Reports
  - Master title plat/status

Additional records research is done and field work is started

Once assigned to the survey project, the surveyor will perform additional research for sources of documentary, testimonial, and physical evidence by:

- Contacting private land owners for permission to cross to private property
- Interviewing local residents
- Contacting absentee and former landowners
- Visiting local county and private professional surveyors
- Checking other common sources of information

Survey evidence includes any information that tends to prove or disprove the position of a property corner or line.

Tfhe field survey is started

The object of the resurvey is two parts.

- Adequate protection of existing "Bona Fide" rights
- Proper marking of the boundaries of the remaining Forest Service lands.

Proper execution of a resurvey is to **"follow in the footsteps"** of the previous survey. Locating the footsteps is an **art** not easily mastered, and involves:

- Knowledge and proficiency
- Interpretation of recorded field notes and plats for essential information
- Gathering of evidence, corner search
- Diplomatic interviewing skills
- Keen observations of manmade physical changes which were intended for the purpose of location or preserving the position of the property line.

Field work for the measurement of angles and distances to determine corner location may be accomplished by conventional traversing techniques (total station) and/or GPS.

Confident and logical interpretation of facts and data obtained assist in the determination or perpetuation of the property line.

Corner monumentation and the property line are marked and posted

The final step of the field work is corner monumentation and marking and posting of the property line, which is intended to :

- Establish a permanent marking of the property lines
- Fix corner positions to locate the surveyed lands
- Perpetuate found or identified corners.

As an aid to permanence, monuments constructed of durable material (aluminum or brass caps and steel posts) are utilized.

Accessories to the corner are established (bearing trees and reference monuments).

To perpetuate the property line, the line is blazed, cleared, marked with signs and/or red paint, with aluminum, steel, or carsonite posts with signs placed intervisible along the line.

A geodetic GPS control survey is performed

The land (cadastral) survey is connected to the National Geodetic Control Network or the High Accuracy Reference Network (HARN), allowing a direct relationship to other surveys, mapping programs, and Geographic Information Systems (GIS) or Land Information Systems (LIS).

The data to be included in GIS/LIS consists of:

- Coordinates of every public land survey system (PLSS) corner that has been established
- Physical description of the monument
- Historical information
- Other data pertinent to the corner
- Land ownership and status

A geodetic GPS control survey is normally done prior to the field work or at the same time to provide control for conventional traversing techniques and for GPS positioning.

GPS positioning for determining corner locations is normally done by static, fast-static, kinematic (post-process or real-time) and is tied to the GPS control network.

Field notes, plats, and records are prepared

The Forest Service surveyor creates the official (BLM) survey record by transcribing field data into the official survey record format. This includes both field notes and the true line plat.

Field notes represent the survey in text form containing the written record describing the survey (monuments found or set and related information), and also the reporting of direction and length of lines

True line plats orstate statue plats represents the survey in pictorial form, accurately depicting the boundaries surveyed in direction and length

State monument records describing monuments found or set along with accessories.

Notes and plats are revied

The field notes, plats and records are examined and reviewed by other experienced land surveyors to ensure the survey, plats, field notes, and records meet all legal, technical, and state requirements.

The official record contains a complete description of work performed and monuments established.

The review process provides:
- Assurance of accurate, official records
- Detailed documentation of the survey
- A basis for decisions made to establish or reestablish boundary lines
- Verified measurements (plats versus field notes), proportions and/or adjustments, acreage and closures
- Thorough, accurate recordation of evidence found or recovered
- Assurance of proper methods and procedures utilized
- Accurate transcription of field data by the surveyor
- A thorough, independent check by an another experienced land surveyor

The survey is approved

The authority to approve land (cadastral) surveys has been granted to the Forest Land Surveyor under state licensing authority for surveys done under the Forest Service Surveyors State License. In some cases the authority to approve (to accept) land surveys is done by the Forest Supervisor or Forest Engineer.

If the survey was done under Special Instructions issued by the BLM to the Forest Service Surveyor, then the authority to approve surveys has been delegated to the Chief Cadastral Surveyor for the BLM at the State Office.

Plats and field notes are officially filed

Until the plat is filed in the official public records (county courthouse and/or BLM state office), the survey is not considered official or legal.

The United States Supreme Court in Cox vs Hart, Cal. 1922, 43 S.Ct. 154, stated:

> The running of lines in the field and the laying out and platting of townships, sections and legal subdivisions, are not alone sufficient to constitute a survey, and until all conditions as to filing in the proper land office, and all requirements as to approval have been complied with, the lands are to regarded as unsurveyed, and not subject to disposal as surveyed lands.

Once the survey has been accepted, the acceptance and filing notice is advertised in the Federal Register and in the local newspaper. This is only true if this was a BLM special instruction survey, it does not apply to surveys done under state license.

Once filed, the surveys become public record.

The survey becomes a permanent public land record

This completes the process for executing a land (cadastral) survey, in compliance with all federal and state requirements, from receiving authorization, to executing a survey, to filing the field notes and plats.

A permanent record now exists serving as a basis for legal descriptions, thereby establishing a direct relationship of ownership on the ground with ownership in the records.

This continues a process that has been in existence for over 200 years and is considered the best in the world.

GPS SURVEYING

With terrain ranging from high mountains with heavy timber and rugged slopes to prairie grasslands, GPS surveying technology is rapidly becoming the surveying method of choice for performing resurveys and retracements.

Although GPS does not perform in all situations, when combined with conventional surveying techniques, significant cost and time savings can be realized. It has been proven to be a 25%-75% reduction in time and costs when conducting field measurements and for marking and posting of property line.

GPS surveying technology is comprised of the following techniques:

Static —

Observation times of 1 hour or longer depending upon length of baseline (1000 km.+)
Positional accuracy is: 5 mm Hz, 1 cm Vert.
Receiver type Trimble 4000 L1/L2 and L1

Used for establishing primary control and secondary control. The preferred technique when tree canopy is present requires increased observation times.

Fast Static —

Observation times of 5 to 20 minutes depending upon length of baseline (<20 km).
Positional accuracy is: 1 cm Hz, 2 cm Vert.
Receiver type Trimble 4000 L1/L2

Used for establishing secondary control and for corner control.

Kinematic —

Post processed - observation times as little as 1 second
Real time - observation times same as post-processed
Positional accuracy is: 1 cm Hz, 2 cm Vert.
Receiver type Trimble 4000 L1/L2, Radio transmitter and receiver for Real-time correction required.

The following procedures are done using one or more of the GPS surveying techniques when performing a cadastral survey.

A primary high accuracy static control network is established outside of the project area. This network is tied to the High Accuracy Reference Network (HARN).

A secondary high accuracy static control network is established within the project area. This control network is used as reference to provide differential corrections for all subsequent GPS survey. The resulting baselines are usually shorter in length, thus requiring shorter observation times. Specifically "Township" corners are used and selected control stations are established for use with conventional surveying methods and to provide a "verification" of the correct calculation when using state plane coordinates.

Once all of the control is established GPS observations are done on "found" corners or "temporary move/azimuth points." These are normally done by fast-static or kinematic techniques.

However, a thorough corner search and evidence evaluation must be done before GPS control is done. This is done by using (Y) code receivers (restricted use, federal agencies only). These receivers are not subject to the effect of selective availability, thus allowing navigation and positioning for corner search to a positional accuracy of <10 meters.

When all of the corners have been found and the corner GPS control is done, another procedure is followed. This includes data processing, data evaluation, network adjustments, and coordinate/datum transformations. When the final GPS data is correct, it is then ready for use in determining corner locations by the procedures specified by the BLM for resurveys and retracements of public lands.

During this procedure, evaluation of original records, subsequent resurveys, and the current GPS survey are evaluated regarding bearing and distance measurement difference and/or errors. At this time, selection of coordinate system and datum is **critical.**

The procedure the USFS Rocky Mountain Region follows is to use state plane coordinates, NAD83 datum with conversion to other coordinate systems as a final step. Combined scale factor is determined and convergency is accounted for to bring the GPS data (coordinates) up to the ground. This is necessary for performing the subsequent sub-division calculations and for the smooth integration into conventional (total station) surveying techniques.

After all the necessary calculations have been performed, the resulting coordinates (Northing and Eastings) are loaded into a total station data collector with Tripod Data Systems software for point location using conventional techniques or into the Trimble data collector (TDC-1) for point location using Real-time Kinematic (RTK) surveying techniques.

Field survey methods for GPS surveys include the normal "checks" for redundancy, measurement of calculated and measured positions for corners, and correct "initialization" for RTK surveys.

All GPS surveys performed by the USDA Forest Service are done in accordance with the current BLM "Standards for GPS surveys done under Special Instructions in Wyoming and Nebraska." These standards require a maximum of 5 cm Network adjusted "point positional error" be achieved for all corner locations used for control and for corners to be set.

Once all of the corners are set, the cadastral survey follows the standard procedures as outlined in the beginning of this paper.

SUMMARY

The use of GPS surveying techniques is rapidly changing the way the U.S. government conducts "official" boundary surveys. GPS technology allows for large land areas to be surveyed in a very cost and time effective manner, and can be integrated with conventional surveying methods.

With all of the "new technology", **the U.S. government surveyor must still walk in the original surveyor's footsteps**, otherwise the best survey process in the world will be lost.

It can only be said of the modern U.S. government surveyor, **"You drive the technology, do not let the technology drive you"**.

REFERENCE

Cadastral Survey, 1991. Bureau of Land Management.

Collecting and Using Site-Specific Vegetation and Terrain Data of Varying Accuracy for Use in Landscape Visualizations of Harvesting Options

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Abstract: Although the visual impact of a harvesting operation is often of great concern to forest owners, it is difficult to assess visual changes prior to completion of operations. In many situations, owners have several harvesting options that can be implemented that would result in very different visual effects. In this paper the authors present two case studies in which landscape visualizations of alternatives were generated. The paper discusses varying accuracy levels for vegetation and terrain data required to develop credible images for visual impact assessments. The authors also present a photogrammetric method for collecting these data in a cost-effective manner.

Key Words: landscape visualization, harvesting, aerial photographs, photogrammetry

INTRODUCTION

Over the past 30 years, public interest in the visual impact of harvesting activities has steadily increased. Concurrently, landscape visualization technology has increased in sophistication while becoming more widely available to harvest planners. In the 1970s and 1980s visual displays of proposed harvest units were limited to: 1) abstract, perspective line-drawings with "stick-figure" details plotted onto gridded terrain models (Nickerson 1979); 2) planimetric maps of areas of inter-visibility (Travis et al. 1975); or 3) artistically altered images of landscape photographs (Zube et al. 1987). McGaughey (1997) provides an overview of various landscape- and stand-level visualization techniques in these proceedings.

In the 1990s several powerful landscape visualization techniques that rely on geometric models of the landscape have become available to produce shaded-relief renderings of terrain surfaces. These systems produce more realistic images of trees, shrubs, roads, and other landscape features. Bergen et al. (1996) describe the Vantage Point package; Orland (1997) describes the SmartForest system; and McGaughey and Ager (1996) present the UTOOLS/UVIEW package. All of these systems utilize digital terrain models (DTM) and detailed vegetation inventory information to produce highly detailed, perspective-view renderings of forested landscapes. In this paper we discuss two case studies completed using the Vantage Point system. However, the outlined data collection methods can be used with most visualization systems that require digital terrain data and vegetation measurements to simulate landscape views.

DATA REQUIREMENTS

The Vantage Point system requires the following categories of data: a digital representation of the ground surface, boundaries of different landscape features, information describing vegetation distribution and size, boundaries of proposed harvest units, intensity of proposed harvest activities, and viewpoint locations.

Digital Ground Surface Data

The most common source of three-dimensional terrain data used for landscape visualization is the digital elevation model (DEM) produced by the USDI Geological Survey (USGS). There are several

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classes of USGS DEMs; however, the 7.5-minute DEMs that correspond to each USGS 7.5-minute quadrangle topographic map provide the highest data resolution. These DEMs consist of an array of elevation points that correspond to regularly spaced grid points on the ground surface. The grid spacing for most 7.5-minute DEMs is 30 m.

Elevation Errors in DEMs

For each USGS DEM, a root mean square error (RMSE) of the elevation data is reported by the USGS. Reported elevation RMSEs are usually under 7 m. It is important to note that the reported RMSEs are computed by comparing DEM elevations to elevations measured from USGS 7.5-minute topographic maps, not from independently measured ground points. Carson and Reutebuch (1997) have found that in mountainous, forested areas DEMs often have errors in excess of 30 m when compared to independently measured ground elevations. Elevation errors of this magnitude can cause severe problems when relying on DEMs for landscape depiction, particularly if large random errors occur near the viewpoint used in a perspective rendering as shown in figure 1. For this reason, in many cases USGS DEMs must be augmented with higher accuracy terrain data in order to produce accurate three-dimensional landscape projections from ground-level viewpoints.

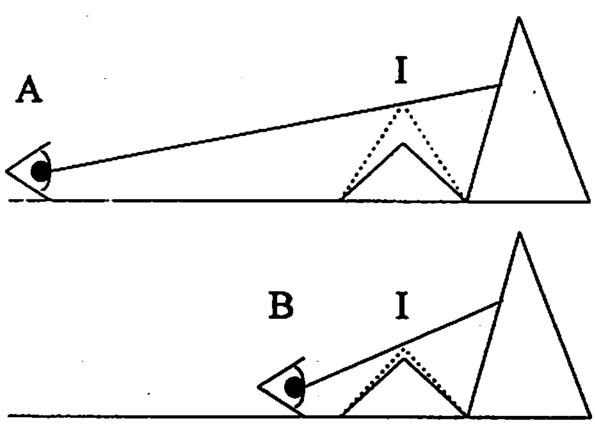

Figure 1. The relational accuracy level for the elevation at the intermediate ridgetop (I) is lower for a distance viewpoint (A) than a closer viewpoint (B). The elevation error at point I would need to be much lower to allow the viewer to see the same portion of the mountain in the distance from viewpoint B as can be viewed from viewpoint A with a higher elevation error at point I.

Planimetric Features and Attributes

Once the ground surface has been defined by the DEM, the planimetric position of important landscape features such as roads, streams, and timber stands must be collected. In addition, the location of viewpoints that are to be used in projections must be accurately located. Some of these data (e.g. roads and rivers) may already be available in digital form from a geographic information system. If they are not, most major roads and streams can be manually digitized from USGS 7.5-minute topographic maps. As with the terrain data, the position of features with respect to selected viewpoints dictates the level of accuracy and detail that must be collected.

Unfortunately, the position and size of many important features are not readily available in a digital format when projects are in remote forest settings. The location of newly built or proposed forest roads and landings, timber stand boundaries, and the physical size, shape, and distribution of vegetation often must be collected specifically for the visualization project. Although these data could be collected using traditional timber cruising techniques and with GPS survey equipment, the level of detail and volume of data make these survey techniques extremely expensive.

Varying Accuracy and Detail Levels

Landscape visualizations of proposed harvesting operations pose difficult data accuracy problems. Usually large areas (e.g. 200 - 5,000 ha) must be adequately modeled at varying levels of accuracy and detail. The location, size, density, and form of vegetation over the entire area must also be modeled, again to varying levels of accuracy and detail. There are two main reasons for collecting data at varying resolution and accuracy. Costs are prohibitive if data for the entire landscape area must be measured and input at the highest detail and accuracy required for some smaller portions of the landscape (e.g. directly in front of a selected viewpoint). Secondly, the data set would be extremely large and would require a computer with much higher processing speeds and storage capabilities if the entire landscape were modeled at the highest data resolution and accuracy.

Relational Accuracy Level of Landscape Features

To overcome the problem of prohibitively large data sets, a strategy has been developed for collecting data based on varying accuracy and detail requirements.

The authors have defined the need for varying levels of accuracy in relation to the position of a feature within a particular three-dimensional projection as its *relational accuracy level.* In other words, the accuracy required for three-dimensional projection of a feature within the landscape is dependent upon proximity of the feature to the simulated viewpoint of projection (figure 1).

Relational Detail Level of Landscape Features

Likewise, the authors have defined the need for varying levels of feature detail in relation to the position of a feature in the landscape as its *relational detail level.* As shown in figure 2, trees that are close to the viewpoint (A) need to not only be measured accurately, but details of their form must be more fully described. Trees that are several thousand feet from the viewpoint (C) may be adequately modeled by a simple vertical green line that has been given an approximate height.

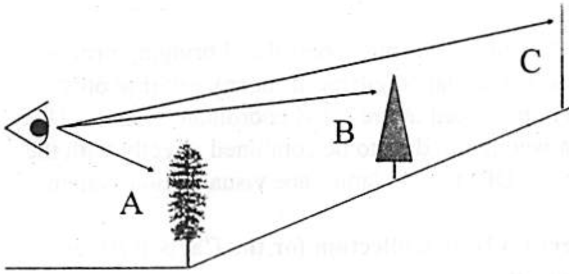

Figure 2. The relational detail level of trees gets progressively lower as their distance from the viewpoint increases.

In some landscape visualization systems, relational detail levels for each feature are computed based on distance from the viewpoint. In other systems, the user must manually specify the level of detail for each portion of the landscape. In either case, changes to feature detail level can be made without collecting new data, provided the original data sufficiently describe the feature.

Unlike the relational detail level, the relational accuracy level of features must be determined prior to data collection, and it can not be improved without collecting new data at a higher accuracy level. For this reason, the location of viewpoints and their position relative to other features should be determined before any terrain or vegetation data are collected. This is particularly important when viewpoints are near ground-level and may have vegetation directly in front of the line of sight.

LANDSCAPE VISUALIZATION PROJECTS

In cooperation with Plum Creek Timber Company, the authors completed two harvest design visualization projects in Washington State. The first project, referred to as the Carbon River project, was located in a deep river valley on a south-facing slope directly north of Mt. Rainier National Park and in clear view of a park picnic area (figure 3). The second project, referred to as the Flaming Geyser project, was located adjacent to Flaming Geyser State Park on a hillside that was visible from many areas of the park.

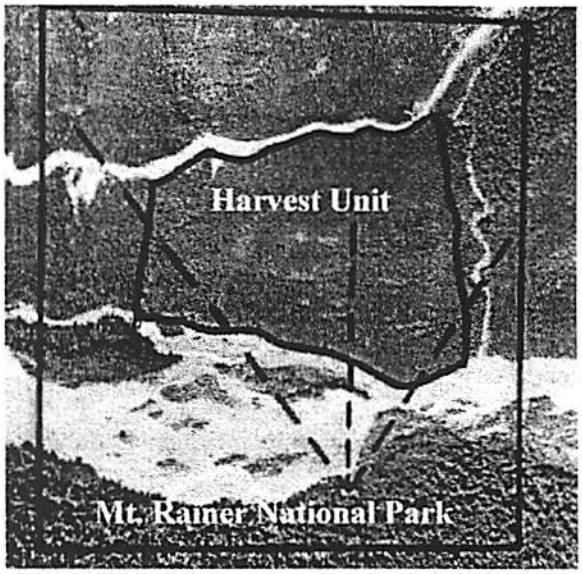

Figure 3. Carbon River project area. The rectangle shows the extent of the photogrammetric patch DEM. The harvest unit boundary is shown along with the viewpoint in Mt. Rainier National Park.

For each project, several alternative harvest intensities and unit designs were visualized using the Vantage Point system. Because of limitations in printing high-quality color images in a proceedings, the authors have chosen to make the images available to the reader via the internet at the following address: **http://forsys.cfr.washington.edu.**

Both projects required visualizations from near ground-level viewpoints that corresponded to likely park user vistas. For the Carbon River project only one viewpoint from the picnic area was selected. For the Flaming Geyser project, several viewpoints were used. To obtain terrain and feature data with differing relational accuracies, photogrammetric data collection methods were developed.

Photogrammetric Data Collection Methods

In both projects, time and expense precluded extensive ground survey methods for data collection. Instead, both terrain and feature data were digitized directly from several sets of aerial photographs using an analytical stereoplotter (Reutebuch, 1987). As with most forestry projects, extensive libraries of suitable aerial photographs were already available. In both cases, photos were available going back several decades and at several different scales. These existing photo sets allowed the authors to collect a wide variety of data types at varying accuracies in a short time and at relatively low cost.

For the Carbon River project three sets of photos were used: 1:12,000 black and white photos taken in 1963, 1:58,000 color infrared photos taken in 1984, and 1:12,000 color photos taken in 1992. For the Flaming Geyser project two sets of photos were used: 1:32,000 black and white photos taken in 1988 and 1:12,000 color photos taken in 1992. All photo sets were standard 9" x 9" aerial photos taken with metric cameras.

Registering Photos to a Common Ground Coordinate System

All photos sets used on a project had to be registered to a common ground coordinate system to allow data collected from one photo set to be combined with data collected from other photo sets. The Universal Transverse Mercator (UTM) coordinate system, North American Datum 1927, was selected because this coordinate system is used by the USGS as the coordinate system for DEMs.

The small-scale stereophotos covering each project area (1:32,000 for Flaming Geyser and 1:58,000 for Carbon River) were first registered to existing USGS 7.5-minute topographic maps using a map control and bridging process outlined by Reutebuch and Shea (1988). The process involved identifying 5-10 points on each small-scale stereopair that could also be accurately identified on the map. These control points were then digitized on the map to obtain UTM coordinates for each point. Once coordinates for these map control points were collected, the same points were measured on the photos and each stereomodel was registered to the ground using a three dimensional least squares fit. Horizontal residuals were in the range of 5-10 m, whereas vertical residuals were under 5 m.

Once a ground coordinate system was established for each small-scale stereomodel, control was bridged to each larger-scale 1:12,000 stereomodel. This bridging process is quite simple and accurate when an analytical stereoplotter is used to measure photo points. UTM coordinates can be directly digitized from the stereomodel for any feature that can be clearly identified on the small-scale photos (e.g. a small tree, a road intersection, a building, etc.).

The photo bridge points were then digitized on the large-scale photos. This allowed the large-scale stereomodel to be fitted to the ground using the UTM coordinates obtained from the small-scale stereomodel. Horizontal residuals were in the range of 2-3 m, whereas vertical residuals were under 2 m for the 1:12,000 stereopairs.

The result of this map control and bridging process was that all data digitized from any set of photos were produced in the UTM coordinate system. This allowed photo data to be combined directly with the USGS DEM in the landscape visualization system.

Terrain Data Collection for the Carbon River Project

For the Carbon River project, a large area of approximately 25 square miles was required because of the wide landscape view that was visible from the picnic area. Sections of four USGS DEMs had to be combined to cover the area. By visual inspection, it was obvious that the resulting combined DEM contained serious errors in the immediate area of the planned harvest operations. Many of the minor ridges and gullies evident on the aerial photos were not adequately modeled by the USGS DEMs (figure 4.a). For this reason, the authors decided it was necessary to collect more accurate terrain data, particularly in the immediate vicinity of the harvest unit and the viewpoint in the park picnic area.

Older photos taken in 1963 were used to collect terrain data. In the newer 1992 photos most of the area, except for the wide, braided channel of the Carbon River, was covered with heavy timber making it impossible to accurately measure the ground surface.

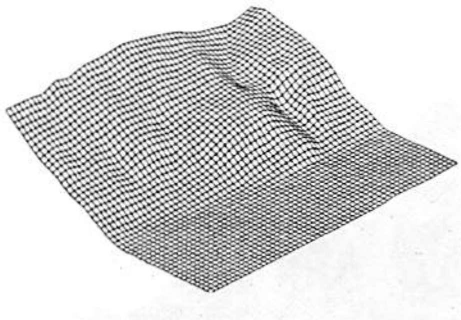

Figure 4.a. A small portion of the USGS DEM for the Carbon River project. Note the lack of detail and smooth appearance.

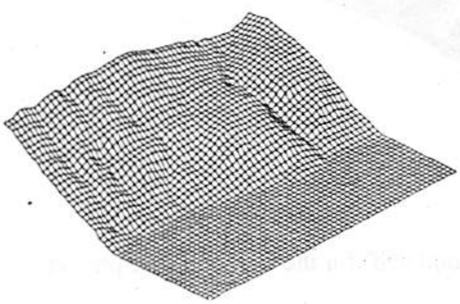

Figure 4.b. The photogrammetric patch DEM. Note increased detail of terrain features.

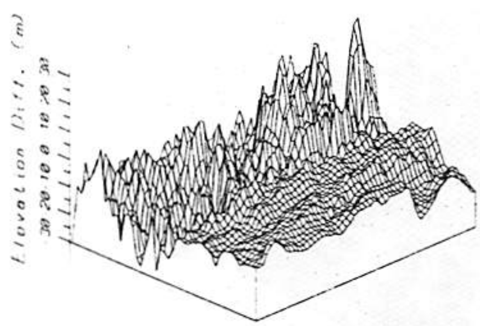

Figure 4.c. Elevation differences between the USGS DEM and the photogrammetric DEM.

In the 1963 photos, the timber in the harvest area was 29 years younger and therefore much smaller than in the 1992 photos. Because of this difference in canopy cover, the ground surface could be more accurately measured from the older photos (Reutebuch and Miyata, 1989). Approximately 1500 ground elevation points were photogrammetrically measured from the 1963 photos in a 250-ha rectangular area that encompassed the proposed harvest units, river channel, and picnic area (figure 3).

These 1500 elevation points were used to construct a small patch DEM that more accurately represented the terrain in the area of the harvest units and viewpoint (figure 4.b). The relational accuracy level within this area was approximately 1 m which corresponds to the vertical measurement accuracy of the analytical stereoplotter when measuring points from 1:12,000 photos.

The differences in elevation between the USGS DEM and the photogrammetrically derived patch DEM is shown in figure 4.c. The standard deviation of these differences was 10 m and the range in differences was -52 m to +32 m. Clearly such large errors would cause distortions in any visualizations produced from a ground-level viewpoint, particularly in areas near the viewpoint.

After constructing the patch DEM, it was inserted into the project DEM created from four USGS DEMs (figure 5). The resulting project DEM provided a relational accuracy level of 1 m in the immediate area of the harvest unit and viewpoint and a relational accuracy level of approximately 7-10 m in the background areas of the landscape.

Terrain Data Collection for the Flaming Geyser Project

The Flaming Geyser project presented much different relational accuracy requirements. All viewpoints were located on flat areas in a river valley similar to the Carbon River viewpoint. Unlike the Carbon River project, no upper mountain slopes or peaks could be seen from the Flaming Geyser viewpoints. The USGS DEM of the area again proved inadequate. A small 200-ha DEM encompassing all viewable areas was constructed photogrammetrically (figure 6). Because timber cover was not as dense, it was possible to digitize terrain data from the 1992 1:12,000 photos. The relational accuracy of this project DEM was approximately 1 m in the vicinity of the viewpoints and 3 m in the remainder of the area.

Collection of Planimetric Features and Attributes

In both projects all major landscape features were digitized directly from the 1992 1:12,000 photos. This included roads, stream banks, islands within

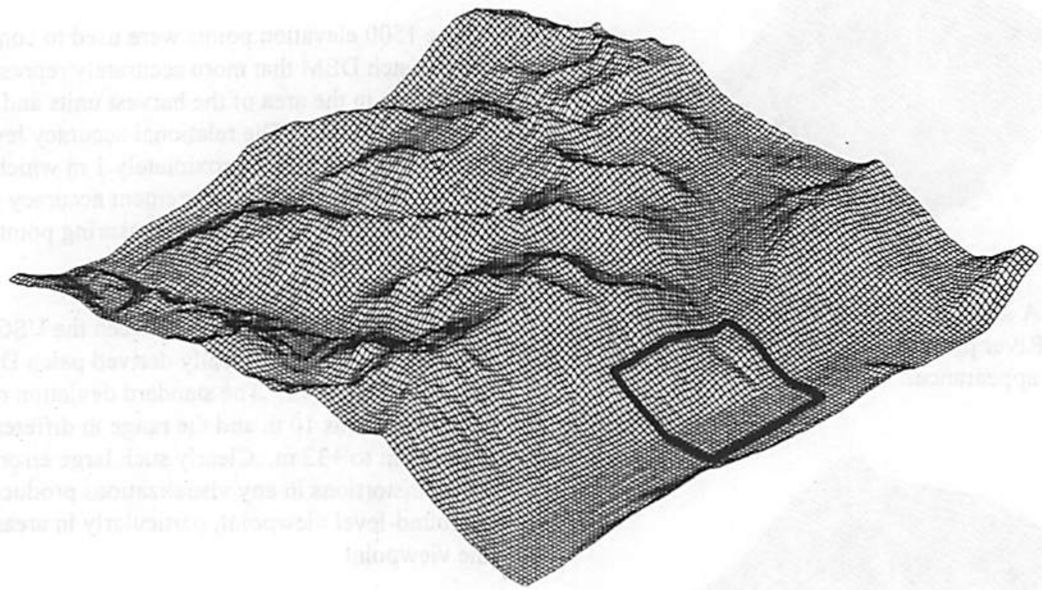

Figure 5. Combined USGS DEM and photogrammetric patch DEM (outlined) for the Carbon River project.

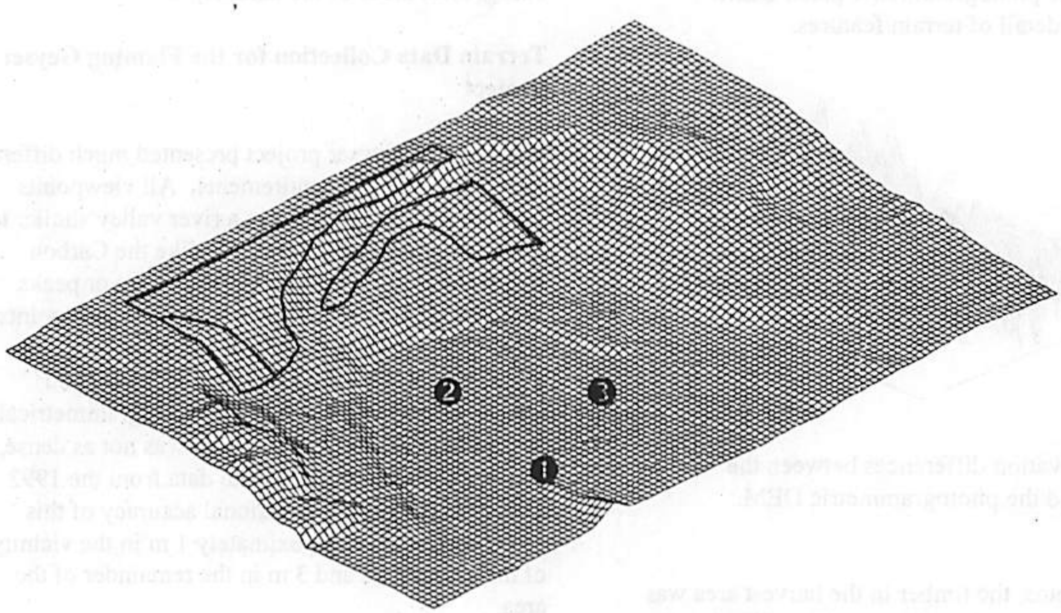

Figure 6. Photogrammetric DEM created for the Flaming Geyser project. Timber stands are outlined. Viewpoints are numbered.

streams, gravel bars, timber stand boundaries, open fields, and viewpoints. In addition, a sample of tree heights and crown diameters in each timber polygon was measured from the photos. Tree type, whether conifer or hardwood, was also recorded. Each polygon was coded by its ground cover type and was assigned a relational detail level based on its proximity to the viewpoints.

These feature data were combined with the project DEMs and alternative harvest options were designed. It should be noted that the project DEMs can also be used with the Preliminary Logging Analysis System (McGaughey, 1991) to assist with the harvest design process.

Simulated Harvest Alternatives

Once all required data were collected and input into the Vantage Point system, landscape visualizations of harvest alternatives were produced.

Carbon River Harvest Alternatives

For the Carbon River project a landscape visualization showing the area in its pre-harvest condition was first produced. This image was compared with photographs taken from the picnic area in the park to insure that the photogrammetric data set provided a accurate approximation of the area. Next, four harvest options were simulated. These included: 1) a traditional clearcut with required stream buffer strips; 2) a mixture of thinning in highly visible areas and clearcuts in more obscured areas; 3) a strip thinning that would facilitate logging in more visible areas and clearcuts in less visible areas; and 4) a clearcut with larger leave areas. All images are available for viewing on the internet. After reviewing the images, Plum Creek chose to implement the third option which greatly reduced the visual impact while allowing for an efficient harvest operation.

Flaming Geyser Harvest Alternatives

For the Flaming Geyser project, only pre-harvest conditions and two harvest options were simulated: 1) a traditional clearcut with required stream buffer strips; and 2) a clearcut with larger leave strips in highly visible areas. After reviewing the images, Plum Creek chose to implement the second option which greatly reduced the visual impact.

CONCLUSIONS

In many harvesting situations planners must consider the visual impact of proposed operations. Several landscape visualization systems are now available that can produce perspective view images of forested areas with vegetation cover. Unfortunately, in many cases, existing terrain and feature data are inadequate for producing credible images that truly model the area of interest, particularly in the immediate vicinity of selected viewpoints. The authors have addressed this problem by developing the concepts of relational accuracy and detail levels and by developing photogrammetric data collection techniques.

The photogrammetric data techniques allow planners to collect both terrain and feature data very rapidly from existing aerial photos with little to no field data collection. The resulting landscape visualizations represent the actual ground much better than visuals based on USGS DEMs and stand boundaries from traditional timber inventories. In the projects described above, photogrammetric data collection took less than two days for each project; however, several weeks were required to order and acquire aerial photos from various companies and agencies. The landscape visualization process required approximately two weeks per project.

In both project areas presented above, the visualizations allowed forest engineers to better design and evaluate alternatives in sensitive areas that greatly reduced visual impact.

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Techniques for Visualizing the Appearance of Timber Harvest Operations

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ABSTRACT: The appearance of landscapes and individual stands after harvest operations is critical to public acceptance of timber harvest practices. This paper reviews four visualization techniques suitable for visualizing the appearance of timber harvest operations: geometric modeling, video imaging, a hybrid technique combining geometric modeling and video imaging, and image draping. Techniques are reviewed for application to plot-, stand-, and landscape-scale project areas. Specific visualization software, both public domain and commercial applications, are identified. World wide web site addresses are given for most software packages.

Key Words: visualization, video imaging, timber harvest, visual simulation

INTRODUCTION

The appearance of landscapes and individual stands after harvest operations is critical to public acceptance of timber harvest practices. Thorough planning, detailed site-specific analysis, and careful monitoring of harvest activities will not result in truly successful operations if the public views the resulting landscape as an eyesore.

Attempts to mitigate the visual impact of harvests include modifying unit boundaries to conform to topography and other natural stand openings, prescribing silvicultural treatments that retain higher numbers of standing trees or groups of trees, and attempting to "hide" or "screen" harvest units from sight. These mitigation efforts can be successful.

However, foresters charged with designing harvest unit shapes and silvicultural treatments often find it difficult to develop visually acceptable solutions by working in the field or with planimetric maps. The ability to visualize the appearance of a treatment or harvest operation before implementation can provide needed visual feedback during the design process.

People exhibit varying abilities to visualize the effect of harvest patterns and silvicultural treatments. Some individuals can look at maps and diagrams showing harvest unit boundaries and read descriptions of the silvicultural prescriptions to make a judgment of the appearance of the resulting operation, but others require more picture-like visualizations. The proliferation of new technology such as geographic information systems and high-resolution satellite imagery have enabled forest managers to provide detailed maps and images showing a variety of resource characteristics.

These traditional products, however, do not necessarily provide realistic representations of the appearance of forested areas before and after harvest operations. In addition, these products do not provide sufficient visual feedback to forest engineers and other resource specialists. Such feedback is essential if they are to design operations that produce a satisfactory visual condition.

Foresters, engineers, and other resource specialists can use computer visualization techniques to create images depicting the appearance of forested landscapes before and after harvest activities. Images depicting a variety of harvest unit designs help them preview the visual appearance of proposed activities. Visualization products, ranging from three-dimensional drawings to highly realistic rendered images, provide feedback while designing harvest units and silvicultural prescriptions. Such products also facilitate communication between the designer, other resource specialists, and the public.

This paper will present an overview of visualization techniques suitable for use in timber harvest planning, discuss their relative strengths and weaknesses, and provide guidelines for selecting an appropriate visualization technique given the terrain, stand, operational conditions, and the intended use of the visualization product.

OVERVIEW OF VISUALIZATION TECHNIQUES

Forestry professionals have used visualization techniques to address a variety of forest management problems. Prior to the advent of computerized methods, they used "artists' renditions" to communicate the effects of land management activities. Such visual and physical models, produced using artistic techniques such as perspective sketching, watercolors, air brush, and scale models, continue to communicate the spatial arrangement and extent of management activities to the lay public.

However, the current trend in forest management is toward more detailed designs involving small treatment areas scattered over a larger landscape and the removal or modification of specific stand components. Alternative treatments utilize different mechanical methods, vary the spatial arrangement of treatment units, and specify different levels of modification within individual treatment units. With such treatments, the traditional "artists' rendition" cannot be made specific enough to represent the subtle differences between alternative treatments.

Computerized visualization methods range from simple diagrams to complete virtual realities. Four methods are suitable for producing visual representations of forest operations:

- geometric modeling,
- video imaging,
- geometric video imaging,
- image draping.

Geometric Modeling

Forestry professionals have used geometric modeling techniques to depict landscape conditions since 1976 (Myklestad and Wager 1976). Geometric modeling methods build geometric models of individual components (ground surface, trees and other plants). The individual component models are then assembled to create a forest stand or landscape model. Scenes depicting the complete model are then rendered from a variety of viewpoints. In its simplest form, this technique can be used to generate perspective drawings showing typical GIS data coverages such as roads, streams, and polygon data overlaid onto the ground surface. More complex applications build very detailed models of individual trees that include small branches and leaves for use in rendering scenes or special effects for motion pictures.

Geometric modeling systems specifically aimed at producing visualizations of forestry activities have been presented by several authors (Bonnicksen 1993, Burk and Nguyen 1992, Hanu, 1995, Kuehne 1993, Fridley *et al.* 1991, Larson 1994, McGaughey 1997, McGaughey and Ager 1996, McGaughey and Twito 1988, Orland 1997). These systems use perspective or orthographic drawing techniques to render stand and landscape images for land areas ranging in size from less than one acre to several thousand acres. Some systems are interfaced to stand projection models to show both the capabilities of the projection model and stand conditions resulting from modeled stand growth and silvicultural treatments over time. Some systems rely on commercial computer aided design programs such as Autocad to render images of the geometric models while others directly employ two- and three-dimensional drawing techniques to render images.

Video Imaging

Video imaging is a computer technique that uses computer programs to "cut-and-paste" or "paint" on scanned full-color video or photographic images to represent changes to the stand and landscape conditions. Video imaging produces television-quality (or better), full-color visual representations that depict current and future conditions. Orland (1988, 1993) reports the use of images created using video imaging techniques for both internal reviews of proposed management activities and for public information and participation.

Digital editing capabilities typically use a library of images representing different forest conditions to replace portions of an original image or to literally overlay objects or vegetation patterns onto an original image. To simulate the appearance of damage caused by defoliating insects, Orland *et al.* (1990) used image processing techniques to analyze the color changes associated with insect damage in forests. They then applied similar color changes to new landscape images to simulate new damage. Larson *et al.* (1988) report using similar techniques to simulate the effects of atmospheric pollution on the quality of photographic images and scenic views.

Geometric Video Imaging

A hybrid approach, called geometric video imaging in this paper, combines geometric modeling and video imaging techniques to produce very realistic images that accurately represent data describing the effects of forest management activities. Operators use geometric modeling techniques to produce scenes used to determine the location, arrangement, and scale of proposed landscape changes. Video imaging techniques are then used to modify a digitized image to reflect these changes. The technique can be extended to use geometric modeling techniques to determine the locations for digitized images, or icons, of single trees. Hybrid approaches result in images that accurately reflect the data describing proposed changes. However, to produce photo-like images, hybrid techniques require extensive libraries of tree images that represent an appropriate range of species, tree sizes, growth forms, and landscape positions. Orland (1997) describes the use of the SmartForest-II visualization system to guide editing efforts on a series of photo images used in public preference studies.

Image Draping

Image draping techniques mathematically "drape" an image over a digital terrain model and render the resulting scene from a variety of viewpoints. Operators usually derive the image from a satellite scene, scanned aerial photograph, orthophoto, or scanned map sheet. Several GIS and image processing applications provide draping capabilities. Most include rectification procedures to properly orient and align the digital image to the ground surface. Simple applications utilize orthophoto images that have already been registered to the ground surface and corrected for elevation, or relief, displacement. Bishop and Flaherty (1991) report the development of an image draping technique that relies on a library of textures to provide the image content needed to create realistic representations of GIS databases.

Image draping techniques can produce visualizations suitable for depicting landscape-scale vegetation patterns. Operators simulate treatment effects by modifying the original image using techniques common to video imaging to reflect harvest activities. It is difficult to model plot- and stand-scale treatment effects using image draping techniques. Details like differences between individual trees or groups of trees cannot be shown because textures are simply mapped onto the ground surface.

Comparison of Visualization Techniques

Table 1 compares the data requirements, operational complexity, level of realism, and data integrity of various visualization techniques. If a technique has high data requirements, this means that either large amounts of data or very detailed data are needed to apply the technique. Realism ratings refer to the image quality relative to a photograph of a similar scene. Operational complexity represents a combination of general software system complexity, data manipulation required to us the technique, and general artistic abilities required of the operator. Data integrity refers to the technique's ability to represent changes in the source data describing a particular treatment in the final image. High data integrity means that the technique can represent small changes in the input data.

Direct comparison of visualization techniques is difficult. Techniques based on some type of geometric modeling generally rely on detailed data describing ter-

Table 1. Characteristics of visualization techniques suitable for depicting the effects of forest harvesting operations.

Visualization technique	Data requirements	Level of realism in final scene	Operational complexity	Data integrity
Geometric modeling	High	Low to moderate[1]	Moderate to high	High
Video imaging	Low	High	Moderate	Low to moderate[2]
Geometric video imaging	Moderate to high	High	Moderate to high	Moderate to high
Image draping	Low to moderate	Moderate	Moderate to high	Moderate

[1] Commercial rendering applications used in motion picture special effects can produce very realistic scenes. However, their high cost and the complexity of the data needed to build the required models limits their usefulness in forestry applications.

[2] Video imaging techniques rely heavily on the operator's skill to manually make changes in the image to represent changes in stand or landscape conditions. A skilled operator can produce visualizations that accurately represent proposed conditions. However, there are no internal mechanisms inherent in the technique to ensure that modified images accurately represent proposed treatments.

rain and stand conditions to create an image representing those data. Video imaging and image draping techniques start with an image and attempt to modify the image to correctly represent proposed changes. All of the techniques mentioned are suitable for forestry visualization. However, inherent limitations in the techniques, data requirements, or quality of the final image products make some techniques better suited to particular applications in forestry.

Operators cannot apply geometric modeling applications embedded into or that rely on a forest growth model to a broad range of visualization projects. Growth models represent specific forest types and geographic regions and cannot be easily applied to other areas or forest types. Applications that rely on commercial CAD packages may be difficult for some individuals to apply. In most cases, the operator is assumed to have access to and be proficient with the CAD application. Operators not familiar with the CAD application must learn to use its features and the procedures to convert the forest or landscape data into a properly formatted geometric model.

Video imaging techniques, usually applied to landscape-scale projects, can be used to represent stand treatments. However, it is difficult to represent small scale, subtle changes affecting individual trees and small groups of trees. Video imaging relies heavily on the operator's skill to visualize the effect of a proposed treatment and make the necessary changes to an image to accurately reflect the treatment. Operators must be familiar with the operations and forest conditions before they can make image modifications that accurately and consistently reflect changes in the underlying data. Simply painting a new texture over a portion of a stand may not adequately communicate changes in stand attributes such as tree spacing and crown closure.

Video imaging techniques lack accurate methods for transferring planimetric information such as treatment unit locations and roads onto the perspective scene represented by the original photograph. Most often, operators manually transfer such features from topographic maps. This can lead to significant errors. The consequences of such errors can be as simple as a misplaced harvest unit. However, incorrectly placed treatment unit boundaries can have a significant impact on the appearance of the unit from specific viewpoints. For example, the position and shape of the unit boundary significantly affect the portionseen from a roadside. Positional errors can result in final images that significantly misrepresent the visual effect of a proposed treatment.

Image draping techniques show unit locations and overall vegetation patterns. Because image draping techniques apply image texture to the ground surface only, they represent very little height detail for trees. For example, the edge of a clearcut usually provides a sharp contrast between the height of an adjacent stand and the bare ground of the clearcut area. Image draping techniques cannot display this height difference. Image draping is also prone to errors when attempting to model the effect of a light source shining onto the terrain surface. Aerial images used to color the ground surface already represent the effect of a light source: the sun. Additional attempts to further shade the terrain surface based on another light source or a different sun angle can create optically confusing scenes. Simply using the intensity of the aerial image will result in a scene with some lighting effects. However, images will often be of low contrast and appear "flat" because aerial photographs are often taken during midday to minimize shadows. This lighting problem also makes it difficult to modify an aerial image to reflect the effect of treatments. Areas of an image used to provide textures for a treatment area must have the same orientation or aspect as areas being replaced in the original image. The lighting effects and conflicting shadows in final image will be confusing to viewers if the orientations are not similar.

By combining geometric modeling and video imaging techniques, geometric video imaging can produce data-driven images that exhibit a high degree of realism. A skilled operator is still needed to modify digital images. Large libraries of images are needed to provide the rich palette of vegetation types, sizes, orientations, and colors needed to make final image modifications realistic. Nonetheless, this technique is the only visualization technique currently available that can produce photographic quality images that reflect small changes to stand and landscape data.

All four methods can use databases describing stand conditions before and after proposed changes to provide a data-driven solution. The degree to which changes in the database are visible in the final image depends on the technique and the operator's skill. Systems must have well-designed databases and linkages between the database and the visualization technique. Such systems allow users to respond quickly to design changes and shifts in management strategies and to provide consistent results for a variety of treatment alternatives. In general, geometric modeling techniques, including geometric video imaging, are considered the most "data-driven." They provide for a one-to-one relationship between data describing a treatment and objects in the final scene. Video imaging and image draping techniques do not provide such a relationship but instead rely on the skill of the operator to accurately reflect database elements in the final scene.

VISUALIZATION PROJECT CONSIDERATIONS

Significant criteria to be considered when selecting an appropriate visualization technique for a project are the:

- size of the project area,
- overall goal of the visualization products,
- amount of detail that must be present in the final visualizations,
- amount of data available describing the project area.

Table 2 summarizes these criteria for three project scales: landscape, stand, and plot. Land areas for these scales are loosely defined. Projects can span more than one scale and the same data set can be used to generate images representing different scales. For example, many projects include landscape-scale images to show overall vegetation patterns and harvest unit locations and stand- or plot-scale images to show harvest unit layout information and specific stand treatments.

As a general rule, the larger the project area, the less detail required in the input data and the final visualizations. Landscape-scale projects usually show the spatial arrangement, scheduling, and cutting intensity of treatment areas. Such projects can be accomplished using geometric modeling techniques based on digital terrain data and stand descriptions consisting of average tree size and stem density. The same project could be accomplished with little or no descriptive data using video imaging techniques. The operator would simply modify photographs of the project area to show the location of harvest units and to reflect the effect of the treatments. Additional photographs showing treatments similar to those being considered provide the image content used to edit the original photographs.

Stand-scale projects, on the other hand, require more detailed descriptions of stand conditions. Tree size, species composition, and possibly spatial arrangement are needed to represent the effects of harvest activities on overall stand structure. With such detail, foresters can use the images to make judgments regarding the habitat quality for a particular species or other site-specific interpretations. Projects designed to show detailed changes to stand structure, for example, small areas to be thinned adjacent to large, highly desirable crop trees, require an even more data describing stand and tree characteristics.

Table 2. Characteristics of visualization projects representing different land areas.

Project scale	Land area	Overall goal	Tree/plant detail	Typical data requirements
Landscape	> 200 ha > 494 acres	Vegetation texture, spatial arrangement of stand types, location of specific treatment areas, visual quality, insect or other stand damage effects	Species, height, color, density	Topography; ground surface characteristics; stand polygons; average tree size, predominant species, and stem density for each stand
Stand	2-200 ha 5-494 acres	Harvest area layout, patch clearcut or group selection treatments	Species, height, color, density, crown characteristics	Topography; ground surface characteristics; stand polygons; tree size and species distributions for each stand, general understory conditions
Plot	< 2 ha < 5 acres	Stand structure, habitat quality, silvicultural prescriptions	Species, dbh, height, crown characteristics, foliage characteristics	Individual tree characteristics, individual or aggregated understory characteristics, spatial arrangement of understory and overstory plants

To some extent, the intended use of images produced by a visualization project dictates the technique used to produce the images.

Geometric modeling techniques are sufficient to communicate the intent and specific details of harvest operations and silvicultural treatments. Such images work well for internal reviews involving resource specialists and others familiar with forest practices.

Different types of images may be needed for public presentation and review. Such uses require images that are more realistic to engage the viewers and provide them with enough information to evaluate management alternatives. The lay public may have difficulty relating the somewhat abstract images produced using geometric modeling techniques to their own, in-woods experiences. Most people readily understand images that closely resemble photographs.

However, highly realistic images can lead to misconceptions of the amount of control foresters have over future conditions of stands and landscapes. It is often difficult to convince a lay reviewer that the project area will not look exactly like a photographic image created using video imaging techniques. Their expectations may, in turn, far exceed what is physically and biologically possible for the project area.

VISUALIZATION SOFTWARE

Many software packages can produce forestry visualizations. Commercial computer aided design (CAD), rendering, and animation systems produce and render geometric models to create images and animation sequences. Unfortunately, commercial systems are expensive, often required a specialized operator to produce satisfactory results, and require extensive data manipulation to convert typical forestry data into a usable geometric model.

Public domain systems provide visualization and image editing capabilities suitable to forestry visualization and are usually available for little or no cost. Table 3 provides a summary and contact information for several visualization tools.

For video imaging applications, Adobe Photoshop is the most common software used for image editing and manipulation. The Gnu image manipulation program (GIMP) for UNIX platforms provides many of the capabilities found in Photoshop and is available free of charge. Additional image manipulation programs such as Adobe PhotoDeluxe, Corel PhotoPaint, and Softkey Photofinish are available from a variety of vendors but none provide the full range of editing capabilities found in Photoshop.

Many GIS and image processing applications provide visualization capabilities. Geographic information systems such as ARC-INFO provide to ability to create perspective views showing the ground surface and vector and raster data layers. Image processing systems such as ERDAS and IDRISI provide image rectification and draping capabilities. However, GIS and image processing systems typically cannot render objects such as trees on the ground surface.

CONCLUSIONS AND RECOMMENDATIONS

This paper has reviewed many techniques suitable for producing visualizations depicting harvest operations and other forest management activities. Visualization techniques and software systems are rapidly evolving as personal computers become more powerful. Recent computer developments such as three-dimensional rendering and image processing functions included as standard features with inexpensive display adapters are making previously impossible levels of realism and rendering speed commonplace.

Even with the most sophisticated visualization systems, the amount of agreement between projected conditions, represented by visualizations, and attainable conditions can vary dramatically. Once a desired visual condition has been identified, achieving the desired condition can be difficult given the operational constraints imposed by forestry equipment, vegetation response to the treatment, topography, and operator proficiency. Harvest systems have specific requirements to ensure safe, efficient operations. When the desired visual condition requires very specific harvest activities and patterns, operations can become unprofitable or, in the worst case, dangerous for logging crews.

Table 4 summarizes the author's recommendations regarding appropriate visualization techniques given the size of the project area, amount of data available for a project, and amount of realism required in the final images.

Video imaging can be used for any project for which data describing terrain and vegetation characteristics is not available. For stand- and plot-scale projects, it may be difficult to accurately reflect the effects of silvicultural treatments using video imaging. When data is available, geometric modeling or geometric video imaging techniques should be used to provide the most data-driven visualizations. Image draping techniques are best reserved for projects designed to show an

Table 3. Software packages for forestry visualization.

Software package	Visualization technique	Scale	Computer platform	Cost[1]	Additional information
Stand visualization system (SVS)	Geometric modeling	Plot	PC-DOS	Free	http://forsys.cfr.washington.edu/svs.html
UTOOLS and UVIEW	Geometric modeling	Stand or landscape	PC-DOS	Free	http://forsys.cfr.washington.edu/utools.html http://forsys.cfr.washington.edu/uview.html
SmartForest	Geometric modeling	Stand or landscape	UNIX (SGI or IBM-RS6000 with OpenGL)	Free	http://www.imlab.uiuc.edu/SF/SF_II.html
Landscape management system (LMS)[2]	Geometric modeling	All scales	PC-Windows	Free	http://silvae.cfr.washington.edu/lms/lms.html
Adobe Photoshop	Video imaging	All scales	PC-Windows, macintosh, UNIX	$$	http://www.adobe.com/prodindex/photoshop/main.html
Gnu Image Manipulation Program (GIMP)	Video imaging	All scales	UNIX	Free	http://www.xcf.berkeley.edu/~gimp
Paint Shop Pro	Video imaging	All scales	PC-Windows	Free, $$	http://www.jasc.com/psp.html
USFS, Southern Research Station visualization system	Geometric modeling	Stand or landscape	UNIX	Free	http://so4702.usfs.auburn.edu/research/prob4/standviews.html
VistaPro[3]	Geometric modeling and image draping	Landscape	PC-DOS, PC-Windows, macintosh	$$	http://www.romt.com/Products/VISTA/index.html
IDRISI	Image draping and perspective views	Landscape	PC-DOS, PC-Windows	$$	http://www.idrisi.clarku.edu
Persistence of vision raytracer (POV-Ray)	Geometric modeling	All scales	Many platforms	Free	http://www.povray.org POV-Ray is a general purpose ray-tracing system capable of producing detailed, realistic images of geometric models.
VisualFX	Geometric modeling	Stand or landscape	PC-DOS	$$	Available from author: John Heasley (303) 223-3149
CLRview	Geometric modeling	Stand or landscape	Silicon Graphics IRIX	Free	http://www.clr.utoronto.ca/CLRVIEW/cvmain.html
Visual Explorer	Image draping and geometric modeling	Landscape	PC-Windows	Free, $$	http://www.woolleysoft.co.uk/
TruFlite	Image draping	Landscape	PC-Windows	Free, $$	http://www.truflite.com/

[1] System cost refers to the purchase price of the software. Free packages are either public domain or otherwise freely available. Software marked with "$$" are commercial products available at retail outlets or from the software producer. Items marked with both "free" and $$ indicate that the product is available as a free trial version as well as a commercial version.

[2] LMS uses SVS to provide plot-scale visualizations and UTOOLS/UVIEW to provide stand- and landscape-scale visualizations.

[3] VistaPro does not provide for individual tree placement or specification of individual tree characteristics making it difficult to use to accurately representing a variety of stand conditions.

Table 4. Recommended visualization techniques given project scale, amount of data available to describe the project area and proposed activities, and the amount of realism required in the final images.

Scale	Amount of data	Required realism	Recommended technique
Landscape	Low	Low to high	Video imaging, or image draping
Landscape	High	Low	Geometric modeling
Landscape	High	High	Geometric video imaging
Stand	Low	Low to high	Video imaging
Stand	High	Low	Geometric modeling
Stand	High	High	Geometric video imaging
Plot	Low	Low to high	No suitable techniques
Plot	High	Low	Geometric modeling
Plot	High	High	Geometric modeling or geometric video imaging

overview of a large project area with few details regarding the treatment or treatment effects.

Computer visualization techniques can be an extremely powerful tool to communicate and educate critics of forest operations. However, they can just as easily be used to mislead people into believing a harvest operation will have little or no detrimental impact on the appearance of a forested landscape.

Practitioners must ensure that visualizations are accurate representations of reality. This does not mean that visualizations must exhibit a high degree of realism to be effective. Images must, however, accurately represent the best data available describing stand and landscape conditions and the effect of a harvest operation on these conditions.

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Visual Quality Assessment of Alternative Silvicultural Practices in Upland Hardwood Management

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Abstract: Visual impacts of forest operations are of increasing concern to forest managers. Tools are available for evaluating, and potentially avoiding, problems in visual quality resulting from poorly designed harvest unit boundaries. One of these visualization tools is applied in comparing various harvest unit shape alternatives in an upland hardwood stand on steeply sloping ground. Visualization tools were found to be most suited to placing small leave strips within larger clearcuts for obscuring some areas from view and giving the impression of a series of smaller cutting units.

Key Words: visualization rendering, visual impacts, quality aesthetics

INTRODUCTION

Forest management in the South has not historically been constrained by visual quality concerns. Although management practices are routinely employed to mitigate visual impacts of harvesting, greater care in design and layout of forest harvest units may become necessary if public sensitivity to appearance increases as it has in other parts of the country.

Visual simulation is one technique available to managers for estimatingthe severity of, and perhaps avoiding, negative visual impacts of forest harvesting. These techniques have not been used widely in the South, but could be of great benefit to forest managers if applied in highly visually sensitive areas. This paper reports on an application of visual simulation in evaluating the change in appearance of a hillslope when harvested using different cut unit boundaries. Various types of design recommendations have been published giving managers some guidance in how to alter a particular harvest block to minimize visual impacts. This paper will report on a particular application of some of these recommendations, report on how they changed cut unit size, and show how effective they were in altering the visual impact of harvesting.

METHODS

There are two main approaches to implementing visual simulation: retouching photos (e.g. Orland 1988; Johnson and others 1994; Palmer and others 1993) and a 'virtual reality' method where the scene is constructed using computer rendering techniques based on a model of landscape features (e.g. Bergen and others 1992; Fridley and others 1991). Both methods have their advantages. Photo retouching tends to be the most realistic, but is constrained by the quality and view point of the original image. It also requires at least a minimal level of artistic skill to perform, and considerable ground work to collect a photo library of appropriate textures and colors for use in retouching the images. It has been used successfully in developing a strategy for harvests in visually sensitive areas (Palmer and others 1993), and seems to be used quite effectively, and often, in the Pacific Northwest region (Taylor 1994). The 'virtual reality', or computer modelling, approach has been used less frequently in practice. This seems mainly related to issues of quality of the images produced and the computer power necessary to generate them. This approach requires generating a 3-dimensional model of the landscape, complete with trees and other features, and then simulating computationally how light would interact with it. It requires large amounts of data and a sophisticated rendering system to implement. Because of the intensity of the computations required, it can also take a long time to generate an image. The advantages of the approach, however, make it a viable option. Although costs of computer hardware might be higher up front, costs per picture will probably be lower because no field work is needed to generate an image. There is also considerable flexibility with the approach. Any forest type at any stage of development can be simulated on the same landscape, making it possible to see changes over time, something very difficult to do with photo editing. Another disadvantage of the photo editing method is locating a particular spot on the ground within a photo. In the modelling approach, any location can be specified exactly within the image. This is especially easy if the rendering system is coupled with a GIS.

Either of these tools would be useful in evaluating visual impacts typical of southern silvicultural practices and landscape conditions. Our particular application was to examine the suitability of strip clearcutting in upland hardwood management. At least two studies (Schweitzer and others 1976; Daniel and Boster 1976) have shown that leave strips can increase the scenic acceptability of large clearcuts. Strip clearcutting of hardwoods on steeply sloping sites could also potentially decrease soil losses by providing filter strips within the stand. Despite these potential advantages, a number of concerns persist over costs and silvicultural effects of implementing strip clearcutting in upland hardwoods.

In 1996 our research unit, along with Champion International, National Forests of Alabama, Alabama A&M University, and Auburn University, installed a study to investigate three harvest systems in upland hardwoods: clearcut, strip clearcut, and deferment cut. Variables measured included estimates of harvest costs and productivity, site impact, soil movement, and regeneration, for each alternative.

Also of interest was the perceived scenic beauty of each harvest alternative. However, because of the study design, it was not possible to implement each treatment on an operational scale. The study was installed on a hillslope in northern Alabama, near the confluence of Thompson and West Flint creeks in Lawrence County. The area available for the study totaled about 20 ha (50 acres), and to have a minimum number of replicates, treatment blocks were limited to 4 acres in size. It was possible to satisfactorily measure economic, silvicultural, and environmental effects on blocks this size, but visual quality was another matter. As an alternative, a computer visualization system was developed to produce images of the treatments implemented aross the entire hillslopee. This paper reports on the use of that system in evaluating the silvicultural treatments installed in the upland hardwood management study, as well as some observations on the validity of images produced, the drawbacks/problems associated with this type of approach, and some observations on the use of harvest unit boundaries and leave patches to mitigate visual impact.

A number of simulations were made using the visualization system. Presented in this paper are views of the uncut hillslope, plus a clearcut and strip clearcut version, and a larger clearcut on the same hill with SMZs and visual screens. All images were made using topography data obtained from USGS and imported into a GIS. The GIS was used to create fictitious cut unit boundaries, as well as to measure areas of treated blocks.

Figure 1 shows a topographic map with the strip clearcut boundaries superimposed. Scale is not shown, but is approximately 8mm per km (1/2 inch per mile). Strips were approximately 46 m (150') wide, with 46 m intervals between. Total area was 18.2 ha (45 ac) for the three strip cuts. These boundaries in figure 1 served as the basis for simulating the strip clearcut, and the outer boundary of the three strips was used for the clearcut. Total area of the clearcut polygon was 31 ha (76 ac).

A view point is also indicated on the map. This view point was about 600 m (2000 ft) from the middle of the hillslope across a narrow valley. It was higher than the surrounding ground and both cleared of trees and accessible. Photos were taken from the view point for comparison with simulated images. This point was also used as the viewer location for all simulated images.

Figure 2a shows topography of the same area with a somewhat larger clearcut boundary superimposed. Within the clearcut are three buffer zones covering the bottom of drains running downhill. This area was used as a potential realization of a large-scale clearcut that might be applied on the hill. Total area of the clearcut was 48 ha (119 ac) excluding the buffer zones. Figure 2b is the same clearcut plus a series of small screens and patches used to both obscure parts of the clearcut and give the appearance of the larger area being composed of several smaller areas. These are standard options for mitigating visual impact of clearcuts.

Figure 3 is a scanned image of a photo of the hillslope taken from the view point in figure 1. The photo was taken using a standard 50 mm lens and recorded on slide film.

Simulated images were made using the system described in McDonald (In Press). This visualization system is built around a general-purpose ray tracing renderer. The renderer provides very flexible control over the 'camera' used to create the images. The simulated images were made using a wide-angle exposure in order to show a greater length of the hillslope for comparison among treatment options. This is in contrast to the photo in figure 3 and should be kept in mind in making comparisons to the actual view.

RESULTS AND DISCUSSION

Figure 4 shows simulated versions of the hillslope in an uncut state, and with the clearcut and strip clearcut treatments imposed. Comparison of the uncut simulated image with the photo from figure 3 shows that there were some obvious differences between the two. The most striking was the amount of relief seen in the simulated ridgetop compared to the real one. The photo from figure 3 shows only a small section of the simulated hill slope in figure 4 and could, therefore, not be truly comparable. But, based on experience with other simulations, it was likely that the use of the USGS digital elevation model (DEM) to generate the topography led to errors. There is variability inherent in the DEM itself, as well as in the conversion from the 30 m grid used in the DEM to the triangular irregular network that serves as the ground surface in the simulated images.

Another obvious difference between the images in figures 3 and 4 were the textural characteristics of the vegetation. The simulated trees seemed somewhat 'smoother' in appearance than the real. The difference was more pronounced in the color versions of the images. The simulated trees were modeled using images of trees painted onto transparent boxes. The tree images used in this process were drawings instead of actual tree photos. The use of photos might have led to more realistic simulations. Although no direct comparison is possible from figure 3, it is likely that the cutover areas of figure 4 would have shown qualitative differences with actual photos of slash and bare ground.

Despite some inconsistencies with reality, the images produced using the system were useful for comparison between treatments. There was a dramatic difference in the amount of visible ground surface between the two cutting patterns. It appeared from these results that the use of strip clearcutting should reduce the potential for negative public reaction to the harvest. No data are available, however, that might indicate the degree of benefit from implementing this silvicultural practice. Without this type of information it would be difficult to determine whether a 40 percent reduction in harvested volume, plus the added expense for marking, would be justified.

Strip clearcutting is a screening technique used to obscure the view of a harvested area. Some have charged (Wood 1988 for example) that this deceives the public concerning the nature of forest management and is counterproductive in the long term. Mitigating the visual impact of a harvest, on the other hand, is considered a prudent approach to gaining, or at least maintaining, public acceptance for the practice of forestry.

Mitigation techniques are more difficult to implement than simple screening. Calculating an average strip width to screen a harvest as in the above example could easily be done given data on slope and tree height. A rendering system for this situation is probably not necessary.

Placing cut unit boundaries for reducing visual impacts, however, is a more subtle process that benefits from the use of a design tool. Relatively small shifts in placement of screens, for example, or small patches of leave trees, can have fairly dramatic effects on the appearance of a harvest.

Figure 5 shows the hillslope of the previous examples with a 42.5 ha (105 ac) clearcut (46.1 ha bounded by cut unit, 3.6 ha in buffer strips). Although the buffer strips help break up the size of the unit visually, the clearcut still dominates the hillside visually. Adding two small, thinned strips and a couple of leave patches (see figure 2), however, seems to reduce the apparent size of the clearcut. Areas of the visual screens totaled 3.8 ha (9.5 ac) (2.6 in strips, 1.2 in patches), reducing total clearcut size to 38.6 ha (95.5 ac). Leave strips and patches had been 'thinned' to 75 simulated trees per ha (30 per ac) (down from about 125 per ha for the uncut areas).

It is also likely in this situation that an adequate job of mitigating visual impacts could have been done without first checking how it might appear using simulation - only a very few simple design principles were being applied on a limited basis. But because the consequences can be great, in some instances simulation can be justified. Also, from a design standpoint, it makes sense economically to retain as little of the harvested area as possible in leave strips. Use of visual simulations allows a designer to use a minimal amount of leave strip area while still doing an acceptable job of mitigating negative visual impacts.

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View Point

Figure 1. Map of the topography of the study area (low-high elevation is dark-light in color). Polygons show the outline of 18 ha (45 ac) strip clearcut. For comparison, a clearcut consisting of the outer boundary of the strips was also simulated. The view point used in all images is shown circled.

a)

b)

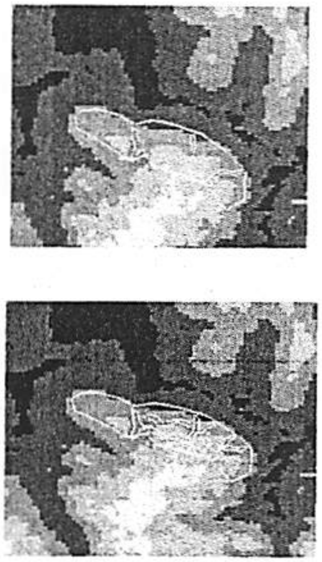

Figure 2. Two elevation maps showing the hillside with a large clearcut boundary. Streamside buffers are included in 2a. The addition of some small patches of leave trees is shown in 2b.

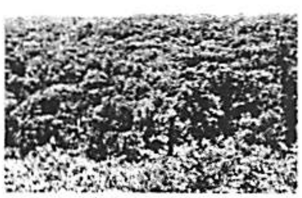

Figure 3. A photo showing how the hillside actually appeared from the view point.

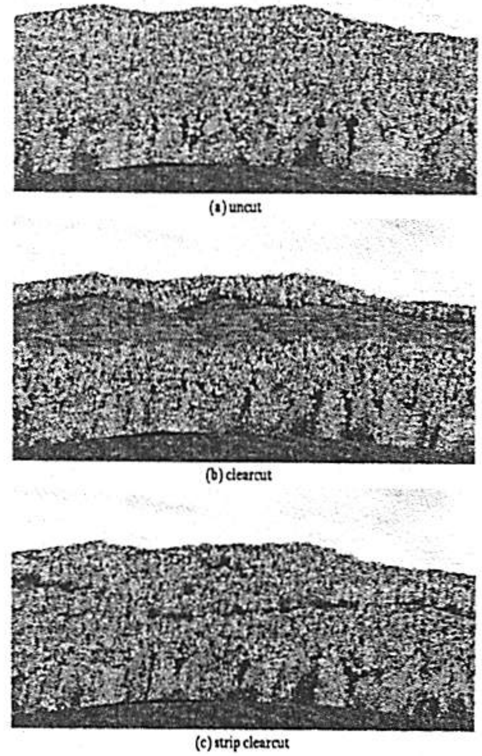

Figure 4. Simulated image as seen from the view point that compares the hillslope in an uncut, clearcut, and strip clearcut state.

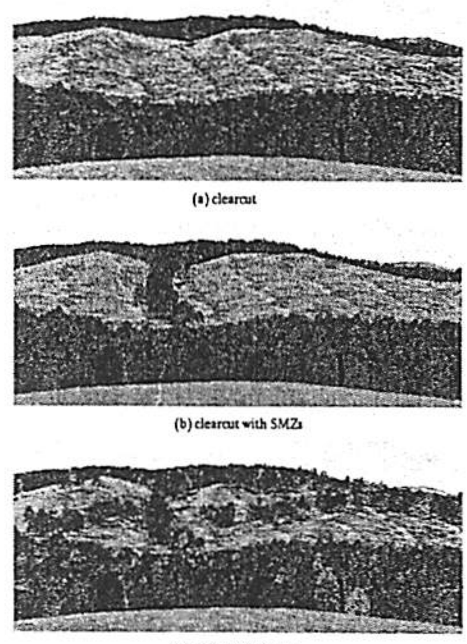

Figure 5. The same hillside with a larger clearcut, with SMZs added, and with additional visual screening patches.

COUNCIL ON FOREST ENGINEERING REPORT NORTHEAST U.S. AND EASTERN CANADA JUNE 1997

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The New England Regional Council On Forest Engineering is alive and well. NERCOFE currently has 14 eastern Canada members and 52 northeastern U.S. members.

On March 3-4, 1997 NERCOFE held a conference at the University of Maine, Orono. Topics were on low impact logging equipment and Maine forestry laws, regulations, and guidelines. This conference received many positive comments from the 127 attendees.

At the annual business meeting NERCOFE members voted to donate $2,000 to the Tom Cocoran Scholarship Fund. This money goes into a trust fund where scholarships are given out using interest or dividends and not the capital.

MAINE

Of particular interest was the Green Party Referendum that was proposed to ban clearcutting and greatly restrict other forestry practices in the state of Maine. To gain support against the referendum Maine's Governor King and the forest industry asked environmental groups such as the Maine Audubon Society, the Natural Resources Council of Maine, and the Sportsman Alliance of Maine what forest industry could do to gain their support.

After much negotiating and consensus, these groups agreed to propose an alternative to the Green Party Referendum called The Compact. Therefore, there were three choices on the November 1996 ballot, 2A The Green Party's "Ban Clearcutting Referendum," 2B The Compact for Maine's Forest, and 2C Against both measures. Industry and Compact supporters were hoping to get 51% of the vote to enact the Compact and possibly be done with the issue.

At the polls, 2A got 29.6 %, 2B got 47.7%, and 2C got 22.7%. It is a dead issue for now and will be voted on in 1997.

This whole issue is a very sensitive one. There are many small landowners who don't want any further restrictions on forest practices. Most of the 13 large landowners in the state have already adopted the Compact on a voluntary basis into their operations. The Green Party supporters will probably vote against the Compact and try to get more restrictive forestry practices including a ban on clearcutting. Polls show that if it was voted today, the outcome would be 50/50. The forest industry will be working hard to gain the undecided voters support for the Compact in this coming November election.

Jonathan Carter, who spearheaded Maine's ban clearcut initiative, is now executive director of the newly formed Forestry Ecology Network (FEN), a non-profit, anti-forestry group committed to regulating forestry practices on all lands in Maine. FEN is supporting two forestry related bills in the 118th Legislature which are sponsored by Rep. Paul Volenik (D-Sedgwick). The first is a statewide ban on clearcutting. The second is a requirement that landowners receiving benefits under the Tree Growth Tax law retain minimum volumes of trees after harvest.

NEW HAMPSHIRE

Boise Cascade Corp., Champion International Corp., Crown Vantage Inc., International Paper, John Hancock Mutual Life Insurance Co.'s Timber Resource Group, Wagner Forest Management and Fred Foss signed and negotiated a voluntary "Memorandum of Understanding for High-Elevation Forest Management," to set standards for harvesting timber on environmentally sensitive lands above 2,700 feet. The agreement covers harvest limits, restrictions on road building, and protection of wildlife habitat on more than 33,000 acres. The Appalachian Mountain Club helped draft and negotiate the pact because it believes voluntary agreements "can often accomplish more than legislation."

VERMONT

The State Senate passed by 20 to 10 a vote to enact a moratorium on the application of herbicide spray as a forest practice. The State House must now debate and decide whether to support moratorium. Governor Dean supports the moratorium.

SOUTHERN REGIONAL REPORT

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INTRODUCTION

It appears as if many in wood procurement, forest management, operations, manufacturing, and sales in the southern U.S. are simultaneously biting the bullet and showing signs of guarded optimism for the future.

On the one hand, during last year, purchasing costs were high, selling prices were low, quotas ruled, machine purchases sagged, and everyone's favorite discussion topic was "SFI." However, there is continued commitment to training, investments in timberland and facilities in the South, new technology implementation, and a common hope that forestry will survive and prosper in the South. As the South becomes the wood basket for the nation, many see opportunities and the potential for a better future. The questions are "how can we afford to get where our industry needs to be" and "who will pay." These questions will need to be addressed in the near future.

HARVESTING TASK FORCE

In 1996, the American Pulpwood Association Southeastern Technical Committee formed a Harvesting Task Force. The purpose of the Task Force is to encourage the development and improvement of systems for economically harvesting trees with reduced levels of soil disturbance on wet sites. Objectives are to:

(1) identify and clarify opportunities for improvement of wet site harvesting,
(2) identify shared perspectives on how to harvest trees on wet sites with a focus on moving trees from the stump to roadside or deck,
(3) provide a framework for testing alternative approaches and sharing results,
(4) provide loggers a forum for input to this process, and
(5) provide a forum for supplying information to equipment and engineering firms for development of alternative concepts.

The Task Force is composed of representatives from five forest industry companies, two universities, the Forest Service, APA, and two logging contractors.

To date, the Task Force has:

(1) identified a protocol for measuring soil surface disturbance,
(2) established some selected machine and system attributes that minimize soil disturbance, and
(3) sponsored logging equipment manufacturers/ loggers forum to discuss more innovative methods of reducing site impacts on wet sites.

The forum had excellent participation with common recognition and concern for the problem of site impacts on wet sites, and strong desire to continue such dialogue. There was excellent discussion concerning that some solutions were already available but expensive, the market will not bear the cost of developing new technologies, technologies were not the only answer (an example was a need for training), and a concern as to who has to pay the cost associated with doing what it takes to reduce site impacts. The Task Force will continue to provide mechanisms for addressing these concerns and looking at solutions.

ROLE OF THE SOUTH

The Southern U.S. has become a major supplier of wood and wood products for the nation. It has over one third of the production forestlands in the U.S., and forestry is the number-one industry in most of the Southern states. In the past year, land and production facilities transactions in the South are an indication of the current and projected role that the South has in timber production.

Two examples are the additional acquisition of over 240,000 acres of commercial forestlands in the South by Weyerhaeuser Company, and the purchase of over 500,000 acres of timberlands in the South by Plum Creek Timber, a Northwest company.

There is also increased interest in the development of fast-growing hardwood plantations by the larger pulp and paper companies. Several companies are doing pilot studies and are in the process of developing large plantation systems, some using irrigated systems that provide supplemental water and controlled nutrient delivery systems to individual trees. The Southern Research Station of the Forest Service has initiated a multi-disciplinary research cooperative to look at site productivity, environmental concerns, and efficient management systems for such plantations. The proposed coop involves the Department of Energy's Savannah River Site and Oak Ridge National Laboratory, three universities, and several forest industry companies.

INNOVATIONS

There have been new, or at least reuse or expanded use, of innovative techniques in forest harvesting.

More companies have implemented or expanded pine plantation thinning. Many are using cut-to-length systems, and several contractors are using small swing-tracked harvesters. An innovation on the tree-length system in thinnings is to use the trees in the cut corridors as matting to protect the ground, especially by using swing, tracked feller-bunchers. Many bottomland and swamp loggers are using swing, tracked feller-bunchers to reduce site damage and to improve the efficiency of their system by building strategically larger bundles, and by working with shovels to the tree-length material to improve skidder access.

Clambunk skidders and large capacity forwarders are being introduced on wet sites to improve production and reduce site damage by eliminating high-trafficked areas. Large shovels and use of cable yarders on flat sites with intermediate supports are also being tried.

Satellite and in-woods flail delimbing and debarking have become commonplace, especially in first thinnings of pine plantations. An innovation by one company is the delimbing/debarking of trees at roadside by flail systems into "barkless" tree-length wood to be sent to drum debarkers at the mill for improved chip quality, almost zero percent bark content when chipped. The system increases the percent of usable fiber per truck load and leaves more of the waste on site to be used for replacing nutrients.

A manufacturer has developed a hydrostatic driven skidder with variable speed control to reduce slip and improve traction while operating on wet sites. It has shown some potential in reducing site disturbance and improving production. Also, a major skidder manufacturer has announced the construction of a skidder plant in Georgia.

Logger training is still a major concern, especially in response to the AF&PA's Sustainable Forestry Initiative (SFI). Almost every state has a logger training program. International Paper Company announced a plan that will require all loggers who supply fiber to their company to support this initiative, complete an education program, and adhere to SFI's harvesting criteria.

Champion International has initiated a Preferred Suppliers Program (PSP) which is an expansion of SFI and its own Stewardship and Sustainability Initiative. It's being pilot tested in the Alabama Region. It requires that loggers exceed many state standards for water quality protection, worker safety, provide for protection of endangered species, and meet wood quality standards.

CURRENT RESEARCH AND EXTENSION EFFORTS

The USDA Forest Service Engineering Research Unit at Auburn, Ala., is completing extensive evaluation of site productivity, water quality, system efficiency, regeneration, and visual quality for upland hardwoods. Other studies include evaluating harvesting systems for bottomland hardwoods, assessing impacts of road construction on side slopes, predicting water quality and soil impacts from different site prep and harvesting treatments, and improving forest worker safety and health.

Auburn University has an active Professional Logging Management Course, having trained over 900 loggers to date. Two video conferences were conducted last year:

(1) The Sustainable Forestry Initiative and Its Impact on Loggers, and
(2) Worker's Compensation Issues and the Logger.

There has been a high demand for workshops such as Logging Cost Analysis, Thinning Methods, and Harvest Planning and Layout. Research has continued on evaluating cut-to-length systems in first and second thinnings and clearcuts.

Other research has included evaluating the spreading of poultry litter and sludge on thinned pine plantations. Researchers have been investigating the prevalence and operating characteristics of animal logging operations in Alabama. They conducted a survey which identified over 50 animal loggers currently working in Alabama. A video conference on horse and mule logging was broadcast to several states and British Columbia in April 1997.

Ongoing forestry operations research at Virginia Tech includes the evaluation of BMPs, logging capacity utilization and cost, soil and site impacts from timber harvesting, chip quality, and logger training. New research is on the effectiveness of logging safety programs and the establishment of SMZs in disturbed wetlands. Extension efforts at Virginia Tech have been the development of logger education programs on safety, business management, and harvest planning for Virginia's Sustainable Forestry Initiative. Over 1,600 logging personnel were trained in these programs in 1996. In cooperation with the American Pulpwood Association's Southwide Safety Committee, a "Knuckleboom Loader Safety" videotape was produced.

The Virginia General Assembly passed a "right to practice forestry" law in 1997 that prohibits local governments from passing ordinances that unduly restrict a landowner's right to practice forestry or harvest timber. Timber harvest levels have increased dramatically in some areas of Virginia over the past 2-3 years, causing concern among state forestry officials and forest industry leaders. The issue is being studied.

A prominent researcher at Mississippi State University, Dr. William F. Watson, retired after a long and distinguished career to partake in the fruits of working for a forest industry company. Research and extension, especially in logging training, will continue, if not flourish in his absence.

The University of Georgia is formally establishing a center for forestry business and is adding five new faculty positions. Current research and extension in forest operations are focusing on labor issues, labor productivity, and SFI training. Computer simulation modeling is being used to evaluate a range of systems working in various silvicultural treatments. New research has been initiated to evaluate the productivity and quality for delimbing and processing.

There is other excellent research and extension being completed at other universities and institutions across the South. Unfortunately, the author had insufficient time to contact everyone and regrets their exclusion from this report.

Regional Report: Lake States and Central Canada

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ABSTRACT: Forestry and forest operations in the Lake States and Central Canada appear to be doing reasonably well. The new reality is "sustainable forestry" as dictated by a number of initiatives and regulations. Many individuals and organizations are continuing to struggle with how to practice sustainable forestry on the ground. Management improvements are being made daily as technology improves, better guidance develops, and information sharing occurs. This report provides a quick overview of the issues, the industry, and related things of interest in the forests of the Lake States and Ontario.

Key Words: forestry, forest operations, forest industry, forest engineering

INTRODUCTION

Forestry and forest operations in the Lake States and Central Canada appear to be doing reasonably well. The big issues in the Lake States region, as in most other regions, are the Sustainable Forestry Initiative, Best Management Practices, logger certification, and landowner certification programs. Issues in Ontario continue to be the Class Timber Environmental Assessment and the Crown Forest Act.

Implementing the AF&PA's Sustainable Forestry Initiative (SFI) has been a major issue in the Lake States. There are many questions and disagreements on how to satisfy the basic tenets of this program. There are also questions about who is responsible for what and who should pay the costs associated with compliance. This has increased tension between wood buyers and suppliers. The APA initiative to help provide on-the-ground guidance for SFI and mill/logger relationships (Tankersley 1997) has the potential to alleviate much of the current controversy.

The implementation of voluntary Best Management Practices (BMPs) in each state is a somewhat less contentious issue. The major efforts being undertaken currently are: 1) surveying harvested sites to determine compliance with BMP guidelines, 2) educating loggers, landowners, and foresters about BMPs, 3) providing technical assistance, and 4) conducting research on better ways to protect water resources (Hausler 1996).

In Ontario, the Environmental Assessment Board has released its ruling on the Class Environmental Assessment for Timber Management on Crown Lands (Kaiser 1996). The ruling provides a timber management planning process with extensive public participation and clear lines of responsibility and accountability. Although timber management is the main objective, by opening up the planning process, the Board has laid the groundwork for progress in integrated resource management.

Another major issue affecting forestry in Ontario is the Crown Forest Sustainibility Act whose purpose is to ensure Crown forests are managed to meet social, economic, and environmental needs of present and future generations (Kaiser 1996). Key features are that it legislates forest, not timber, management; it introduces a new forest management licensing regime; it significantly increases Ministerial power; and it provides for stiff enforcement provisions. Of particular concern to the forest industry is the uncertainty in wood supply and fines for infractions possible under this Act.

FOREST RESOURCES AND MANAGEMENT

Forest resources in the Lake States were assessed recently by the Lake States Forestry Alliance (1995). Timber volume is increasing with growth exceeding harvest by about 90%. The forests are diverse and healthy, with each measure increasing as better management practices are used. Insect and disease threats to forest health are generally localized, with drought being the only potential hazard likely to affect large areas.

Forest area has increased in the last 15 years by several million acres. Nonindustrial private and state and county forests constitute 80% of the productive forest in the region. This ownership pattern can create difficulties in applying good management practices across the landscape. Management in this region tends to be less intensive than in several other regions. Management will have to become more intensive in the future to achieve sustainable production of the forest resources in the Lake States.

Several guiding principles for the environmental management of Lake States forests are included in the Lake States Forestry Alliance report (1995). These include the following:

The diversity of Lake States forests can be safeguarded and enhanced through management. Techniques are available to influence stand structure and biological composition to mimic the structure and dynamics of natural stands.

Human activities, such as forest management, industrial development, and recreational use, can be structured to minimize adverse effects on water quality and quantity.

Areas of concentrated tourism require careful design to maintain their attractiveness and to minimize negative effects on water and other natural resource values.

Practical and effective strategies are needed to mitigate environmental effects due to human use if forests are to be sustained.

Interactions among resource uses and values range from complimentary to compatible to competitive. Except for some especially incompatible uses, specific mitigating measures can be used to minimize conflict.

FOREST INDUSTRY

Forest industry in the region is in reasonably good shape, even though pulp and paper production is nearing the bottom of a down cycle (Johnson 1997). The lumber sector is doing well owing to continued strong demand for housing and the imposition of a tariff on Canadian softwood imports.

Caterpillar is acquiring the majority of assets of Skogsjan AB, a Swedish cut-to-length equipment manufacturer. The company manufactures forwarders, harvesters, and harvester heads. This equipment is expected to fill a gap in Caterpillar's current product line.

Forest operations in many areas of the region are moving increasingly toward cut-to-length systems, due mainly to environmental benefits, as well as good person-day productivity in smaller trees. Highly mechanized systems are the norm in some areas, particularly Minnesota where aspen clearcutting is prevalent. The underwater salvage logging operation at the bottom of Lake Superior near Ashland, Wisc., is expected to continue for many years.

Several pieces of equipment have been introduced recently from the Lake States region. Fabtek recently debuted its new 16-ton, 8-wheel forwarder. Timbco has developed a 16-ton, 8-wheel forwarder to be paired with their new single-grip harvester, which uses their well-known carrier. SISU Valmet has revamped its single-grip, 6-wheel 911C harvester to address the needs of North American loggers, which includes a local parts supply. Forest Technology has developed a stroke processor head with updated hydraulic and electronic controls.

Prentice has introduced two new tracked feller bunchers (the 620 and 720) that feature automatic leveling, allowing them to work on slopes up to 55%. Tigercat has introduced a tracked feller buncher featuring extra ground clearance, low ground pressure, and generous lift capacity. Timberjack has added many new features in their tracked feller bunchers, including more ground clearance, fuel capacity, swing torque, and tractive effort. Deere has added more power and a hydrostatic drive to their 843G wheeled feller buncher. Blount has introduced the Hydro-Ax Tri-Wheel feller buncher featuring good stability, maneuverability, and control.

Caterpillar has introduced their new purpose-built, 527GR tracked skidder featuring an elevated sprocket drive system, added power, reduced ground pressure, and better ground clearance. Hahn has introduced a tracked, roll/stroke delimber (the HSW 110/T) designed to delimb in the woods behind a feller buncher. Timberline has introduced the SDL2a stroke delimber featuring a computerized measurement and control system and optional four-way leveling. Timberjack is currently developing a walking machine that they expect to have operating in the woods by year 2005.

FOREST SHORTS

A ban on logging white pine in Minnesota had been proposed due to greatly reduced inventories from historical levels. A compromise was reached with the DNR to provide advanced notice of sales involving white pine.

Menominee Tribal Enterprises in northern Wisconsin is unique in North America in that it has become the only company with dual certification from both the Scientific Certification Systems (Green Cross) and the International Rain Forest Alliance (Smart Wood).

The extremely low-frequency communications network installed by the U.S. Navy in upper Michigan has caused the adjacent trees to grow faster than normal - up to 50% diameter increase for aspen.

An eastern red cedar tree growing in northern Wisconsin has been estimated to be 1290 years old.

Farm groups in Wisconsin support the legalizing and growing of industrial hemp, mainly as a supply of fiber to the pulp and paper industry. One acre of hemp provides as much fiber as 4 acres of trees.

A Native American tribe in Wisconsin is raising European red deer to supplement income from gambling. The meat is valuable, with all parts of the animals being used.

Plans for the Lake States Wood Consortium, a collaboration between industry and research, are beginning to take shape in the region.

Several automatic weather stations are being set up along roadways in Wisconsin to monitor road conditions. The information collected will help determine road maintenance needs, weight restriction timing, and road closures.

A University of Minnesota study shows that myths abound about forest health and management issues. Continued efforts to educate the public are critical.

A University of Wisconsin study claims that habitat protection does not hurt logging jobs.

Other sources of information about the current status and important issues in the Lake States and Ontario can be found in Brock (1996), Dahlman (1996), and Sturos (1995).

RESEARCH

One of the more significant research studies associated with forest operations being implemented in the region is a study in Minnesota looking at the ecological effects of managing riparian forest areas. The study is a cooperative effort between the Minnesota Department of Natural Resources, the University of Minnesota, the Natural Resources Research Institute, and the USDA Forest Service.

The purpose of the study is to assess the degree to which several riparian forest prescriptions are effective in meeting ecological, downstream, timber, economic, and cultural resource objectives. Several silvicultural and harvesting treatments will be applied in riparian areas under both summer and winter conditions, with responses being monitored. The study is expected to continue through 1998.

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Inland West Regional Report

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ABSTRACT: Forest industry conditions in the inland west continue to be affected by the supply of wood from federal lands. The use of cut-to-length systems continues to grow throughout the northern part of the region and helicopter logging is frequently specified for harvests on federal lands. Future harvest activity on federal lands will likely emphasize thinning and restoration harvest prescriptions.

Key Words: forest industry, timber harvesting, logging, mechanization

INTRODUCTION

The "inland west" is defined for this report to include Montana, Idaho, Utah, Wyoming, Colorado, New Mexico, Arizona, Nevada, and South Dakota. Forest industry issues in all states are affected by the high percentage of commercial forest lands that are managed by federal agencies, namely the U.S. Forest Service and Bureau of Land Management.

The industry of the region has been dominated by primary lumber producers. Manufacturing of pulp and paper, plywood and other composite products occurs in the region, but not at the level of lumber. The secondary manufacturing continues to grow. In 1991 the region supplied about 29% of the United States' production of softwood lumber. In 1995, that share was reduced to 22% of U.S. production (Random Lengths 1996). Many of the state, industrial and non-industrial private forest lands are being managed more intensively in an effort to offset some of the reductions in harvest volumes from federal lands.

Two major environmental reports, the Interior Columbia Basin Study and related Upper Columbia Basis Study, have recently been completed (USDA 1996). These will form a basis for management plans on federal lands in the northern part of the inland west. The report recommends a decreased level of timber harvest activity on these lands, but also calls for thinning and other work to make stands less susceptible to stand-replacement wildfires. If the recommendations are translated into land management plans, much of the harvest activity on federal lands will involve harvesting and handling smaller trees. An essential part of that strategy will be the availability of viable markets for products that can be manufactured from smaller trees.

SHORT ROTATION INTENSIVE CULTURE

At least two major corporations in the inland west have programs involving intensively grown, short rotation crops. These fiber farms will produce fiber initially for pulp and paper mills within the region but have the potential to produce fiber for other composite products. One of the companies began harvesting its first rotation this past year. The second company will begin harvesting in 1999. Rotation age of the crops is between 5 and 7 years.

Harvesting methods currently involve conventional feller-bunchers, forwarding with skidders or front end loaders, and processing through chain-flail delimber-debarkers. Additional enhancements in the harvesting systems for these fiber plantations are anticipated in the future.

TIMBER HARVESTING SYSTEMS

The balance of timber harvesting systems have not changed dramatically from those reported by Starnes last year (Starnes 1996). Conventional tractor systems (wheeled skidder or crawler) with motor-manual felling are still the most common single system in the region.

There has been significant growth, however, in the number of cut-to-length systems used in parts of the region. These systems have operated predominantly on industrial ownerships in a first commercial thinning of previously regenerated stands. Some operations occur on non-industrial, private lands where the landowner wants to emphasize a relatively low removal intensity and high levels of site protection. The increase in units operating in the region has led to a wider variety of available systems with most manufacturers currently represented in the region.

Cable systems continue to be used on steeper slopes. Several manufacturers are offering new yarder models appropriately sized for inland conditions. Yarders with the capability to swing the logs into a deck are still the most common. Newer yarders often allow rigging options that include standing, running, and live skyline configurations. With the decreased activity on federal lands, long line yarding systems with distance capabilities beyond 600 meters (2000 feet) are less common.

Off-road jammers have been used extensively in southern Idaho. Their use is beginning to spread to other parts of the region. The system utilizes a high speed winch mounted on the boom of a tracked carrier that can travel off haul roads. Carriers for steep slope feller-bunchers are often used as the base for the system. The boom on the carrier is used to "throw" tongs down-slope so that logs can be prebunched to ridge-top skid trails. Prebunched trees or logs are then forwarded to the landing for processing and loading.

Use of helicopter systems has been common in recent salvage operations on federal lands, especially salvage operations following wildfires. Several helicopter operations have utilized the newer K-max model helicopter.

Several harvesting research projects in the region involve equipment and systems to handle small trees with accompanying studies on the impacts of these systems.

EDUCATION / TRAINING

Efforts in logger education continue through partnerships between industry associations, state universities, and their associated extension organizations. These are generally directed at the education elements recommended in the American Forest and Paper Association's Sustainable Forestry Initiative. Elements of the training include ecology and silviculture, water quality, safety, first aid, and business management.

The timber harvesting option in the Forest Products Department at the University of Idaho was recently accredited by the Society of Wood Science and Technology. It was accredited along with the other forest products options in the department.

ENVIRONMENTAL CONCERNS

The northern part of the region has received higher than normal moisture the past 2 years. Record snows, record fall moisture levels, rain on snow events, and saturated soils have resulted in flooding and a high amount of landslide activity. A task force is currently investigating causes of slides in parts of the region and the U.S. Forest Service has begun road obliteration programs on a number of forests.

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Western United States Regional Report

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ABSTRACT: Some key issues in the western U.S. region in 1996/97 are forest management practices related to stream habitat and salmon, landslides following severe wet weather, and forest health and restoration. Timber harvest levels have remained approximately the same as the previous year. There has been an increasing emphasis on thinning and small wood handling. Land management activities on federal land are directed at forest structure based objectives and increasing emphasis on uneven aged silvicultural strategies. An increasing number of short rotation hybrid poplar plantations are being harvested. The Sustainable Forestry Initiative™ of the American Forest and Paper Association has stimulated increased efforts in logger education in several western states. Considering the issues and challenges continually facing forest operations, the demand for professionally trained forest engineers in expected to continue.

Key Words: Western U.S., harvesting, legislation, forest industry, forest engineering.

INTRODUCTION

The current trend in forest management in the western region of the United States is toward more intensive and diverse management regimes, and this trend is expected to continue into the 21st century. Intensive management involves practices such as multiple thinnings, fertilizations, and pruning. This report highlights several key issues that developed in 1996/97 that will have long-term effects on the forest industry. In addition, an overview of forest management/timber harvesting operations and forest engineering education/logger training is presented.

SALMON ISSUE LEADS TO INNOVATIVE PLAN IN OREGON

Declining numbers of wild coho salmon recently prompted the National Marine Fisheries Service to consider listing some coastal Oregon populations as threatened species. A listing could have given the federal government authority to significantly restrict management practices on private lands to maintain critical stream habitat for the fish.

As an alternative, Oregon's governor led an effort to develop a detailed voluntary plan to not only maintain existing stream habitat for coho, but also conduct widespread habitat and watershed improvement projects. Both the Oregon legislature and the forest industry agreed to help fund the plan to a total of about $30 million. The success of the plan will be followed closely over the next few years, as it represents a unique state and local approach for dealing with both environmental and private land concerns as they relate to the Endangered Species Act, and could serve as a model for addressing other species listings.

LANDSLIDES ARE FOCUS OF STUDIES AND POLICY DECISIONS

The wet weather of 1996 and 1997 led to a large number of landslides on forest lands in Oregon, including one that killed four people. The slides ignited public concern about possible effects of timber harvesting and logging roads, and prompted agency and political interest in both studies of these effects and potential changes in forest practices to reduce landslide problems. Oregon's forest industry also took the significant step of voluntarily suspending logging on unstable areas until further studies of the problem could be completed.

Initial studies have included new analyses by the Oregon State University Forest Engineering Department and the Oregon Department of Forestry. Both efforts confirmed that harvesting and roads can play a role in some landslide events, but that management and policy responses are not necessarily clear or simple. Especially challenging is the issue of clearcutting and landslides, because of the variable effects observed as well as difficulties in developing and administering cost-effective forest practice modifications. Nonetheless, at least some modification of Oregon's Forest Practice Rules is expected in the near future, along with a more intensive research effort directed at landslide problems and solutions.

PRIVATE FOREST LANDS ASSUMING A MORE IMPORTANT ROLE AS TIMBER SUPPLIER

Forest ownership in the western U.S. Region is largely federal. For example, the ownership breakdown for Oregon and past harvest levels compared with 1995 harvest levels is shown in Table 1. The historical and projected Oregon timber harvest levels is further displayed in Figure 1. Timber harvested on private lands is primarily from second-growth forests originating in the 1920s to 1940s.

In California, there has been further consolidation of one industrial landowner, Sierra Pacific Industries, with the purchase of Georgia Pacific's operations in the Sierra Nevada mountains. Tree pruning efforts in California are expanding, mostly in ponderosa pine, by Sierra Pacific Industries, Louisiana Pacific, and members of the Forest Landowners of California. There have also been private industry land exchanges and company reorganizations in Oregon.

Even-aged management, with commercial thinning and clearcutting, remains the most common silvicultural system on industrial land. Implementation of President Clinton's plan on federal land involves forest structure based management. Thinning of young stands is being pursued to enhance diversity. In addition, another growing trend on federal land is the harvesting of special forest products such as floral greenery and mushrooms.

Employment levels in logging have fallen in the region. For instance in Oregon, the logging employment level has lowered from 14,000-15,000 in the 1980s to 11,425 in 1990 to a most recent level of 9,089 (Oregon Covered Employment series, Oregon Employment Department). The same series shows the current level of Forestry Services (planting and other contractors) employment has dropped to 2,773, down from the 4,000 plus level of the 1980s.

FOREST HEALTH AND RESTORATION TREATMENTS

Wildfire has played a major role in shaping species composition and structure in Pacific Northwest forests. In low-elevation dry forests in the eastside region, frequent low-intensity fires controlled underbrush and overcrowding of trees. Following the exclusion of fire in these stands, many sections of these forests have accumulated high fuel levels and they are affected by bark beetles and defoliating insects, especially in the last 10 years.

Salvage logging efforts and stand improvements have been limited mainly to private lands. There is considerable debate and assessment of salvage logging on federal land. Today, wildfires in these dead and dying stands pose a significant threat to human life, homes, and forest-dependent resources. During the summer of 1996, wildfires occurred, such as the Summit fire (37,961 acres) within the Middle Fork of the John Day River watershed in Oregon.

There is political support from people like Oregon Governor Kitzhaber, Congressman Smith, and Idaho Senator Craig for eastside forest ecosystem restoration. Federal land managers are working through the process toward implementation of treatments aimed at reducing

Table 1. Forest ownership and harvest levels in Oregon.

Ownership	*Amount owned*		*Harvest levels* *1983-1987 avg.*		*1994*	
	(million acres)	*(%)*	*(MMBF)*	*(%)*	*(MMBF)*	*(%)*
Federal	9.8	51.9	4,321	54	688	17
State	0.7	3.7	387	5	235	5
Industrial[a]	5.6	29.6	2,952	37	2,471	59
NIPF[b]	2.8	14.8	360	4	773	19
Total	18.9		8,020		4,167	

[a] Large corporations.
[b] Nonindustrial private forest, individual owned forests less than 5,000 acres per holding.

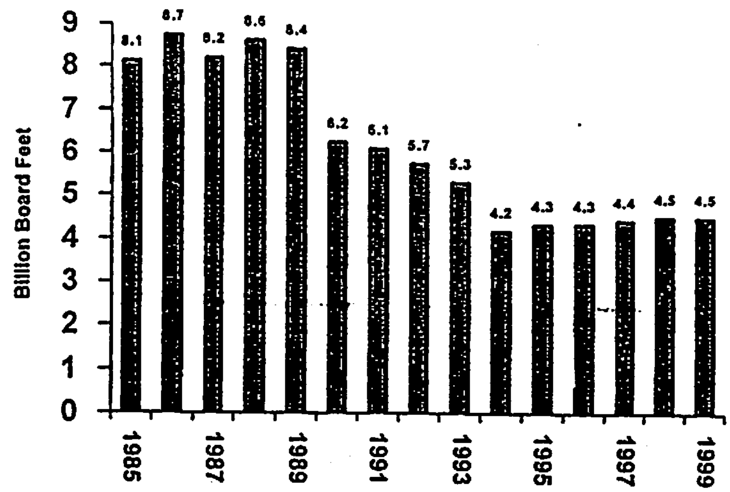

FIGURE 1. Historial and projected Oregon timber harvests, 1985-99. (Source: Lettman, Oregon Department of Forestry.)

fuels and managing stand density to help restore forest ecosystems. Often the challenge is developing economically viable timber sales while also attempting to meet a diverse set of forest resource management objectives and policies.

Innovative silvicultural prescriptions and forest operations are needed to utilize high capital costing harvesting systems, such as helicopters, cut-to-length systems, and skyline operations. The use of prescribed fire and underburning is also being considered and used more frequently on eastside forests. In California, continued weak markets for biomass fuels have resulted in a drop in understory thinning and fuels reduction operations; however, there is an increasing public awareness of the forest fuels and wildfire problems.

HARVESTING OPERATIONS IN SHORT ROTATION PLANTATIONS

There are approximately 85,000 acres in California, Oregon and Washington under intensive management for short rotation woody crops. The major industrial operations are with Simpson, Boise Cascade, Potlatch, James River, Georgia Pacific, and McMillan Bloedel, plus other smaller woodlot farmers.

Hybrid poplar is the major tree species being intensively managed; however, Simpson is growing eucalyptus. Crop rotation lengths typically vary between 6 to 7 years which produces trees approximately 8 to 10 inches on the stump and 70 feet tall. Simpson and James River have the most years into harvesting operations. Boise Cascade began harvesting on their 17,000 acre tree farm in northern Oregon in January 1996. Harvesting operations are 2 to 3 years into the future for Potlatch and McMillan Bloedel.

Rather than developing new equipment for harvesting, most experience involves innovative applications of conventional equipment such as shears, grapple skidders, front end loader, and flail chippers. Harvesting operations involve a variety of materials handling issues such as determining the best location for tree processing into chips and determining optimal transportation systems (truck, barge, rail) from the plantation to the mill sites. Another challenge is the large amount of stumps produced daily from harvesting operations and the need to dispose of stumps or utilize the woody biomass. Copicing from stumps is not preferred because of the desired hybrid tree characteristics. Materials handling options to date have involved grinding stumps and trials with pulling stumps out of the ground.

LOGGING TRAINING ACTIVITIES AND FOREST ENGINEERING EDUCATION

The Sustainable Forestry Initiative™ (SFI) of the American Forest and Paper Association has stimulated increased efforts in logger education in several western states and across the US. Some 40 states have engaged in logger education efforts partially in response to the SFI. Western states have been engaged in various forms of logger education over time and through more recent efforts of the Cooperative Extension System Logger Education to Advance Professionalism (LEAP) programs.

The logging associations often recognize logger education efforts through programs such as the Washington Contract Logger Accredited Logging Professional program or Associated Oregon Loggers' PRO-LOGGER program. In California, over 200 loggers have received some training with over 50 completing all the "required core" of 17 units and at least 3 units of electives. Efforts are needed to make logger education a sustainable activity in support of sustainable forestry operations.

Two efforts are underway to help loggers and others better understand logging costs and bidding practices. "Cruise Control" is a logging estimation program offered through the Washington Contract Loggers Association. A recent (Oregon State University) LEAP program on "Understanding Logging Costs & Bidding Practices" used an Excel™ spreadsheet program called LOGGER BUDGET96 which is now available through the OSU Forest Engineering Department with an accompanying manual.

In the recent years, there has been an increasing demand for professional forest engineering practitioners in the west coast region of North America. Considering the issues and challenges continually focusing on forest operations, the demand for professionally trained forest engineers is expected to continue. Characteristics of the three main forest engineering or forest operations programs in the region are summarized in Table 2. In 1997, the U of W forest engineering program was accredited by the Accreditation Board for Engineering and Technology. In April 1997, OSU broke ground for the Forest Ecosystem Research Laboratory (FERL). The new building will abut the corner of existing Peavy Hall and it will consolidate Forest Science and Forest Products faculty to improve management, communication, and intra-departmental cooperation in the College of Forestry.

The 9th Pacific Northwest Skyline Symposium was held in May 1996 in Campbell River, B.C. Canada. The Forest Engineering Research Institute of Canada (FERIC) and the University of British Columbia sponsored the joint symposium with the IUFRO 3.06 Research Group. The next Skyline Symposium is scheduled for March 1999 to be held in Corvallis, Ore., sponsored by the Department of Forest Engineering, Oregon State University.

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TABLE 2. Characteristics of university programs.

Program Characteristic	Oregon State Univ. (OSU)	Univ. of Washington (U of W)	Univ. Of BC, Canada (UBC)
Baccalaureate Degree	BS, FE BS, FE/CE	BS, FE	BSF[1]
Program Length (years)	4, FE 5, FE/CE	4	4
Approx. Number of Students Enrolled (1996-97)	65 in FE 40 in FE/CE	25[2]	50-60
Number of Faculty[3]	8[4]	5	4

[1] UBC offers a BSF program with a major in forest operations.
[2] Juniors and seniors only; freshmen and sophomores are in the pre-engineering pool of students.
[3] Full-time faculty (9-12 month appointments) with forest engineering teaching responsibilities.
[4] Two additional faculty in FE extension.