Managing Forestry Operations In A Changing Environment

COFE

1990
Proceedings of the
13th Annual Meeting
of the Council on Forest Engineering

August 12 to 16, 1990 Outer Banks, North Carolina

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COUNCIL ON FOREST ENGINEERING

13th Annual Meeting

MANAGING FORESTRY OPERATIONS IN A CHANGING ENVIRONMENT

August 12-16, 1990
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College of Forest Resources
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FOREWORD

The Council on Forest Engineering (COFE) was formed in 1978 and is headquartered in Corvallis, Oregon. The basic objectives of COFE involve the enhancement and development of forest engineering expertise in industry, government, and in university teaching, research, and extension programs to promote the best methods of managing private and public forests; to serve the forestry profession on matters of policy in the areas of forest engineering; and to disseminate technical information on forest engineering subjects. COFE membership is open to anyone with an interest in forest engineering. Members receive quarterly newsletters and a membership directory.

Each year the activities of COFE are highlighted by an annual meeting. The annual meeting brings members together to focus on forest engineering problems related to the conference theme and on the unique problems of the geographic region hosting the conference. This year's conference concentrated on "Managing Forestry Operations in Changing Environment" and the unique conditions of the wetlands and poccosins of the Southern Coastal Plain Region, with keynote speakers from the Wood Products Industry and Federal and State Agencies. The Conference was held in the Outerbanks (Kill Devil Hills) of North Carolina, August 12-16, 1990. The Conference participants were from all regions of the U.S., Canada, Europe, and New Zealand.

We would like to thank our sponsors and hosts; Blount, Inc-Omark Material Handling Division, Caterpillar Tractor Co., Franklin Equipment Co., Union Camp Co., and Weyerhaeuser Co. The COFE 1990 meeting activities and finances would not have been possible without their support. We would like also to thank our Institution, NCSU - College of Forest Resources, and our staff especially our assistants, Bill Swint and Abdul Tohmaz, our secretaries, Elga Hahn and Debbie Cox, and all the students who helped in performing different tasks over the last two years. We would like to thank Mrs. Betsy Deal for her time, support, and patience throughout the planning and operation of the conference. Our special thanks go to the meeting participants, speakers, and attendees whose enthusiasm and support made COFE 1990 a success. We are glad to have completed our mission and we wish the best to all future conferences of COFE.

The papers in this Proceedings were presented at the COFE 1990 Meeting and printed directly from author prepared copy without NCSU Technical Review. The authors assume responsibility for the contents of their papers.

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NORTHEAST REGIONAL REPORT

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The past year has been an interesting one for forest engineering in the Northeast due to concerns over shifts in forest landuse and ownership, changes in industial ownership, and uncertainty about regulation.

CHANGES IN LANDUSE

A major item of interest in the Northeast that will have impacts on forest engineering, both directly and indirectly, is a heightened level of concern over changes in forestland ownership and land use.

Forestland Fragmentation

Recent increases in sales of large tracts of forest land have been the cause of concern throughout the Northeast. Most of these sales have been to land development corporations whose primary objective is subdivision of these tracts into second-home building lots. Recent large sales of tracts in the Adirondacks in New York and several tracts in both New Hampshire and Maine have raised questions about the long-term impacts of removals of large areas of productive forest land.

Governmental Reaction

Several commissions were formed in 1988-89 at both the state and national level to consider the implications of changing land ownership. The Governor's (New York) Commission on the Adirondacks in the Twenty-First Century, and the Governors' Task Force on Northern Forest Lands both released the results of their studies in 1990. Both of these commissions arrived at the same surprising conclusion, at least to many members of the public, that while forest land subdivision in rural areas usually results in long-term detrimental impacts on the biological and social fabric of the area, forestry operations provide a stabilizing force in those areas. Another conclusion in these reports that the best method to prevent forestland fragmentation is to encourage forest management activities.

Timber Harvesting Regulations

Although the special commissions mentioned above have concluded that forestry production is beneficial for the region, regulations restricting forestry operations have continued to proliferate in the region.

In New York, these regulations are at the township level which results in the logger facing a wide variety of regulations depending upon the location of the timber sale. In addition to their wide variability, some of these local harvesting show a major lack of understanding of harvesting operations; i.e. the recent township ordinance that requires all skid trails to be gravelled.

In Maine, the impact of the state forest practices act has yet to be fully felt since specific parts of the legislation are still being formulated; i.e. limits on the sizes of clearcuts. However, the forest products industry in the state feels that, for the most part, they can live with the forest practices act.

CHANGES IN THE FOREST PRODUCTS INDUSTRY

An event that has the potential for directly affecting forest engineering and the number of forest engineers employed in the region was the buyout of Great Northern Nekoosa by Georgia Pacific Corporation. While this transaction has national impact (the largest corporate buyout of a forest products company) it has special impact in Northeast. In Maine, Georgia Pacific has gone from a relatively small player in terms of forest land ownership (less than 500,000 acres) to the largest private forest land owner (approximately 3,000,000 acres) in the state. The final impact on forest engineering is unknown at this time.

WETLAND REGULATIONS

A number of questions and concerns were raised in the region in respect to forestry operations in wetlands. While most of the states in the region had previously established programs of voluntary "best management practices", concerns have been raised over the methods being employed to designate areas as wetlands. While some states are using a combination of soil survey and land cover information to delineate wetlands, others are using only overstory (and sometimes understory species) for this determination. In New York, this problem is exacerbated by the fact that wetland determinations are made by one of two agencies, depending upon the location within the state. Each of these agencies uses different criteria in classifying wetlands.

SAFETY/OSHA REGULATIONS

Safety concerns and dealing with OSHA regulations continue to be a major area of interest in the region. Because of the nature of the Northeast's forests, a large number of logging contractors will be covered by OSHA regulations for the first time. The major concern in the region deals with questions about how to implement the new regulations. To address the requirements for annual safety training and training of new employees, a consortium of forest products companies, state agencies, and educational institutions has been formed to develop training materials and methods.

FOREST ENGINEERING EDUCATION

The past year has been a mixed one for the forest engineering colleges in the region. On the positive side, job placement for graduates has been high and a number of significant research activities have been started. However, on the negative side, new student enrollments in forest engineering are either constant or down from last year.

University of New Brunswick

Over the past year, the research facilities of the Faculty of Forestry, University of New Brunswick in Fredericton have been consolidated into the new Hugh John Fleming Forestry Centre. The University wing of the Centre has been named the Tweedale Centre for Industrial Forest Research and now houses the Wood Science and Technology Centre, the Soil and Plant Testing facility, and the Forest Engineering Research Centre. All of these units were previously housed in separate buildings on the Fredericton campus. The director of the Tweedale Centre is Dr. Ian Smith, Professor of Wood Engineering, Department of Forest Engineering.

As a result of these new facilities, contract and grant research has grown from $200,000 to over $1 million annually. Current projects include: a stress-grading project for the Chilean government; a non-destructive test project on power transmission poles for a major power distribution utility; vibration testing of chip-board floor structures for a factory-built housing company; and the development testing of a high-speed, off-road, long-distance forwarder.

University of Maine

Over the past year, researchers at the University of Maine have started or continued work on several research projects of interest to forest engineering. Work is continuing on expanding the state of knowledge in road location theory. Research is also continuing on the use of artificial intelligence techniques for land classification. Finally, research has started on the use of animation in simulation.

State University of New York

Several research efforts at the SUNY College of Environmental Science and Forestry have application to forest engineering. The past year saw continued work on projects dealing with geometric modelling of satellite imagery for resource mapping and the use of LANDSAT Thematic Mapper data in mapping land cover. Research projects are also continuing in the use of Geographic Information Systems (GIS) for: hydrologic modelling and watershed management in the Northeast; utilization of spatial information in environmental analysis; and prediction of harvest impacts on wildlife habitat.

NORTHEAST REGIONAL COFE

The Northeast Regional COFE group continued to be active in 1990. A two-day "Environmental Regulations Workshop" was held on March 5-6, 1990 in Orono, Maine. The workshop had an attendance of 67 people.

The first day of the workshop concentrated on regulations governing road construction, shoreland zoning, non-point source pollution, and forest management in wetlands. Representatives of Maine's Land Use Regulation Commission also answered questions about their regulations in the state's unorganized townships.

The second day of the workshop dealt exclusively with new erosion control practices. Included were discussions about the use of recycled materials for erosion control, hydroseeding, and "Texsol."

SOUTHERN REGIONAL REPORT - 1990

by

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ABSTRACT

This article reviews recent issues concerning forest operations in the southern USA and the status of the Southern Regional Council on Forest Engineering.

CURRENT ISSUES

Foresters and forest engineers across the South were contacted during the preparation of this paper. They indicated a high level of activity in their respective states and regions on a number of issues. The status of each of these issues is briefly described in the following sections.

Hurricane Hugo

Hugo, one of the strongest hurricanes to hit the East Coast in recent memory, slammed into South Carolina last September leaving heavy damage as far inland as Charlotte, North Carolina. In South Carolina alone, Hugo damaged 2.2 billion cubic feet of timber on more than four million acres. Over 36 percent of South Carolina's forestlands were damaged. Damage levels to timber due to Hugo far exceed those caused by Mount St. Helens in 1980.

Salvage efforts began in earnest immediately after the storm and by early summer over 301 million cubic feet of storm damaged wood had been salvaged or about 14 percent of the total timber volume damaged. Pine products account for 87 percent of the salvaged timber with most of this in the higher valued sawtimber products. Loggers from across the South assisted in the massive salvage effort and several logging innovations were tried to expedite the salvage activities.

Commercial Drivers License

By April 1, 1992, all commercial drivers in the United States will be required to obtain a Federal Commercial Drivers License (CDL). The statute creating the CDL also stiffened the standards used to determine if a driver is under the influence of alcohol while in a commercial vehicle and created a nationwide database for monitoring violations of commercial drivers.

State legislatures in a few southern states have enacted laws which specifically exempt drivers of logging trucks and some other vehicles from the requirements of the CDL. It appears that these exemptions will have to be repealed to prevent states from losing a share of their Federal highway funds. Several southern states began issuing the CDL in late 1989 and most others are beginning to implement the requirements during 1990.

State forestry associations and the American Pulpwood Association are working to provide training materials and/or workshops to educate log truck drivers about the requirements of the CDL and the type of test questions they will face. The level of involvement varies by state. The Georgia Forestry Association, for example, has endorsed CDL training materials produced by the Georgia Safety Council and is distributing these to their membership to assist in preparation for the exams. Alabama, on the other hand, is developing a videotape for log truck drivers and an intensive workshop patterned in many ways after the Skilled Driver

Workshops which were widely held in the South a couple of years ago.

Workers Compensation Insurance

In May of 1989, a new job classification for workers compensation insurance (WCI) was added in Mississippi for highly mechanized logging. This new classification, Code 2719, featured a manual rate 15 percent lower than that for 2702 - Logging and Lumbering (NOC).

To qualify for coverage under the highly mechanized class, a logging operation had to be certified by the Mississippi Loggers Association or the National Council on Compensation Insurance (NCCI) as meeting the criteria of the class. Criteria include felling and delimbing primarily by mechanical means, mechanized loading, less than 25 percent of payroll paid to chainsaw operators, and at least 50 percent grapple skidding.

In addition, use of uninsured subcontractors (usually for hauling) was prohibited and premiums were based only upon payroll. Many southern logging contractors obtain insurance on the basis of their production, using an upset factor to convert production to payroll. Production-based premiums are increasingly opposed by the insurance industry which argues that an excessive amount of premium slippage occurs under this system.

The highly mechanized code in Mississippi is considered experimental by NCCI and the insurance companies. However, early indications are promising. This summer, an additional nine percent reduction in manual rate was granted to 2719 based upon premiums paid and losses incurred during its first year.

Loggers in most other southern states are watching the progress of this new code in Mississippi with great interest. Proposals to add this type of classification for logging are surfacing in a number of other states in the South. If the success in Mississippi continues, the political pressure from loggers on insurance regulators will likely force addition of this class in other states.

Local Logging Regulations

Regulation of harvesting activities by local and municipal governments is continuing to increase. Most of this regulation is intended to minimize the damage incurred to roads, bridges, and right-of-ways due to log hauling. Regulations are increasingly appearing in Georgia, Louisiana, Mississippi, and other southern states.

Hardwoods

Hardwood consumption in the South has increased 23 percent since 1986 and is expected to continue this trend. Hardwood now accounts for 35 percent of the 67.4 million cords of pulpwood consumed in the South. Consumption is expected to increase to 76 million cords by 1993, with hardwood accounting for 37 percent.

Wetlands

With reliance on hardwood fiber now at high levels and expected to continue increasing, proposed regulations on management of forested wetlands is a big issue among foresters in the South. Extremely liberal definitions of "jurisdictional wetlands" have been proposed by some government agencies. If adopted, these guidelines could severely impact forest products companies in the South. Hardest hit would be mills relying on hardwood for a major portion of their furnish.

President Bush has stated his support for a policy of "no net loss" of wetlands. The exact meaning of this policy and the method of implementation are still not clear, although a key issue will certainly be mitigation where wetlands are disturbed.

Environmental Activism

Ecoterrorism actions such as tree spiking, equipment vandalism, and other practices advocated by groups such as Earth First! are just beginning to be observed in the South. One highly publicized incident recently occurred near Sylva, North Carolina. On two occasions people visited a logging operation owned by T&S Hardwoods and attempted to vandalize equipment, spike trees, or roll logs off the deck. No group has taken credit for the action and a reward has been posted for information leading to the arrest of the parties involved.

Endangered Species

The primary endangered species affecting timber management in the South continues to be the red-cockaded woodpecker (RCW). Hurricane Hugo extensively damaged one of the largest concentration of colonies in the South when it leveled the Francis Marion National Forest in South Carolina last year. Most sizeable colonies continue to be located on government lands, either in National Forests or on large military reservations.

In early 1990, the U.S. Forest Service issued new interim RCW guidelines restricting timber harvests within 3/4-mile of RCW nesting sites. This decision has been challenged in federal district court in Atlanta by the Forest Service Timber Purchasers Council. The Council charges that the Forest Service ignored provisions of several forest management acts in the process used to issue these interim guidelines. Several National Forests in the southern coastal plain, especially those in Texas, Louisiana, Florida, and South Carolina are severely impacted by these guidelines.

SOUTHERN REGIONAL COFE

In May of 1989, the first annual meeting of the Southern Regional Council on Forest Engineering (SR.COFE) was held in Auburn, Alabama. This meeting was highly successful with about 100 people in attendance. Technical sessions lasted a day and a half with a full day field trip in western Alabama the following day to Weyerhaeuser thinning operations.

Robert Tufts was elected Chairman of SR.COFE, Dale Greene as Chairman-Elect, and Bryce Stokes as Secretary-Treasurer. Since the national COFE meeting was slated for North Carolina in 1990, members of SR.COFE decided against holding a regional meeting in hopes of enhancing attendance at the national meeting.

The Second Annual SR.COFE meeting is now planned for March 5-7, 1991 in Macon, Georgia hosted by the University of Georgia. Further plans about this meeting will be forthcoming in the fall of 1990.

Report from the West

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The three major issues in the West are wood supply, wood supply and wood supply. Not much else matters. Federal forests are reducing harvest levels by 20% and more based on their new management plans. Set asides for spotted owls add significantly to this reduction, and will also severely hit private lands. So called 'New Forestry' silvicultural systems (which remind one of old fashioned 'real estate cuts') are being applied across the landscape on federal lands, adding to the reduction in cut and creating major ecological disasters for future generations to deal with. Initiatives in 'The People's Republic of California' prohibit clear cutting in many situations, increase the bureaucracy involved in forestry, protect old growth and are driving everyone interested in profitable forestry and private property rights from the state. Impacts from all of the above will devastate the forest products industry and destroy rural communities throughout the region.

Western states, in an effort to augment declining timber supplies, have restricted raw log exports from state lands. Representatives in Congress are moving toward legislation to restrict log exports on private lands - which will remove much of the financial incentive to intensively regenerate and manage private timberlands. A bloody political fight is expected on this issue.

On a positive note, several members of the Forest Service's Timber Harvesting Research Unit in Seattle have joined forces with University of Washington forest engineers, with offices and shared facilities on the UW campus. This group is well equipped to provide helpful analysis through these calamitous times.

FOREST MANAGEMENT IN A CHANGING ENVIRONMENT

INTRODUCTION TO ECOLOGY AND MANAGEMENT FORESTED WETLANDS

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About 82 million acres of commercially-valuable, forested wetlands exist in the continental U.S., with over half located in the Southeast. These forests provide timber for construction, furniture, pulp and firewood. The value of these wetlands for timber production has been estimated in billions of dollars, and their continued use need not be degraded by timber harvesting. With proper application of best management practices, timber production can complement other uses of the resource and actually serve to protect the integrity of large ecosystems.

Best management practices (BMPs) are not just a collection of appropriate actions for protecting forested wetlands, but they are also a salient feature of the Clean Water Act regulations to reduce nonpoint sources of pollution. The U.S. Environmental Protection Agency (EPA) defines BMPs as "a practice, or combination of practices, that are determined by a state, or designated area-wide planning agency, after problem assessment, examination of alternative practices, and appropriate public participation, to be the most effective, practicable (including technological, economic and institutional considerations) means of preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality goals." The BMP approach, which has proven so effective for upland sites, holds promise for application to wetland sites. Many southern states have refined their BMPs to include wetland ecosystems and are also initiating BMP monitoring programs to assess compliance.

Forested wetlands are important ecosystems for maintenance of water quality, providing a habitat for a variety of fish and wildlife, and regulating flooding and stream recharge. If these functions are significant to regional ecological balances, and if these wetlands can be degraded by forestry practices, then there should be a serious look at what values society will lose from any misapplication of silvicultural activities. Since wetland forests are a result of hydrological conditions which encourage hydrophytic soils and vegetation, a proper understanding of the forcing functions of hydrology are required to lessen impacts and promote effective management of these important ecosystems.

The frequency and duration of flooding and the subsequent soil moisture are among the main determinants in the functioning of wetland forests. The inundating waters may also bring in nutrient-rich sediments to the forest and carry away organic and inorganic materials so vital to food chain support. The timing and length of the hydroperiod depends on several factors, including precipitation patterns in the watershed, the level and slope of the wetland, the drainage area upstream, soil composition and the vegetation composition. In the gently sloping Coastal Plain of the southeastern U.S., where conditions are usually ideal for the development of meandering rivers and streams through wide floodplain areas rich in forest species, the vegetation of the wetland forests are often dominated by a high diversity of tree species that are adapted to the wide variety of environmental conditions described above. The most important environmental condition, therefore, is the hydrology, which determines the moisture gradient or the degree of waterlogging.

With population pressures in the region and good agricultural land already under intensive use, larger numbers of people are looking at the remaining forested acres as either a way to preserve wetlands or as a way to reap development profits. It is apparent to all that the high and diverse productivity of the forested wetland resource allows for a wide variety of options as long as the resource utilization preserves the hydrologic functions and ensures the processes and linkages in the food chains are left intact. Forest production towards sustainability is a goal to meet, but good information is necessary for appropriate planning, especially when continuous resource utilization is considered. Although there is considerable information amassed on the functions of forested wetlands, there is a considerable dearth of information on the effects of sustainable forest management practices on wetland functions and processes. Prior to implementation of management practices it would be wonderful if we knew what wetland processes we were affecting and the dynamics of the population responses to our management regimes. However, this information is not readily available and our judgements are based on the thready information that is currently available.

A major component which cannot be omitted from our planning and management decisions is the role of a strong environmental education campaign. This is fundamental to attain public support and respect for forested wetlands management scenarios, as well as instilling the tenor of best management practices into the hands of operators of forestry equipment. The Southeast is experiencing unprecedented awareness by the public for wetland conservation. This recognition can be seen in the growing number of national parks, wildlife refuges, forest reserves, and preservation organizations. It is incumbent upon resource managers to provide the necessary information to an increasing body of environmental overseers and engage in fruitful dialog to ensure sustainable resource extraction from all wetlands, forested or otherwise.

Preparing for and alleviating natural and management impacts on wetlands will require much additional study, technological advancement, public education and continued emphasis on BMP training and compliance. Communication and cooperation with resource agencies and the public will surely foster the sharing technologies and understandings which are critical to reduce man-made impacts to forested wetlands. The ultimate transfer of our findings to the public policy makers is the final crucial step to ensure sustainable development of our wetland forest resource. Traditionally, scientists have not stepped forward to force the necessary changes in public policy because there are always gaps in our knowledge. The time is right to advocate resource utilization, all the necessary information is available to step forward now. If not now, when?

MEETING THE CHALLENGE OF WETLANDS REGULATION

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ABSTRACT

Wetlands regulations is not a perceived problem that exists only because people don't understand what we are doing. We should recognize that a problem does exist and although our record is better than we get credit for, we can certainly improve on what we're doing.

In order to decide how to meet a challenge, I first have to understand it. In the case of wetlands regulation I tried to do so by asking myself these questions:

What is the nature of the regulation?

Why are they being proposed?

Who is issuing the challenge?

Are the challenges and regulations well intentioned and well founded?

At the outset let me clarify that when I speak of wetlands, I am including riparian areas, which may or may not truly be wetlands. I do this for two reasons:

1. So far we only have arguable definitions of wetlands.

2. I don't believe this problem is purely about wetlands functions any more than the problem in the Northwest is really about owls. That one is about old growth timber ecosystems and this one is about ecosystems in association with wetlands.

What is the nature of the regulations?

Regulations are simply rules to govern behavior. They are familiar to us. We willingly abide by regulations of one kind or another every day. We often suggest and encourage regulation of business activities, though most often of other people's businesses rather than our own. But that is not unique to us--it is common in the business world.

We are normally suspicious and distrustful of newly proposed rules which would regulate our behavior. They impose limitations which we may not exceed, even if the exception would benefit us and we think no harm would be done. Rules limit our alternatives and reduce our right to act in accordance with our professional judgment.

So, in the simplest form, that is what we face: Someone proposes to govern our behavior with respect to operations in wetlands.

Why would someone want to govern our behavior?

Regulations most often come about as a result of a noticeable threat of unacceptable behavior. I suspect that most regulations were even proposed and adopted after unacceptable behavior was observed. Now granted, the contest usually centers on just what should be deemed unacceptable. But our society developed systems to deal with that, decisions are made, and regulations are adopted.

I believe, then, that someone wants to govern our behavior either because it has been unacceptable, or because they believe it is about to be.

Who is issuing the challenge of regulation in wetlands?

Don't be concerned that I will try to name them all--time won't permit that--but I do think I can categorize the two primary sources of the challenge. One is the traditional environmental groups, with whom we have jousted for a few decades now; the other is the state and federal agencies (we think of them as the bureaucracies) responsible for environmental protection.

It is instructive to think for a moment about what is happening to those challengers lately. Consider, for example, that the federal EPA is very likely to achieve cabinet status. And have you noticed the influence of state environmental agencies being watered down lately? Hardly. How about the private environmental groups? I can tell you that recently compiled figures showing their membership and annual budgets are astonishing. I said "traditional" environmental groups--they are still there and growing--but look at some of the newer ones. In July, Times Mirror Magazines launched its TMM Conservation Council "aimed at preserving America's natural resources," inviting their 30 million readers to join them. (Readers of Field and Stream, Yachting, Skiing, Popular Science, Salt Water Sportsman, Golf Magazine, Outdoor Life, Home Mechanix, and Ski Magazine.) The first of their initial three key issues encompasses wetlands protection.

Up to this point, I conclude that some potent forces want to govern our behavior with respect to wetlands because it has been (or threatens to be) unacceptable.

What can we conclude about the legitimacy of these challenges?

This is going to be difficult because we should consider whether something is unacceptable. It would be convenient if we could say that means it certainly degrades the wetlands, but many of us disagree on when a wetland is truly degraded (not to mention whether it is truly a wetland). But, anyway, what is our record in wetlands? Has our industry steadfastly recognized their sensitivity and importance and conducted our forest operations with due respect during the past 25 years? If you answered yes and happen to be afflicted with the same condition as Pinochhio, you probably just goosed the person in front of you. The truth is that--despite our training in forestry--factors such as water quality, hydrology, and aquatic habitat were given little consideration in many forest operations until we were faced with regulations. So we acquiesced by adopting Best Management Practices (BMPs) to protect against non-point source water pollution. We agreed that rules were necessary, but insisted that they be voluntary. Unfortunately, somewhere along the way many people forgot two things about BMPs:

- Few had substantial research to determine their efficacy; and

- They were designed to protect water quality, not ecosystem integrity.

Worse, the name BMP came to be taken quite literally, as though they really were best. Consider, too, that in 1990, in some states, we are discussing the need to monitor compliance with BMPs.

Should we be surprised at the surge of interest in governing the behavior of industry in wetlands? Probably not.

Does this mean all the proposals for wetland regulation are legitimate and well-intentioned? Of course not. There is a similarity to the Northwest's old-growth issue where people see all the old trees as beautiful, majestic, and vitally functional. Here they seem to believe that all wetlands are similarly beautiful and vitally functional and valuable. Wetlands, however, are much more variable.

What has been our response to the challenge of wetland regulations?

Predictably, we have insisted that we do not harm wetlands, we need not be regulated because we will do the right thing voluntarily, and jobs and local economies are too important to be threatened by the protection of wetland ecosystems. I say predictably because that is the way we have responded to most environmental issues. Once the criticism reached a feverish pitch, we formed task forces to research and manage the issue. In doing so, I still believe we mistook it as a technical issue about the functional value of wetlands rather than about preserving wetland ecosystems.

We find ourselves in the proverbial catch-22. We have to conduct expensive long-term research to show that most wetlands functions and values can be protected along with our forest operations. But that won't satisfy many of our detractors because they really want to preserve the ecosystem functions in their natural state.

I now think I understand the challenges of wetland regulation well enough to suggest how we should meet them.

- First, we resist the temptation of declaring this a non-issue; i.e, we should not insist that people only perceive there is a problem because they don't understand what we are doing. Instead, we ought to recognize that a problem exists. Our record is better than we get credit for, but certainly can stand improvement.

- I think it is time we stopped habitually insisting that our industry should not be regulated in such matters. Let's give second thoughts as to whether some practices which are plainly incompatible with good environmental protection should be illegal--not simply inadvisable.

- We should carry the issue rather than chase it. It should be agreed that wetlands have important intrinsic values that need to be protected and we have a compatible economic use. We have never fully seized the opportunity to make this point. Two likely alternatives for wetlands are commercial development which will not protect the functions and values, and government ownership which removes it from the tax rolls. The greatest difficulty here is overcoming the emotional appeal of perserving wetland areas in their natural state. We need to document, and then explain, that important functions and values can be protected--often values can even be enhanced.

- We have not adequately studied the effects of forest operations on wetlands functions and values. The ecosystems are so variable and so complex that we probably never will. That simply makes it more important that we carefully prescribe what research to fund. The proper way to do that is in concert with concerned environmentalists and wetland scientists outside our industry. They are largely the impetus for our increased wetlands research and it only makes sense that we work together on defining the studies. This should add to the credibility of results.

- We cannot afford to be naive about the challenges. A strong defense against legislation which would unnecessarily restrict our operations and damage our business is necessary. While sound scientific data is necessary, we must not be lulled into believing that environmental regulation always results from scientific imperative.

- There's an old saying about "where the rubber meets the road...." In our business that happens mostly with our field foresters, road crews, and loggers. Have we properly communicated our expectations to them--that is, our commitment to environmental responsibility? Have we made sure that they have the competence and the information required to abide by existing BMPs?

- In the forest products industry we compete in the marketplace, but we are like comrades in arms facing challenges to wetlands operations. There is only one sensible plan for all of us, and that is to conduct environmentally responsible operations which are sensitive to the concerns and values of the public. Compromises to remain united will ensure unity in loss of public confidence and deserved regulation. As an example, I suggest that present BMPs should not be treated as the limits to which we can operate, but rather as the minimum standards of protection to be afforded. If we cannot achieve unanimity on that within the industry, then regulation may be prudent to maintain a level competitive playing field.

I will leave you with wisdom borrowed from The Art of War compiled over two thousand years ago by the mysterious Chinese philosopher, Sun Tzu. Many believe it is most clearly illustrated in the successes of post-war Japan. It is based on his belief that "To overcome others' armies without fighting is the best of skills."

"Plan for what is difficult while it is easy, do what is great while it is small. The most difficult things in the world must be done while they are still easy, the greatest things in the world must be done while they are still small. For this reason sages never do what is great, and this is why they can achieve that greatness."*

*Cleary, Thomas (Translator), <u>The Art of War - Sun Tzu,</u> Shambhala Publications, Boston & Shaftesbury, Boston, Massachusetts (1988).

Impact of Forestry Operations On Pocosins and Associated Wetlands

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ABSTRACT

Current forestry practices in pocosins and associated wetlands (PAAWS) operate against a 300-year legacy of harvesting, drainage, fire, and management history. Forestry operations consist of site-specific prescriptions to harvest the existing timber, to re-establish a forest stand, to increase growth of crop trees, and to manage for non-timber values. Most activities are directed at short-term modifications of site-specific limitations to inherent productivity. Forestry operations have progressed from the cut-and-run practices of exploitative harvesting to intensive management of productivity potential with environmentally sound techniques. Research to understand the interaction of various site factors and management practices is a continuing effort. With site-specific prescriptions based on research and economic principles, investments in productive forestry allow our forest product demands to be met while maintaining other forested wetland values.

Key Words: forest practices, wetlands, pocosins, silvicultural impacts, wildlife habitat, water management.

RESOURCE ECOLOGY

Soils

The Lower Coastal Plain of North Carolina includes the Wicomico, Talbert, and Pamlico systems from sea level to the Surry Scarp (28.5 m). The Middle Coastal Plain is between 29 and 94 m with the Brandywine, Coharie, and Sunderland plains (Daniels, et al., 1984). Carolina bays are common on sandy uplands of the Middle Coastal Plain. Pocosins and associated wetlands (PAAWS) are common on the interstream divides of the Lower Coastal Plain. Wet mineral soils developed in clayey or loamy sediments are classed as aquults (wet Ultisols) with an accumulation of clay in the argillic horizon and low base saturation. Soils developed on sandy sediments may be classed as aquents, aquods, or aquepts. Aquods have an accumulation of organic matter, iron and aluminum in a spodic horizon. Aquents and aquepts have minimal profile development. When the organic matter percent of the upper 40 cm exceeds 20%, the soil is classed as a Histosol. All of these hydric soils have water tables that are at or near the surface (within 30-45 cm) for some part of the growing season with average weather conditions.

Forest Types

Although recent alluvial soils in active floodplains support forested wetlands, most of these sites are not considered for intensive pine plantation management. Muck swamps with organic soils, bottomland (first terrace) hardwoods on wet Entisols and Inceptisols, and black riverbottom forests with shallow organic soils over sandy sediments occupy narrow floodplains in the Lower Coastal Plain. Although loblolly pine (Pinus taeda L.) is a component of these forest ecosystems, regeneration following harvest is from seedlings and coppice.

Older sediments and associated Histosols support the PAAWS that are considered for intensive pine plantation management. Swamp forest types are often transitional between pine pocosin and alluvial swamp forests, but include cypress ponds and typically have organic soils or highly organic mineral soils. Wet flats on interstream landforms have loamy or clayey mineral soils with some surface organic accumulation. Vegetation ranges from cypress [Taxodium distichum (L.) Rich] to mixed hardwoods with scattered loblolly pine to loblolly-sweetgum (Liquidambar styraciflua L.) stands. Pocosins are located on broad, level landscapes with wet mineral soils grading to deep Histosols. Pond pine (Pinus serotina L.) and loblolly pine are dominant species. Pine savannahs are common on Spodosols and some Ultisols with longleaf pine (Pinus palustris Mill.) dominant with some loblolly and pond pine. Carolina bay forest dominates the highly organic mineral soils on bay landforms in the Middle Coastal Plain. Loblolly and pond pines occur with red bay [Persea borbonia (L.) Sprengel.], sweetbay (Magnolia virginiana L.), and loblolly bay [Gordonia lasianthus (L.) Ellis]. On organic soils the dominant overstory species is pond pine.

History

The North Carolina coastal plain has a history of agricultural clearing and drainage for wetland agriculture and forestry dating back to the early 1700's. The extensive stands of longleaf pine were harvested for naval stores. Cypress, white cedar, and pine timber was logged with the better soils being converted to agriculture. The European settlers adopted many of the Indian philosophies concerning the use of fire. Fire was used to clear agricultural land by removing debris following logging. Frequent burning of the pocosins also improved grazing for livestock and game, as well as, access for hunting. In the late 1800's and early 1900's, steam engines and logging railroads were used to log the remaining old growth stands. The 1909 drainage district legislation enabled a large number of drainage projects using steam dredges to be initiated (Lilly, 1981). Some of these failed due to lack of capital. Others failed to adapt upland practices for farming in the wetlands. Wildlife populations were greatly reduced by habitat loss and hunting pressure. By the 1930's the history of logging, drainage and fire had created second growth pine stands that were acquired by the newly-established paper companies. Fire control by these companies and the N.C. Forest Service and removal of livestock from the woods allowed fully stocked pine stands to develop, with scattered residual loblolly, pond, and longleaf pines providing the seed source. Additional drainage and forest road construction began in the 1950's followed by harvesting in the late 1950's and early 1960's. Regeneration behind these early clearcuts consisted of drum chopping, burning and disking followed by planting or aerial seeding. By the late 1960's growth of these plantations was less than expected. Many of the aerially seeded stands were complete failures. Poor site preparation, severe phosphate deficiency, and vegetative competition contributed to the poor stocking and growth.

By the mid-1970's most privately owned forest land had some level of management. The mosaic of predominantly pine stands reflected the history of harvesting, fire control, regeneration, drainage, and road systems. Interspersed with the dominant pine stands, hardwood, cypress, and Atlantic white cedar [Chamaecyparis thyoides (L.) BSP.) occupied stream bottoms and drainage lows on the landscape with long intervals between major fires. Forest management ranged from harvest followed by incidental natural regeneration to intensive plantation establishment. Large landowners, especially industrial, developed management plans to schedule harvest and regeneration. Wildlife populations, particularly deer, began to increase dramatically.

With the Clean Water Act of 1977, regulation of wetlands as waters of the United States require permits for discharges of dredged and fill material. Normal farming, silviculture, and ranching activities are exempted under Section 404(f). Discharge of dredged or fill material into the waters of the United States still required a permit if the purpose of the activity was to convert the use, where the flow or circulation might be impaired or the reach reduced. Definition of wetlands as "waters of the United States" and interpretation of nationwide permits continued to be refined by court cases. As recently as 1985, isolated wetlands in the headwaters which are or would be used as habitat by migratory birds were included under 404 jurisdiction. While regulatory definitions and interpretations have evolved, forestry practices have also evolved in response to regulation, as well as to opportunities to implement new research developments. Forested wetlands, whether or not they meet the jurisdictional definition ("areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions"), are an environmentally-preferred land use. By properly applying Best Management Practices (BMP's), forestry operations are compatible with the full range of wetland functions, including: timber production, wildlife habitat, recreational opportunities, hydrologic functions, and diverse plant communities of water tolerant vegetation.

Forestry Research

Since pulp mills and other wood processing facilities require a large capital investment at one location, an assured supply of pine and hardwood timber is essential. Purchase of roundwood from landowners and independent loggers has provided a primary supply. Weyerhaeuser timberlands have been used to supplement this supply and assure a continuous flow of raw material. Recognition that productive plantations were not being established with existing technology led to a major research effort by forest industry, universities, and the U.S. Forest Service. Research studies on water management, genetics, drainage, site preparation, and fertilization produced new techniques for intensive plantation management and increased productivity on PAAWS. Additional research efforts were directed to evaluation of the impact of these new techniques on wildlife, water quality, associated vegetation (biodiversity), soils, and ecosystem trends.

Productivity Potential

These new techniques were based on the premise that intensive plantation management that increased productivity could lower cost per unit volume grown even when investment per acre increased. Once systems were developed that could reliably produce highly productive plantations, effort was directed at reducing costs, optimizing systems to individual sites, and improving quality control. Compliance with Section 404(f) exemption requirements and BMP's was consistent with biological and economic objectives to maintain the values and functions of forested wetlands while increasing productivity.

Allen et.al. (1989) discussed two strategies to improve productivity: 1) shorten the period of time it takes for a tree crop to reach full site occupancy, and 2) raise the level of maximum leaf area that a stand maintains at full site occupancy. These strategies are based on the premises that leaf area is highly correlated with productivity and that leaf area is limited by nutrient and water availability. Although productivity is defined as total stemwood production per unit area, some management regimes are based on values dictated by individual tree volume/value growth. Growth and value of the crop trees were increased using silvicultural options that:

1) improve the effective availability of a sites inherent nutrient and water resources,

2) allocate existing resources to the crop trees by reducing competing vegetation,

3) add the limiting resources,

4) select species or genotypes that are effective in utilizing the inherent nutrient and water resources of a site (Allen and Campbell, 1988)

Water management and bedding are examples of option 1. Water table management of PAAWS with minor drainage and water control structures increases the volume and quality of the rooting environment during wet seasons and maintains adequate soil moisture during dry seasons without losing wetland values. Bedding increases the rooting volume for young seedlings and increases quality of the root environment by concentrating organic matter and nutrients. Minor drainage and bedding contribute to earlier site occupancy while water management maintains higher leaf areas in fully stocked stands.

Option 2 treatments include vegetation control and thinning. Nutrient, moisture, and light resources of a site may be more effectively allocated to the crop trees by controlling competing vegetation. Competition control begins with the bedding operation and may be supplemented with herbicides to increase the rate of full site occupancy by the crop trees. Thinning of a fully occupied site allocates limited site resources to the residual crop trees and increases individual tree leaf area. Stand productivity is transferred to individual trees until maximum leaf area is restored.

Option 3 treatments are restricted to nutrient additions through fertilization. In limited cases water and nutrients are added with land application systems for waste water. Growth responses to nutrient additions are usually inversely proportional to the magnitude of the deficiency. Multiple element deficiencies or other limiting factors (i.e. high water table or severe vegetative competition) can limit response. Corrections of phosphorus deficiency increases early growth and maintains higher leaf areas after stand occupancy.

Option 4 alternatives may be limited to small responses unless water and nutrient stresses are ameliorated. Early survival and growth is generally better for intolerant species adapted to growth on disturbed sites. After full site occupancy growth may be better for other species, particularly in no thinning regimes.

Silvicultural activities can also negatively impact the availability of site resources and productivity. Soil puddling, rutting, and compaction during harvesting, thinning, or site preparation can reduce the quality and quantity of rooting volume producing a negative option one. Water management, seasonal scheduling, and high flotation equipment contribute to reduction of these negative impacts. Slash disposal windrowing that results in soil displacement removes nutrients from seedling microsites producing a negative option 3. While nitrogen plus phosphorus fertilization can restore partial productivity, the industry has developed slash disposal techniques for in-place reduction to minimize nutrient redistribution.

The concept of maximizing leaf area of crop trees during the life of the stand by rapid occupancy and increasing the fully stocked level is dependant on techniques to manipulate the site to make resources more available. It assumes leaf area is an estimate of light interception and photosynthate production. Productivity or stemwood production increases as the result of resource manipulation during rapid growth opportunities during the life of the stand. With silvicultural systems designed to maximize wood per unit area, stand leaf area is maximized over the relatively short stand life. To maximize individual tree growth (size), leaf area of individual crop trees is maximized by multiple thinnings and a longer stand life. This system provides the opportunity for a diverse community of understory plants and wildlife, as well as high-value saw timber. Weyerhaeuser's management is directed at production of high-value saw timber and veneer from the crop trees and pulp from intermediate thinnings while maintaining wetland functions and wildlife habitat values.

Plantation Cycle

Although site-specific prescriptions, management plans, and ownership objectives contribute to the unique history of each tract of forest land, a generalized cycle of plantation management activities can be discussed. Intensity of management varies depending on the individual or industrial owner's objectives. Road and primary drainage construction is usually installed at least 3 years prior to harvest. Most ownerships have the basic systems in place and may only require minor additions. Roads provide access for harvesting, fire control, site preparation, thinning and other silvicultural activities. Primary drainage utilizes natural outlets to improve seasonal water flow. Water control structures and storage ponds for fire control are usually installed during initial construction, but may be retrofits on existing systems. Pre-harvest field ditching usually accompanies primary construction. New construction of drainage systems and forestry access roads should comply with the Section 404(f) exemption, voluntary forested wetlands BMP's and other relevant state guidelines. After road systems stabilize and water control is established, harvest of existing timber is scheduled. Industrial harvest timing or purchase of private timber is based on a complex, dynamic planning system that considers weather conditions, site operability, tract management, alternative supplies, wildlife habitat, plantation age class distribution, and environmental sensitivity.

Following harvest, maintenance of existing ditches may be prescribed or, in some cases, additional minor drainage to alleviate soil damage during site preparation due to high water tables. Non-merchantable stems and stumps may be sheared. With low stumps and small residual stems a drum chopper may be adequate. A prescribed fire is often used to further reduce the debris. Bedding and pre-plant fertilization follows. All site preparation activities are weather and water control dependent to minimize soil damage. Planting occurs during the following dormant season. Competition control with herbicides during the spring may be required on some sites. All water management and plantation establishment activities are performed in accordance with voluntary forested wetland BMP's and within the Section 404(f) exemption. Once the plantation is established, fire prevention, growth monitoring, and road and water management system maintenance are primary activities for the next 10-20 years.

Depending on the management plan, a stand may be scheduled for a first commercial thinning between ages 12-20. Thinning allows early recapture of part of the investment and redistribution of growth to fewer crop trees. Additional thinnings may be scheduled every 5 to 7 years. After each thinning the stand may be control burned to reduce wildfire hazard. Fertilization with nitrogen or nitrogen and phosphorus may be used to reduce nutrient limitations after each thinning or on a 5 to 7 year cycle. Road and road canal maintenance are scheduled throughout the rotation as required for operations. Following the clearcut harvest, between ages 30-40, regeneration activities are repeated. During a 35-year rotation with two thinnings and fertilizations, activities occur on the site less than six percent of the time including the first regeneration year. Tree growth and wildlife activity are the primary activities for the other 94 percent of the time. During the development of the plantation, most PAAWS sites go through plant community succession similar to that on natural sites with comparable levels of disturbance. Early concerns that this succession sequence might not provide adequate browse for the primary game species, deer, were addressed by cooperative studies. Hazel (1976) found up to 17 times more browse in plantations compared to the optimum natural stand. Species diversity was also greater. Diversity and browse production declined with unthinned plantation age and approached natural stand levels as tree size became similar.

IMPACT OF SILVICULTURAL PRACTICES

Drainage/Water Management

Drainage, or the removal of excess water on a seasonal basis, had beneficial effects on tree growth in natural stands and early plantations (Klawitter and Young, 1965; Maki, 1971; and Ralston, 1965). Terry and Hughes (1975) summarized many of these early studies and found a range of mean annual tree growth response for drainage from 80 to 1300 percent. The duration and magnitude of growth response following drainage depends on the soil type, species, landform, degree of drainage and water control management. Water control results in a 3 to 5 meter increase in site (base age 25) by age 15 to 20 that will be maintained through a 30 to 35 year rotation.

Early concerns of drainage impacts were directed at downstream effects and impact on aquifer recharge. With modern drilling technology, Daniels et.al. (1978) were able to show evidence that the large interstream divides were not recharge areas for the underlying deep water aquifers. Recharge for the Castle Hayne aquifer occurs much further to the west in the upper part of the Coastal Plain. Improved surface water infiltration does decrease the number of days with soil saturation to the surface, but may not substantially increase total runoff. Hughes, et.al. (1989) present data for drainage discharge of 20% of annual rainfall from a mixed plantation/natural watershed, 30% for a ditched (free drainage) natural stand, and 18% for unditched natural timber. Intensive monitoring of a nearby 16-year-old plantation showed 18% discharge for 1988. Comparison of these data with other land uses (Table 1) indicates much higher runoff for agricultural land. Runoff tends to decrease as plant biomass increases. Hence, fully stocked plantation or natural stands have less runoff than pasture, young plantations, or partially stocked natural stands. Agricultural fields and drained brushland have the highest runoff. Seasonal hydrographs support the comparison of plantations and fully stocked natural stands. Amount and length of discharge are not significantly different, but individual runoff events may vary for plantation and natural stands.

Water relationships in undrained pocosins show seasonal extremes. Timber volume, soil type, and distance to natural drainage produce a range from 30 cm above the soil surface to as much as 120 cm below. On a seasonal basis, additional variation occurs. The water table stays close to the soil surface through winter and early spring due to low rates of evaporation and transpiration. During the spring fire season, high temperatures, wind, evaporation, transpiration, and low rainfall produce a rapid drop of the water table. Late spring and early summer rains return the water table to the soil surface. Late summer thunderstorms or hurricanes can maintain high water table levels. The lowest water table level usually occurs in early fall of dry years.

TABLE 1. FOREST PLANTATIONS COMPARE FAVORBLY TO OTHER LAND USES

Land Use	Location NC County	Year	Runoff as % of Precipitation	Soil Type	Study
Row Crops	Tyrrell	1977-8	54	shallow organic	Skaggs, et.al.
Drained Pocosin Brushland	Tyrrell	1977-8	48	shallow organic	Skaggs, et.al.
Agricultural	Tyrrell	1978	44	mineral	Skaggs, et.al.
Drained Natural Woodland	Tyrrell	1978	42	mineral	Skaggs, et.al.
Pine Plantation 4-7 years old	Jones	1981-4	38	shallow organic	Herrmann & White
Pasture	Washington	1976-8	36	organic	Skaggs, et.al.
Drained Pocosin Woodland	Tyrrell	1976-8	35	deep organic	Skaggs, et.al.
Drained Pocosin Woodland	Carteret	1985-8	29	deep organic	Herrmann & White
Undrained Pocosin Woodland	Carteret	1988 1985-8	23 18	deep organic	Herrmann & White
Pine Plantation 15 years old	Carteret	1988	18	mineral	Weyerhaeuser

During wet seasons plantations with free drainage may have a water table 30 to 60 cm lower than in an undrained pocosin, with less seasonal fluctuation. Standing water is minimized, although complete soil saturation is a common occurrence during the wetter seasons. The drained soil provides an empty "sponge" that can adsorb rainfall until saturated when percolation through the soil profile to the ditch occurs. With an undrained soil the "sponge" may be nearly full and runoff occurs across the soil surface if channels have been developed. Otherwise ponding occurs until a hydrologic gradient is created. Thus, forestry drainage does not change the basic hydrologic cycle or affect conversion of wetlands to uplands, but increases the length of time the surface soil is in an unsaturated condition.

Recognition of the need to practice water management in addition to drainage was a logical outgrowth of drainage research (Campbell, 1976). An engineered drainage system provides the ability to lower the water table on a seasonal basis. Maximum drainage is required early in the rotation when tree biomass is small. As crown closure is reached, transpiration increases. Additional water can be tolerated and utilized by the trees. Ditch decadence, earthen plugs, and water control structures can be used to hold more water on site. Maximum drainage for early stand growth and during equipment operation can be achieved by opening the drainage system. Water control structures in an engineered system allow release of stored water from specific management units to improve operability.

While tree growth response has been clearly documented, operational and soil damage impacts have less quantified information. Operability on undrained sites with conventional harvesting equipment has been limited to drier seasons. Excessive rainfall and hurricanes in the early 1970's severely impeded wood supply and equipment activities in Eastern North Carolina. Limited operability and severe site damage supported drainage as the only means to extend operating windows (Campbell and Hughes, 1981). Soil damage resulting from harvesting or site preparation equipment during wet site conditions can reduce site index (base age 25) by 3 meters or more and may only be partially offset by subsequent ameliorative treatments (Terry and Campbell, 1981).

The basic impact of drainage on PAAWS is to lower the water table on a seasonal basis. This extends the growing season for established trees and provides a longer operating window for equipment to minimize soil damage. Newly planted trees are able to establish themselves sooner with more rapid early growth. Water control allows effective drainage during tree establishment and during periods of equipment operation. Water can then be held at higher levels after crown closure when trees are able to utilize more water. Annual water discharge (or runoff) may not be greatly different from an unditched, unmanaged system in the same stage of stand development.

Slash Disposal

The regeneration sequence following drainage and harvesting typically consists of slash disposal, bedding, fertilization, and planting. Slash disposal may consist of chopping and burning or shearing, chopping and burning. Piling debris and root mat material had been a standard practice until fairly recently. Even under the best circumstances, a considerable portion of the site's nutrient capital was concentrated into windrows (Morris, et.al., 1983; Bengtson, 1981). The forest industry has taken a leadership role in developing new methods of slash disposal that maintain the integrity of site nutrient capital and lower operating costs. Site-specific prescriptions that combine new shearing techniques, chopping with burning or layover time have greatly reduced area piled. Following slash disposal, most coastal plains sites are bedded although some better drained soils may be regenerated by flat planting.

Bedding

Bedding is essential for rapid early growth on hydric soils. The bed is a mechanized version of the natural hummocks created by wind-thrown trees. The bedding disc blades till the soil, incorporate organic matter, control competition, and create a raised microsite. The chopper or roller on the back of the bedding harrow shapes the bed surface to improve planting quality. The benefits are improved seasonal surface infiltration with a slightly raised microsite for seedling root growth above the water table, tillage of the surface soil to increase macropore space, increase root penetration, and incorporate organic matter, and competition control (Haines, et.al., 1975; Terry and Hughes, 1978; Broerman et.al., 1983; Morris and Lowery, 1988). Growth responses on poorly drained coastal plain soils are variable by soil type and phosphorus availability. Height growth responses at ages 10-13 are typically 1 to 2 meters (Gent et.al., 1986; McKee and Wilhite, 1986) although responses over 2 meters at age 18 have been documented (Campbell and Hughes, 1981).

Phosphorus Deficiency Remediation

Productivity on many sites in the PAAWS is limited by low levels of available phosphorus. Work in Florida by Pritchett in the 1950's demonstrated a dramatic early response to pine growth that stimulated additional research. Large, long-term response on many hydric soils have been demonstrated (Pritchett and Comerford, 1982; Gent et.al., 1986). Broadcast phosphorus at 40-60 kg/ha before planting can increase site index (base age 25) 2-4 meters or more depending on soil type. With hydric clay soils, Gent et.al. (1986) showed age 12 site index responses of 3.7 m for bedding, 5.2 m for fertilization, and 8.8 m for phosphorus incorporated in the bed. Projected to age 25 control stands averaged 13.7 m in site index and 132 m^3/ha while bedded and fertilized stands averaged 22.6 m in site index and 353 m^3/ha. Harvest values were 3 times greater for the bedded and fertilized stands (Gent et.al., 1986). From 1982-1986 phosphorus has been applied at planting or on a catch-up basis to over 286,000 ha of pine plantations in the Southeast (Allen et.al., 1989).

Competition Control

Control of competing vegetation with herbicides has been developed within the last few years as a method of increasing pine growth. Large early growth gains on sites with intensive site preparation and fertilization have been documented (White and McKee, 1985; Allen, 1989). Ground application of herbicides broadcast, banded, or spot-sprayed over the seedling bed kill or slow the growth of competing vegetation, some more quickly or selectively than others. The intent is to remove competition for water, light, and nutrients. Even on fertilized beds, water and nutrients may limit pine growth at intervals during the growing season. This reflects the limited reach of pine seedling root systems in the first year relative to the potential root biomass of competing vegetation. Competing vegetation reduces pine growth by reducing light through overtopping or interception. Seedling death late in the growing season may result from a combination of insufficient light to maintain adequate photosynthate production and root growth to utilize soil moisture from a large soil volume (Dougherty and Gresham, 1988). The effect of herbicide treatment on the competing vegetation is a delay in succession that allows the planted pines to out-distance most of competition. Understory plant communities develop one to two years later with herbicide use. On wet, phosphate-deficient soils, bedding and phosphate fertilization responses appear to be additive with weed control response. By age eight, absolute response to bedding and weed control is usually achieved while phosphate response may continue. The net effect is for the pine stand to reach full occupancy of the site earlier (Allen, 1989).

Species/Genotype Selection

Commercial forestry on wet pine sites in the Southeast has concentrated on loblolly pine and slash pine (P. elliottii Engelm.). Both species have wide site adaptability/tolerance and potential to respond to intensive management. Longleaf pine continues to be a viable alternative on more well-drained soils for rotations that emphasize high-value specialty products, i.e. pine straw, poles, and piling. Pond pine site index (base age 25) has rarely been within 3 m of loblolly in species comparisons over a range of Eastern North Carolina sites (R.G. Campbell, unpublished data). Pond pine also has difficulty meeting grade requirements for lumber and plywood, limiting its use to lower value pulpwood.

Most industrial organizations and many small private landowners use first or second generation improved pine. Loblolly volume growth gains of 8 to 15 percent per generation and even larger gains in value from tree straightness, and wood specific gravity increases have been estimated for the better genotypes (Hollowell and Porterfield, 1986). With the capability of maintaining half-sib integrity from the orchard to the field and interest in vegetative propagation, questions have been raised about the opportunity to prescribe families by site. Tree breeders have generally selected broadly adapted progenies which perform well across a broad range of sites, displaying low levels of genotype x environment interaction. From the operational viewpoint, the costs of maintaining separate tree breeding programs and progeny testing and research efforts requires larger responses than currently indicated. Fertilizer additions have generally shown strong responses for relatively low costs compared to genotypic selection for nutritional efficiency (Troth et.al., 1986). Other soil factors that could be addressed by prescribing family to site are air/water relationships and soil structure/texture. These soil properties that influence early root development are altered with the bedding operation to produce a microsite with beneficial air/water relationships and good root penetration. The potential G x E response through selection would have to be larger than currently apparent in order to justify development costs. Although some growth data indicates potential G x E for some half-sib familes on some site types, the lack of physiological process information for identifying causal factors discourages intensive study. Escalation of breeding programs into second generation material and beyond, discourages the long-term effort to establish G x E interaction for specific genotypes (Duzan and Williams, 1989). While selection of best available genotypes is a continuing process, it is now recognized that growth gains resulting from tree breeding will not be fully realized unless environmental limitations are ameliorated (Allen et.al., 1989).

Established Stand Practices

Once pine stands are established on wet sites, silvicultural activities may be limited to road and water management system maintenance, fire and pest protection, and growth monitoring. While stands may not receive silvicultural treatments between establishment and harvest due to landowner objectives or site-specific prescription, many stands are thinned, control burned, or fertilized. Thinning reduces the number of trees per hectare, thus allocating site resources to fewer trees. Water table elevation and increased nutrient availability may occur until leaf area production compensates for crown biomass removed. Pre-commercial or early commercial thinning is advocated to take advantage of the most rapid growth years. Late commercial thinning may result in delayed response or minimal response (Hughes and Kellison, 1982). Thinning transfers site productivity potential to fewer stems per hectare. The resulting trees are larger and have more sawlogs with values that are three to ten times equal volumes of pulpwood (Timber Mart - South, 1989). Multiple thinning entries during a sawtimber rotation open the forest floor to light that stimulates understory growth and increases wildlife habitat values. Adverse impacts can occur when improper harvesting is done under excessively wet soil conditions (Nebeker et.al., 1985).

Prescribed burning in established stands on wet pine sites is used primarily as a fuel reduction technique. Indians and their European replacements burned coastal plain forests to improve game habitat and reduce dense undergrowth that contained ticks, snakes, and other hostiles while preventing travel. The open-range forest grazing that required annual burns to improve forage was phased out at the end of World War II by fence laws, better cattle, improved pastures, and a more profitable tobacco and row crop economy. A strong "Smokey Bear" policy created dense stands with tremendous accumulations of highly combustible fuels. Fewer fires occur, but they are more intense and destroy more timber value. The investment in plantation forestry and increased rural housing have demanded protection from uncontrolled wildfire. In more recent years, controlled burns to reduce fuel, thinning, permanent fire lanes, established water supplies, and more sophisticated fire suppression organization and equipment have been used to reduce hazards. Prescribed fire, under proper weather conditions, consumes the fine fuel component of the forest floor. Soil moisture prevents combustion of the soil humus and protects root systems and soil flora and fauna. Vegetation with stems greater than 10 cm in diameter are not severely damaged but numbers of stems in 5-10 cm sizes are dramatically reduced even by low intensity fires. Numbers of small stems (0-2.5 cm), and grasses and forbs increase (Ralston, et.al. 1982). The net effect is a shift of vegetation that is preferable for many wildlife species. Soil and water effects are variable depending on the fire frequency, duration, and intensity; soil characteristics, and rainfall, runoff potential, and watershed characteristics. On PAAWS sites, erosion is generally not a problem due to the flat topography. While fire releases nutrients bound in organic matter, most soils have a relatively high adsorption capability with little movement of nutrients off site. Thus, water quality effects are minimal with a properly planned burn (Wade and Lunsford, 1989).

Fertilization in established stands following thinning with nitrogen or nitrogen plus phosphorus generally produces a greater response than in unthinned stands. Nutrient demand to replace stand leaf area removed by the thinning operation is at a maximum. Light and moisture availability favor maximum response if the nutrient limitation is met. Value is increased by accelerated growth, by shortening time required to regain maximum stand volume growth, by increasing individual tree size and potential product yield at the end of the rotation, or by shortening the rotation to achieve a target tree size (Allen, 1987). Growth responses of 3-5 m^3/ha/yr over a 5 to 8 year period are typical across a wide range of site types. This is in response to the disparity between nutrient needs of the stand and supply available on the site. Tree response is visible as accelerated growth associated with increased leaf area (Allen et.al. 1989). Understory plants also respond to the higher nutrition level and with the available light and water in a thinned stand grow vigorously. Species shifts to include plants from earlier successional stages are common. Transition from the open condition following thinning to more complete canopy coverage is dependent on thinning level, site productivity, and weather conditions, but usually takes 5-10 years. Understory vegetation responds to this change in overstory. Fertilizer nutrient movement off site in groundwater through leaching is limited by soil adsorption and uptake by plant roots. Direct application of fertilizer to open water may result in transport off site depending on soil adsorption in the runoff channels (Allen, 1987). New water quality data monitoring an operational fertilization in the lower coastal plain indicates minimal losses from ditched watersheds (R. G. Campbell, unpublished data).

IMPACT OF FOREST MANAGEMENT ON WILDLIFE HABITAT IN PAAWS

Forest management in PAAWS has both advantageous implications and limitations for wildlife, depending upon the wildlife species and upon the stage of forest development. We will discuss a number of forestry factors with respect to wildlife implications. The discussion is not exhaustive, is particular to Weyerhaeuser but in general will be true for other industrial forest lands, but is less representative of non-industrial private and governmental forest lands. Weyerhaeuser's eastern North Carolina ownership includes 236,000 hectares, most of which are PAAWS. About 200,000 hectares will eventually be managed pine plantations, most of which were originally forested by natural pine stands. The remaining 36,000 hectares will be managed as natural stands, the majority in hardwoods. Although tract size is variable, an integrated road and water management system has been established on most ownerships. On major tracts, roads dissect the land into timber blocks that are about 1600 m long by 800 m wide, i.e. 130 ha each. The water management system consists of ditching at 100 or 200 m spacing within timber blocks, these drain to roadside canals which in turn outlet to natural waterways. Flashboard riser dams and sediment ponds are progressively being installed at more locations to facilitate water management.

Advantages of Intensive Management

PAAWS are forested wetland habitats. Forest management maintains the forest status. Proper silviculture and water management also maintains the wetland status. Alternate land uses alter or destroy both forest and wetland functions. A recent satelite image of the Albemarle-Pamlico Sound region of North Carolina makes this point very clearly. Major remaining forest areas are "islands" surrounded by PAAWS and forested uplands that have been cleared for agriculture, urban development or other uses. The major forested "islands" are the Great Dismal Swamp, the Alligator River/Dare County complex and the Croatan National Forest. Bottomland hardwoods are linear forest "islands" adjacent to major rivers and creeks. The remaining significant forest "islands" are private ownerships -- predominantly Weyerhaeuser. In fact, a Weyerhaeuser ownership map is a near match with the largest forest "islands" on the satelite image between the Neuse River, the Great Dismal Swamp and west of the Alligator River. These lands would have been lost as both forests and as wetlands if it were not for industrial ownership and management.

PAAWS managed for forestry have more habitat diversity than those maintained in a so-called "natural" condition. Increased diversity results from the "edge" provided by the road and water management systems and the aquatic habitat created by the water management system. The greatest areal diversity results from the mosaic of timber management blocks that are of different ages, which range in size from perhaps 20 to 200 hectares, with a typical size of 40 to 80 ha. Natural PAAWS often have very old, dense, uniform timber stands that are much larger in area, ranging in size from a few hundred to a few thousand hectares. The white tailed deer provides a good example of the wildlife impact of this difference in habitat diversity. The managed forest mosaic gives a consistent increase in the quantity and quality of deer browse, resulting in increased deer population density. Natural PAAWS have populations of about 15 deer per square kilometer, whereas those managed for forestry may have up to 75 deer per square kilometer (Monschein, 1981). Because of the higher density, industrial forest lands leased to hunt clubs account for a disproportionate, very high percentage of the reported deer harvest in North Carolina (Mason, 1989).

In addition to the timber management block mosaic effect, forest management treatments almost universally increase the quantity and quality of browse production (Hurst, 1989). Clearcutting, logging-slash disposal, mechanical and chemical site preparation, pre-plant fertilization, slash burning, thinning, stand fertilization, and prescribed burning all stimulate the production and improve the quality of browse. Production is maintained at relatively high levels because one or more of these treatments are normally applied at intervals of 5 to 10 years. Selection and regeneration harvests in hardwood stands result in increased browse production and, in oak and gum stands where shelter wood and/or seed trees are used, can also increase mast production. Few if any "natural" PAAWS are treated with this intensity or frequency and thus are much less productive for most wildlife species.

Forest management reduces the fracturing of PAAWS. For certain species, such as black bear, this is a positive factor. To be cost efficient, forestry requires very large tracts of land. Most companies have worked hard to buy large tracts (≥200 ha) and to buy adjoining lands to further increase total tract size. A PAAW example is the peninsula between the Neuse and Pamlico Rivers which contains all of Pamlico County and parts of Beaufort, Craven and Pitt Counties. The dominant land use is forestry and by far the largest landowner is Weyerhaeuser. Company lands on this landscape total about 65,000 hectares. Forests are nearly continuous along the length of the peninsula from Goose Creek Island on the east end to Greenville on the west, and from river to river in several places. This extensive forest cover is due to Weyerhaeuser's acquisition of perhaps a hundred or more adjoining tracts since 1935 and the management of these lands for forestry. Black bear populations appear to be expanding in this area. Contributing factors certainly include forest cover on a landscape-scale, control of hunting through lease agreements, gated road access, Weyerhaeuser's no-bear-hunt policy since 1970, and inclusion of major Company tracts in the bear sanctuary system, in addition to the protection afforded by the N.C. Wildlife Resources Commission. Industrial ownership and control are very important factors. Though it rarely occurs, the pieces of Humpty Dumpty have been put back together in this area. Ownership by several hundred non-industrial private individuals would have resulted in a very different land use mosaic and a diminished if not extinct bear population.

Limitations of Intensive Management

PAAWS intensively managed for forest production are not "natural". Some of the specific implications for wildlife will be mentioned in the following points. However, most "natural" PAAWS are not climax communities relative to long-term ecological history. For example, the almost universal artificial exclusion of fire for the last 40 years has resulted in an ecological shift for wet savannah sites, a major PAAW type. Most of these have evolved to much drier forested wetlands as the open pine savannahs became closed pine forests. As wet savannah they may have supported pitcher plants and venus fly traps; as forested wetlands, they usually do not. With the higher transpiration rates associated with fully stocked stands, water and light are less available for understory species common in an open savannah.

Crop cycles for intensive timber production are relatively short -- 30 to 50 years. Some wildlife species require at least some timber that is older than this to satisfy habitat requirements. The best example is the red cockaded woodpecker which nests in old pines that have heart-rot disease. The most suitable pine stands exceed 60 years in age. Industry has set aside some existing red cockaded colony areas. An alternative to old timber is the use of artificial cavities in younger timber. These are apparently being used with success in the Francis Marion National Forest in the aftermath of Hurricane Hugo. Hugo was particularly destructive of red cockaded nesting trees (Graham, 1990). Federal and state ownerships can be managed on long rotations, low stocking levels, frequent fires, and use artificial cavities as techniques to increase woodpecker populations. Small private or industrial landowners usually have more economically-driven objectives.

PAAWS managed for forestry are accessible by extensive road systems. Easy access may result in excessive hunting pressure on certain wildlife such as black bear. Weyerhaeuser has taken steps to limit the impact. Most tracts are gated, hunting pressure is controlled by club leases, bear hunting is excluded from leasing, and key tracts are included in the N.C. Wildlife Resources Commission bear sanctuary system. Anecdotal data indicate that bear populations are expanding, in part due to these actions.

PAAWS include some hardwood flats that are planted to pine or hardwood after natural stand harvest. The wettest hardwood swamps and runs, if harvested, are regenerated by stump sprouts and seedfall back to hardwood. The net effect is a loss of hardwood acreage on industry land. However, this acreage is more than offset by other private lands that often regenerate to hardwood when pine stands are harvested. The recent forest survey for coastal North Carolina indicates that 192,000 hectares of forest lands were converted to other uses between 1974 and 1984 (Sheffield and Knight, 1986). This net loss was for pine and pine-hardwood mix timber types. Conversely, the net area change in pure hardwood forest types for this period was essentially zero. Local habitat changes do occur as industry tries to insure a pine supply from both a shrinking forestland base and a decreasing proportion of pine-type acreage.

Prior to Section 404 regulation, drainage altered hydrology in some wetlands. Some wildlife species were helped by the alteration, others were no doubt hurt by this activity. With water management, canals and ponds provide open water habitat for wood ducks, otter, fish, and other water dependent species in areas that are seasonally limited without drainage or with free drainage. The net effect for wildlife habitat is greater habitat diversity than the natural system.

Economic Considerations of Wetlands Forestry

Forest industry is very important to the North Carolina economy. Compared to all other industries state-wide for 1986, forest products were second in value of shipments ($10.6 billion), third in value added by manufacture ($4.9 billion), second in employment (144,761 people) and second in payroll ($2.5 billion). Within the US, North Carolina ranks second only to California in both forest industry employment and payroll (Levi and Beck, 1989). The proportion of the wood supply in North Carolina produced in wetlands has not been calculated but certainly is significant. For example, 70% of the pulp mill capacity in the state is located in the coastal plain and is highly dependent upon forested wetlands for timber supply (Hutchins, 1989). Softwood saw mills and plywood plants are also concentrated in the coastal plain and rely significantly on wetlands timber. Furniture and hardwood lumber manufacture, concentrated in the piedmont and mountains are the least dependent upon wetlands for timber. Few people, including many employed in the industry, realize the importance of forestry to the North Carolina economy. North Carolina mirrors the situation in all the southern states. In economic importance, forestry is first in 6 southern states, second in 3 states and third in the other 3 (USDA, 1988).

The Emphasis is on Pine Plantations

Why do Weyerhaeuser and most other forest landowners plant pine but very little hardwood? Most all timber usage is pine; for pulp, lumber and veneer. For example, our pulp mills use about 80% pine and 20% hardwood. However, the existing timber inventory in the coastal plain is more than 50% hardwood. In fact, pine growth just barely exceeds the use of pine. Conversely, hardwood growth greatly exceeds hardwood usage. A complicating factor is that harvested stands of either pine or hardwood do not experience the catastrophic wildfires that encourage regeneration. By default, highly competitive stump sprouts of low value hardwoods often dominate regeneration. Therefore, pines must be planted to insure the future supply. Even with the emphasis on pine regeneration, the future supply is not assured. For example, only 77% of the pine stands harvested in North Carolina between 1974 and 1984 and that were retained for forestry have been regenerated back to pine. Tree planting was used for about two-thirds of this area with the other third successfully naturally regenerating to pine (Sheffield and Knight, 1986).

Intensive Forestry as a Business Investment

Why practice intensive plantation forestry? The simple answer is "to provide a continuous, reliable supply of timber to forest product mills at competitive but profitable prices". Intensive plantation culture is the lowest risk system that will do this. It is a relatively new system in the South, dating from the 1950's. Intensive management replaces the "clearcut-and-run" exploitation practices and the resulting "boom-and-bust" cycles that occurred in every timber region in the US, starting in mid-1800's, and which was completed in the South by about 1930. Exploitative practices are consistent with neither environmental stewardship nor with long-term billion dollar investments in mills that cannot be moved to another supply of wood.

Weyerhaeuser has made large investments in timber growing in eastern North Carolina to guarantee a continuous supply of forest products to Company-owned plywood, lumber, pulp and paper mills in Jacksonville, New Bern, Greenville and Plymouth. Logs are also sold to other mills in the area. Timber is grown to generate income, to yield a profit on the timber growing activity, and to supplement other sources of raw material for the wood processing facilities. PAAWS require one of the highest per hectare forest management investments in the US. Roads, water management systems, logging slash disposal and site preparation are more intensive and thus more expensive than on the better drained sites that prevail in most other timber growing regions. However, the extra expense is more than off-set by several factors. First, due to proximity, Eastern North Carolina PAAWS have a transportation advantage for products going to the largest markets in the US and to Europe. Second, PAAWS are efficient producers of wood due to the flatland and excellent road and water management systems. Third, PAAWS that are intensively managed for pine production have the highest timber growth rates of any extensive area in the South. Average pine plantation site index across the South is 15-19 meters (25 year-base), with a mean annual growth rate of 8-10 cm/ha/yr. PAAWS that are intensively managed for pine typically have a site range of 21-24 meters, with a mean annual growth rate of 14-17 cm/ha/yr. These growth rates are exceptionally good compared to plantation growth rates across the South. PAAWS with intensive pine management are from 300 to 600% more productive than were the typical, second growth natural stands of longleaf, loblolly and pond pine that were common to these sites. Intensive management produces economic yields that are competitive with many other investments; extensive management of natural stands is not competitive. Any lands that are privately owned and held primarily for timber production demand intensive management to make an acceptable return on the investment. "There are already competeing demands and widespread dissatisfaction with the low returns from current (i.e. low intensity) timberlands management" .... (privately owned) "FORESTS UNDER LITTLE OR NO MANAGEMENT ARE HEADED FOR EXTINCTION" (Vardaman, 1989).

LITERATURE CITED

Allen, H.L. 1987. Forest Fertilizers: Nutrient Amendment, Stand Productivity, and Environmental Impact. J. For., 85(2):37-46.

Allen, H.L. 1989. Manipulating Loblolly Pine Productivity with Early Cultural Treatment. IN Proceedings of the 7th North American Forest Soils Conference, Vancouver, BC. (In press).

Allen, H.L. and R.G. Campbell. 1988. Wet site pine management in the Southeastern United States. IN. D.D. Hook, et.al. (ed.) The Ecology and Management of Wetlands. Vol. 2. Timber Press. Portland, OR, pp 173-184.

Allen, H.L., P.M. Dougherty, and R.G. Campbell. 1989. Manipulation of water and nutrients - practice and opportunity in southern U.S. pine forests. For. Ecol. and Mgt. (in press).

Bengtson, G.W. 1981. Nutrient Conservation in Forestry: A Perspective. So. J. Appl. For. 5(2):50-59.

Broerman, F.S., T.I. Sarigumba, and M.J. Immel. 1983. Site preparation and slash pine productivity. IN E.L. Stone (ed.), The Managed Slash Pine Ecosystem. School of Forest Resources and Conservation, Univ. of Florida, Gainesville, pp. 131-149.

Campbell, R.G. 1976. Drainage of lower coastal plain soils. IN W.E. Balmer (ed.), Proc. Sixth Southern Forest Soils Workshop. USDA State and Private Forestry Southeastern Area, Atlanta, GA., pp. 17-27.

Campbell, R.G. and J.H. Hughes. 1981. Forest management systems in North Carolina pocosins: Weyerhaeuser. IN C.J. Richardson (ed.) Pocosin Wetlands. Hutchinson Ross, Stroudsburg, PA., pp. 199-213.

Daniels, R.G., E.E. Gamble, W.H. Wheeler, J.W. Gilliam, E.H. Wiser, and C.W. Welby. 1978. Water movement in surficial coastal plain sediments, inferred from sediment morphology. N.C. Ag. Expt. Sta. Tech. Bull. No. 243, 31 pp.

Daniels, R.B., H.J. Kleiss, S.W. Buol, H.J. Byrd, and J.A. Phillips. 1984. Soil Systems in North Carolina. Bulletin 467, N.C. Agr. Res. Serv., Raleigh, NC, 77 pp.

Dougherty, P.M. and C.A. Gresham. 1988. Conceptual Analysis of Southern Pine Plantation Establishment and Early Growth. South. J. Appl. For. 12(3):160-165.

Duzan, H.W., Jr. and C.G. Williams. 1988. Matching Loblolly Pine Families to Regeneration Sites. South. J. Appl. For. 12(3):166-169.

Gent, J.A., Jr., H.L. Allen, R.G. Campbell, and C.G. Wells. 1986. Magnitude, duration and economic analysis of loblolly pine growth response following bedding and phosphorus fertilization. South. J. Appl. For., 10, 124-128.

Graham, F. Jr. 1990. Matchsticks! In Audubon Vol. 92, No. 1, pp. 44-51.

Hazel, D.W. 1976. Deer browse production associated with the practice of site conversion in a North Carolina Pocosin. M.S. Thesis, N.C. State University. Raleigh, NC, 30 pp.

Haines, L.W., T.E. Maki and S.G. Sanderford. 1975. The effect of mechanical site preparation treatments on soil productivity and tree (Pinus taeda L. and P. elliottii Engelm. var elliottii) growth. IN B. Bernier and C.H. Winget (eds.), Forest soils and forest land management. Laval University Press, Quebec, pp. 379-395.

Herrmann, R.B. and W. M. White. 1985. Bates Tract (Jones 5 Plantation) Runoff Character Monitoring and Environmental Impact Studies. Weyerhaeuser Research Report 044-3003. 56 pp.

Hollowell, R.R. and R.L. Porterfield. 1986. Is tree improvement a good investment? J. For. 84(2):46-48.

Hughes, J.H., J.B. Bergman, R.G. Campbell, P. Farnum, R.B. Herrmann, and W.M. White. 1989. Research on the effects of minor drainage and forest management on the hydrology of a forested wetland and biology of an adjacent estuary.

Hughes, J.H. and R.C. Kellison. 1982. Stocking control - silvicultural thinning during the rapid growth years. IN Symposium on the Loblolly Pine Ecosystem (East Region), Raleigh, NC, pp. 136-145.

Hurst, G.A. 1989. Forest Chemicals and Wildlife Habitat. In Forest Farmer, Vol. 48, No. 4, pp. 10-11.

Hutchins, C. H. Jr. 1989. Southern pulpwood production, 1987. Resour. Bull. SE-106. Asheville, NC: US Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 28 pp.

Klawitter, R.A. and C.E. Young, Jr. 1965. Forest drainage research in the coastal plain. IN Irrig. and Drain. Div., ASCE 91 (IR3), Proc. Pap. 4456, pp. 1-7.

Levi, M., and D. Beck. 1989. Forestry information source book. N.C. Agricultural Extension Service loose leaf notebook.

Lilly, J.P. 1981. A history of swampland development in North Carolina. IN C.J. Richardson (ed.) Pocosin Wetlands. Hutchinson Ross, Stroudsburg, PA, pp. 20-42.

Maki, T.E. 1971. Drainage: effect on productivity. Forest Management Tech. Sess., Proc. 50th Anniv. Meeting, Appalachian Sec. Soc. Amer. For.

Mason, D. S. 1989. Private deer hunting on the coastal plain of North Carolina. Southeastern Geographer, Vol. 29, No. 1, pp 1-16.

McKee, W.H. Jr., and L.P. Wilhite. 1986. Loblolly pine response to bedding and fertilization varies by drainage class on Lower Coastal Plain sites. South. J. Appl. For., 10:16-21.

Monschein, T. D. 1981. Values of Pocosins to Game and Fish Species in North Carolina. IN C.J. Richardson (ed.) Pocosin Wetlands. Hutchinson Ross, Stroudsburg, PA. pp. 155-170.

Morris, L.A. and R.F. Lowery. 1988. Influence of Site Preparation on Soil Conditions Affecting Stand Establishment and Tree Growth. So. J. Appl. For. 12:170-178.

Morris, L.A., W.L. Pritchett, and B.F. Swindel. 1983. Displacement of nutrients into windrows during site preparation of a flatwoods forest. Soil Sci. Soc. Am. J., 47:591-594.

Nebeker, T.E., J.D. Hodges, B.K. Karr, and D.M. Moehring. 1985. Thinning practices in Southern Pines with pest management recommendations. USDA For. Serv. Tech. Bull. 1703. 36 pp.

Pritchett, W.L. and N.B. Comerford. 1982. Long-term response to phosphrous fertilization on selected Southeastern Coastal Plain soils. Soil Sci. Soc. Am. J., 46, pp. 640-644.

Ralston, C.W. 1965. Forest drainage. IN Guide to Loblolly and Slash Pine Management in the Southeastern USA. Ga. For. REs. Council Rep. 14, pp. 278-319.

Ralston, C.W., W.H. McKee, Jr., O.G. Langdon, and W.R. Harms. 1982. Prescribed Burning: uses and effects. IN Symposium on the Loblolly Pine Ecosystem (East Region), Raleigh, NC, pp. 154-162.

Sheffield, R. M. and H. A. Knight. 1986. North Carolina's Forests. Resour. Bull. SE-88. Asheville, NC: US Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 97 p.

Skaggs, R.W., J.W. Gilliam, T.J. Sheets and J.S. Barnes. 1980. Effect of Agricultural Land Development on Drainage Waters in the North Carolina Tidewater Region. Water Resources Research Institute Report No. 159, Raleigh, NC. 164 pp.

Terry, T.A., and J.H. Hughes. 1978. Factors related to the growth of intensively managed loblolly pine (Pinus taeda L.) on selected soils in the North Carolina lower coastal plain. Ph.D. Dissertation, N.C. State University, Raleigh, NC, 163 pp.

Terry, T.A. and R.G. Campbell. 1981. Soil management considerations in intensive forest management. IN Forest Regeneration Proc. Symp. Engineering Systems for Forest Regeneration. Am. Soc. Agr. Eng., St. Joseph, MI, pp. 98-106.

Terry, T.A. and J.H. Hughes. 1975. The effects of intensive management on planted loblolly pine (Pinus taeda L.) growth on poorly drained soils of the Atlantic Coastal Plain. IN B. Bernier and C.H. Winget (eds.), Forest soils and forest land management. Laval University Press, Quebec, pp. 351-378.

Timber-Mart South. 1989. North Carolina Stumpage Price Charts. Vol. 14, No.3.

Troth, J.L., R.G. Campbell and H.L. Allen. 1986. Nutrients: Use of Forest Fertilization and Nutrient Efficient Genotype to Manage Nutrient Stress in Conifer Stands. IN T.C. Hennessey, P.M. Dougherty, S.V. Kossuth, and J.D. Johnson (eds.) Stress Physiology and Forest Productivity. Martinus Nijhoff Publishers, Dordrecht. pp 61-99.

US Department of Agriculture. 1988. The South's Fourth Forest: Alternatives for the Future. USDA, Forest Service. Forest Resource Report No. 24. 512 pp.

Vardaman, J. M. 1989. Tree Topics. Vardaman's Green Sheet Newsletter. 15 Oct. 1989. Jackson, MS. 4 p.

Wade, D.D. and J.D. Lunsford. 1989. A Guide for Prescribed Fire in Southern Forests. U.S. For. Serv. Tech. Publ. R8-TP 11. 56 pp.

White, L.P. and W.H. McKee, Jr. 1985. Site preparation and phopshorus application alter early growth of loblolly pine. South. J. Appl. For. 9:103-109.

APPLYING CABLE LOGGING SYSTEMS TO HARVEST WETLANDS

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ABSTRACT

This paper presents the experiences of Forest Engineering Inc. in applying cable logging systems to harvest wetlands. The use of cable systems was considered because of the difficultly of utilizing ground skidding systems for the conditions encountered.

Key Words: Cable Yarding, Wetlands

INTRODUCTION

Forest Engineering Inc. has applied cable harvesting techniques to wetland areas in various parts of the world. We have completed two projects in the United States and one in Canada related to applying cable systems in swamps. We have also completed two projects in Colombia and Papua New Guinea related to applying cable systems in areas considered to be "too wet" for ground skidding systems because of extremely high rainfall.

COLOMBIA

The native hardwood forests of the Bajo Calima concession near Buenaventura, Colombia, receives 7,400 millimeters (290 inches) of rainfall annually. The terrain is similar to the surface of a golf ball with divots from 50-200 meters (164-656 feet) in depth. Roads are built only on the major ridges by clearing the right-of-way to bare ground and then laying down a geotextile, which is covered with a layer of river gravel.

Trees are felled with axes and bucked with chainsaws into 1.5-meter (4.9 feet) lengths. The pieces are then debarked with machetes. The debarked wood is hand-carried (shoulder wood) to a skyline road and stacked in racks of approximately one cubic meter. The falling and debarking crews are paid by the bundle.

Two skyline yarding systems are used to transport the bundles to the roadside. Both systems utilize sled-mounted drumsets and rigged trees for headspars. The first system is a double-drum modified North Bend using a standing skyline (Figure 1).

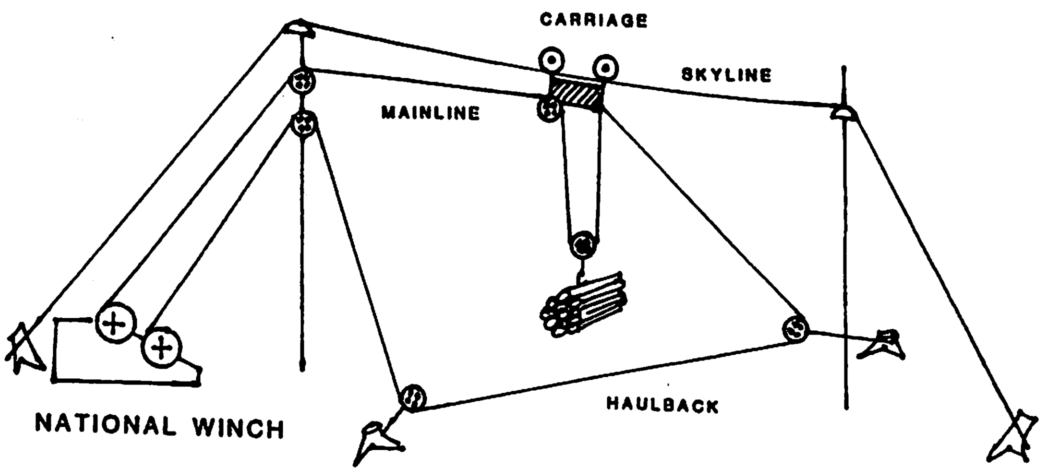

Figure 1. Modified North Bend System.

The simple 44-horsepower National winch is made in Colombia and can yard up to 300 meters (984 feet). Settings are usually fan-shaped with a distance of up to 25 meters (82 feet) between tailholds. The stacked bundles are yarded fully suspended to either a roadway or a swing landing.

The second skyline system utilizes an Iwafuji Y-28 three-drum continuous line yarder rigged in a Tyler configuration (Figure 2). The system is usually rigged as a multispan and also utilizes a standing skyline.

These two cable systems work together to yard single, double, or triple combinations of settings (Figure 3). The swing capabilities of the Japanese winch allow yarding distances of up to 1,000 meters (3,200 feet).

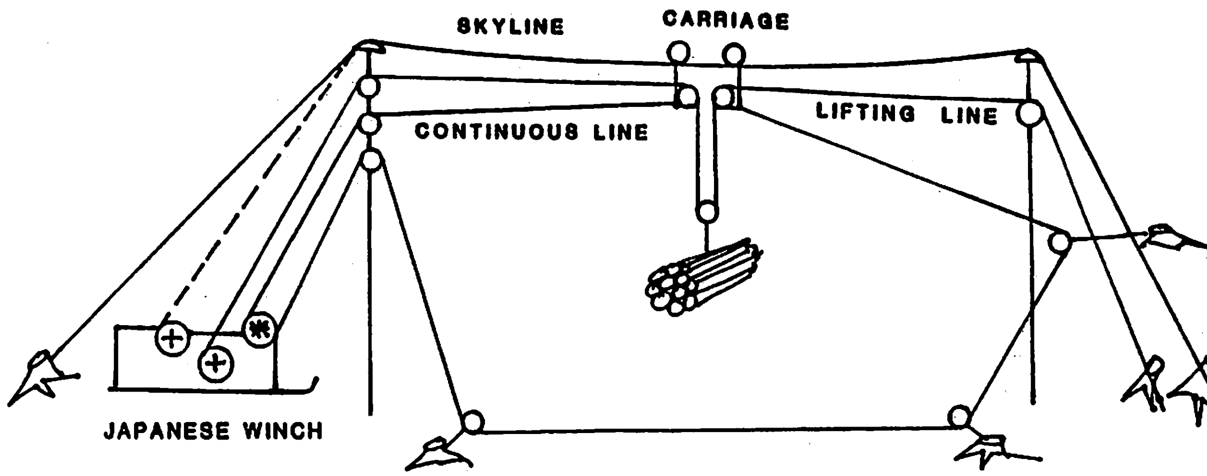

Figure 2. Continuous Line Tyler System.

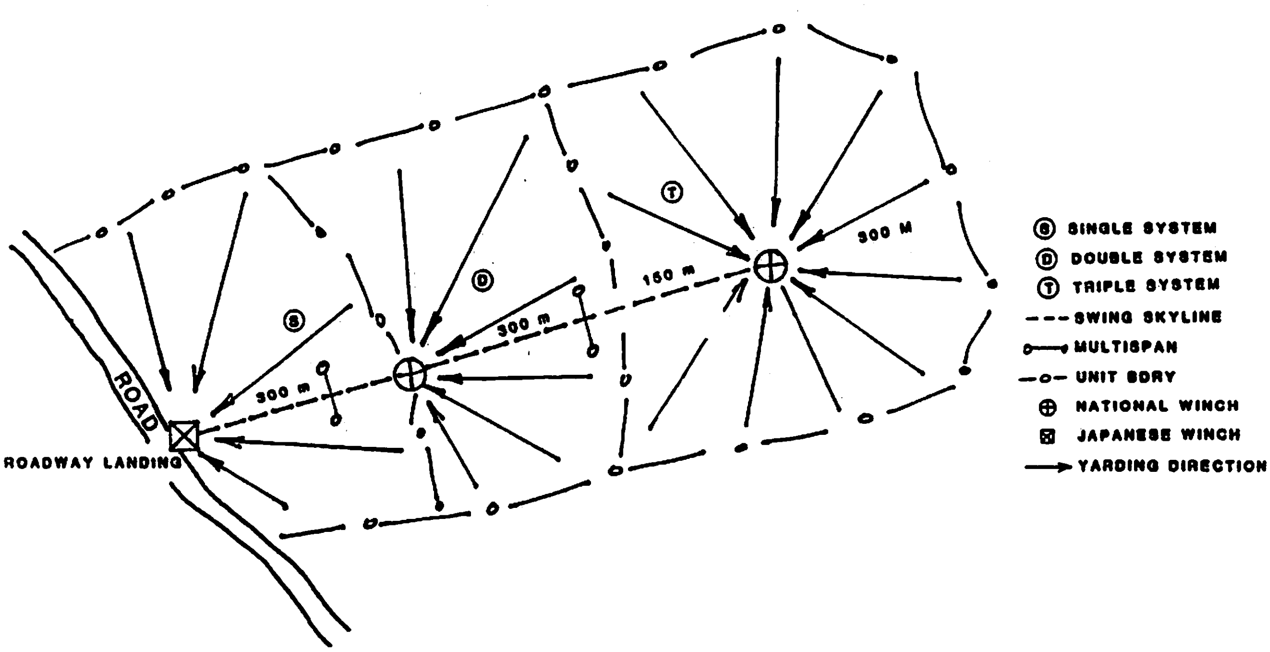

Figure 3. Cable Systems Working in Combination.

OREGON

James River Corporation has a hybrid-cottonwood fiber farm along the Columbia River near Clatskanie, Oregon. Cable systems are one of the many harvesting options currently being evaluated since year-round harvesting is desired.

The terrain is flat with numerous drainage ditches and dikes. The ground is wet six months of the year from November through April. The tree size at harvest is relatively small. The trees at a target age of 6 years will be 18 meters in height (60 feet) and 18 centimeters (7 inches) in diameter at breast height.

Forest Engineering Inc. conducted a field test and evaluation of a small cable machine during the month of July 1990. The objectives of the test were to evaluate equipment and technique while utilizing the hybrid-cottonwood trees for anchors and structures. The equipment was chosen because it was small enough to have a chance of success when utilizing the available trees.

A standing skyline with a double-tree support and clamping carriage was the system used (Figure 4). The distance between the tower and intermediate support was approximately 90 meters (300 feet). The yarder was a Koller K 300 with an optional haulback drum. The haulback allowed it to operate on flat ground up to 215 meters (700 feet).

The carriage was a Koller SKA 1 clamping carriage capable of passing an intermediate support jack (Figure 5). The carriage does not assist in pulling slack, but the mainline can be pulled through the clamped carriage and out to the side by hand. Lateral yarding is typically around 30 meters (100 feet) on each side of the skyline. Ring chokers and a T-bar on the end of the mainline allowed presetting of cable chokers.

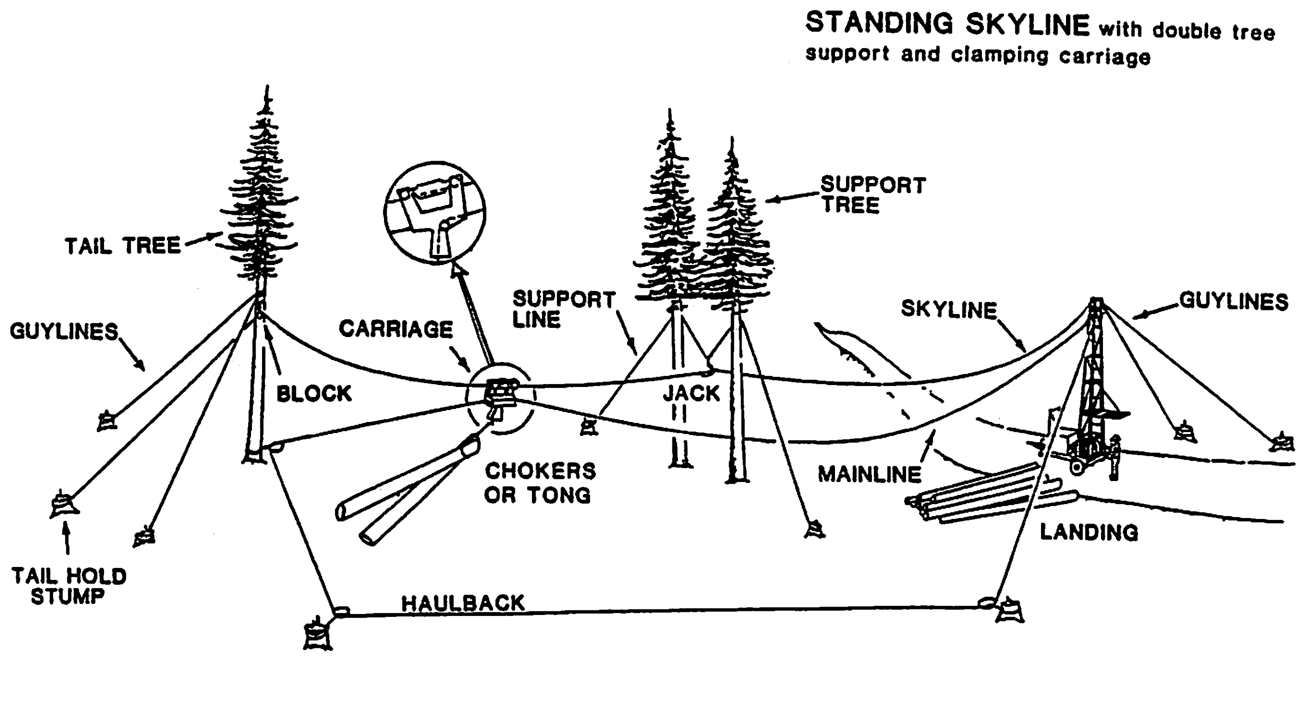

Figure 4. Standing Skyline with Two-Tree Support.

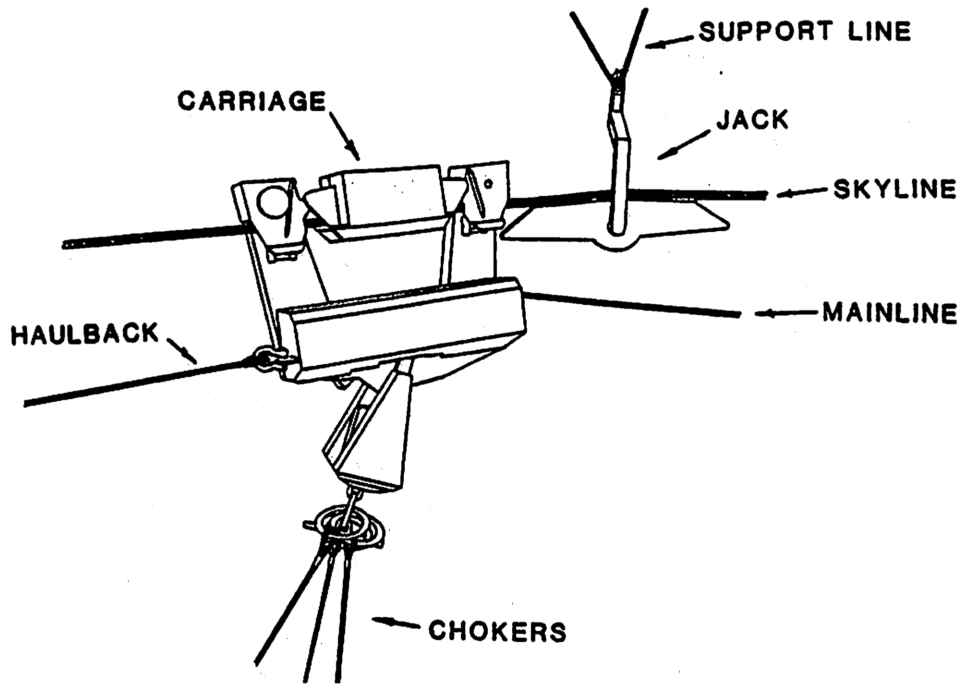

Figure 5. Koller SKA 1 Carriage and Support Jack.

The mainline on a K 300 yarder is only 9 millimeters (3/8 inch). Even with this small line size, it is very difficult for one person to pull line to the side when yarding over 150 meters (500 feet) on flat terrain. To overcome this problem, the haulback was attached to a ring on the T-bar. With the carriage clamped to the skyline, the haulback pulled the mainline and chokers out to the side (side-blocking). This technique only works in a clearcut.

ONTARIO, CANADA

R.K.M. Wood Products, located in southern Ontario, Canada, is a milling firm producing pallet stock and chips. Most of their wood comes from private owners and some comes from conservation lands primarily devoted to water control activities. The timber is predominantly hardwoods with soft maple being the preferred species. Ash and poplar are also present. Forest practice rules dictate that only trees with a diameter of 16 inches or greater, one foot off the ground, may be cut. Harvesting is therefore restricted to systems which can operate in a partial cut.

The terrain is basically flat. Water is on or very near the surface year round. Winter logging with skidders on frozen-snow skidroads can be halted by winter rains without much notice. Some swamps do not freeze because of the heat generated by the decomposing vegetation.

R.K.M. Wood Products started a cable logging program by purchasing and training their rigging and layout crews on a Highland Trailer Alp yarder. Forest Engineering Inc. conducted an intense training program in the use of the equipment.

Engineering layout, rigging and guying of intermediate supports and tailtrees, partial cutting for cable systems, chokersetting, equipment operation, and splicing were covered.

The Highland Trailer Alp yarder has enough drum capacity to yard approximately 300 meters (1,000 feet). It has a 7-meter (23 foot) tower and is towed and powered by a 65-horsepower agricultural tractor.

The Koller SKA 1 clamping carriage was used with the Highland Trailer Alp. Ring chokers and a T-bar on the end of the mainline allowed presetting of cable chokers. A tong was also used very successfully to pull logs out of the mud.

PAPUA NEW GUINEA

Beechwood Pty. Ltd. is considering cable systems as an alternative to their current harvesting methods. Tree-length hardwoods are presently being skidded with FMC 220 Cable Arch skidders up to 1.5 kilometers (4,900 feet). Because of the high rainfall and soil types found, most of the skid roads have to be corduroyed with small logs to enable the FMCs to traverse the ground. Turn times are averaging one hour.

Small bush sawmills are used to break the skidded logs down into "flitches" approximately 7.6 centimeters by 30 centimeters by 7 meters (3 inches by 12 inches by 23 feet). The "flitches" are loaded onto a truck and hauled to the base sawmill for resawing. All haul roads are constructed by hand. Some roads use a fabric underlayment, but most are corduroyed with available poles and split logs. Volcanic cinders are spread over the corduroy material.

In order to determine the suitability of using cable systems, a harvest and transportation plan (Figure 6) was developed for an example area of 1,265 hectares (3,124 acres). The plan indicated the roading system and equipment requirements necessary to harvest the terrain encountered. Skyline payload analysis indicated that structures such as intermediate supports and tailtrees were required due to the gentle terrain with limited chance for deflection.

Since most of the skid roads need to be corduroyed, one advantage of utilizing cable systems is related to the reduction in constructed skid roads. For the sample area analyzed, approximately 19 meters of truck road per hectare (25 feet per acre) would need to be built if cable harvesting were used. Because of the scattered trees, 425 meters of skid road per hectare (580 feet per acre) would need to be built utilizing the current logging practices. Even when considering the differences in standards between skid roads and truck roads, the amount of skid roads required to be built is excessive.

A live skyline system with lateral yarding capabilities was recommended (Figure 7). The system should be able to reach 500 meters (1,640 feet) and have one-end suspension of the turn most of the way. The yarder should be track or sled-mounted to move over primitive corduroyed roads. The tower needs to be at least 14 meters (46 feet) in height.

Because of the rolling terrain, a system utilizing tailtrees and intermediate supports was also recommended (Figure 8). The carriage should have lateral and slack-pulling capabilities and be able to pass an intermediate support jack when necessary.

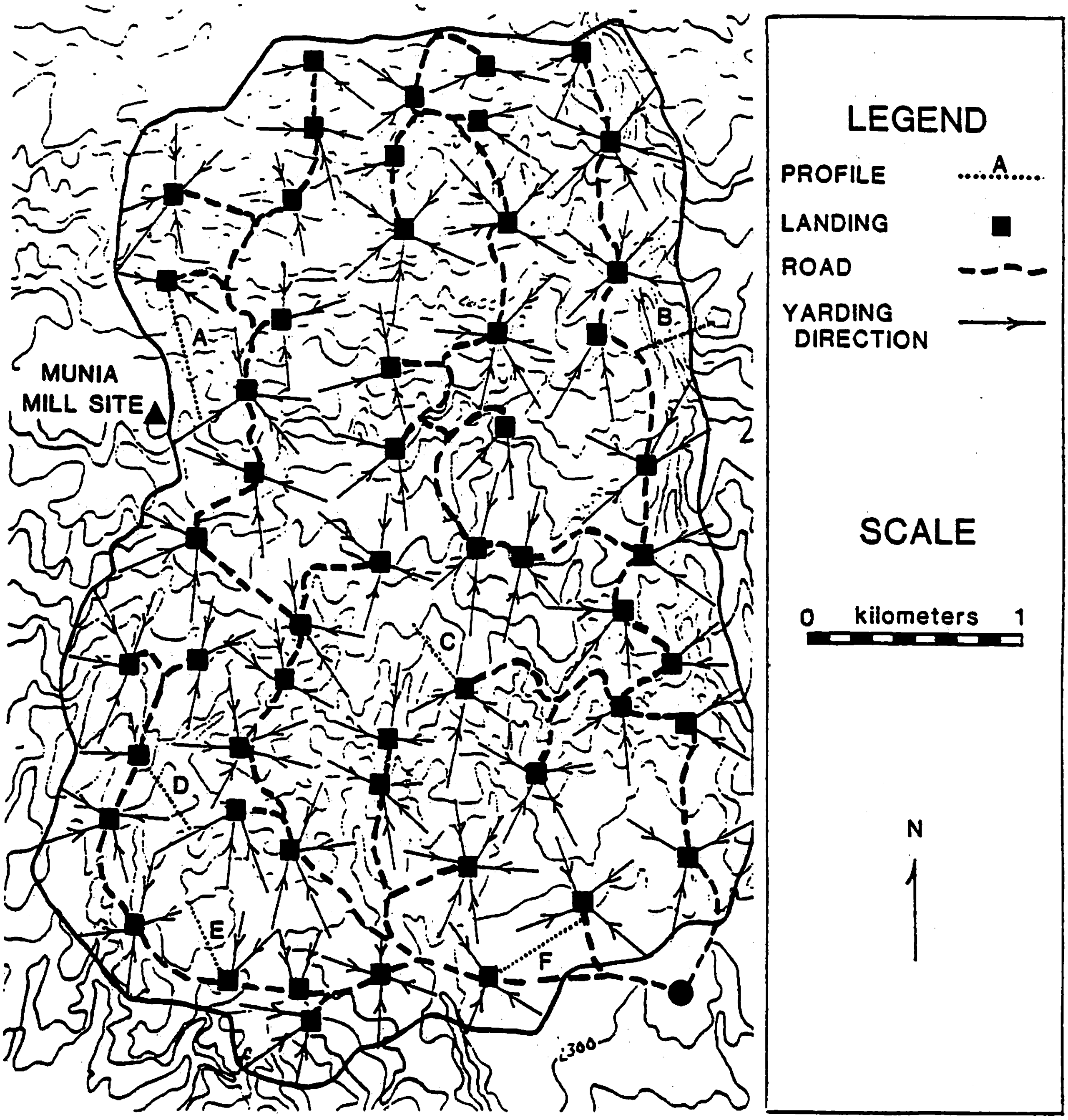

Figure 6. Cable Logging Plan.

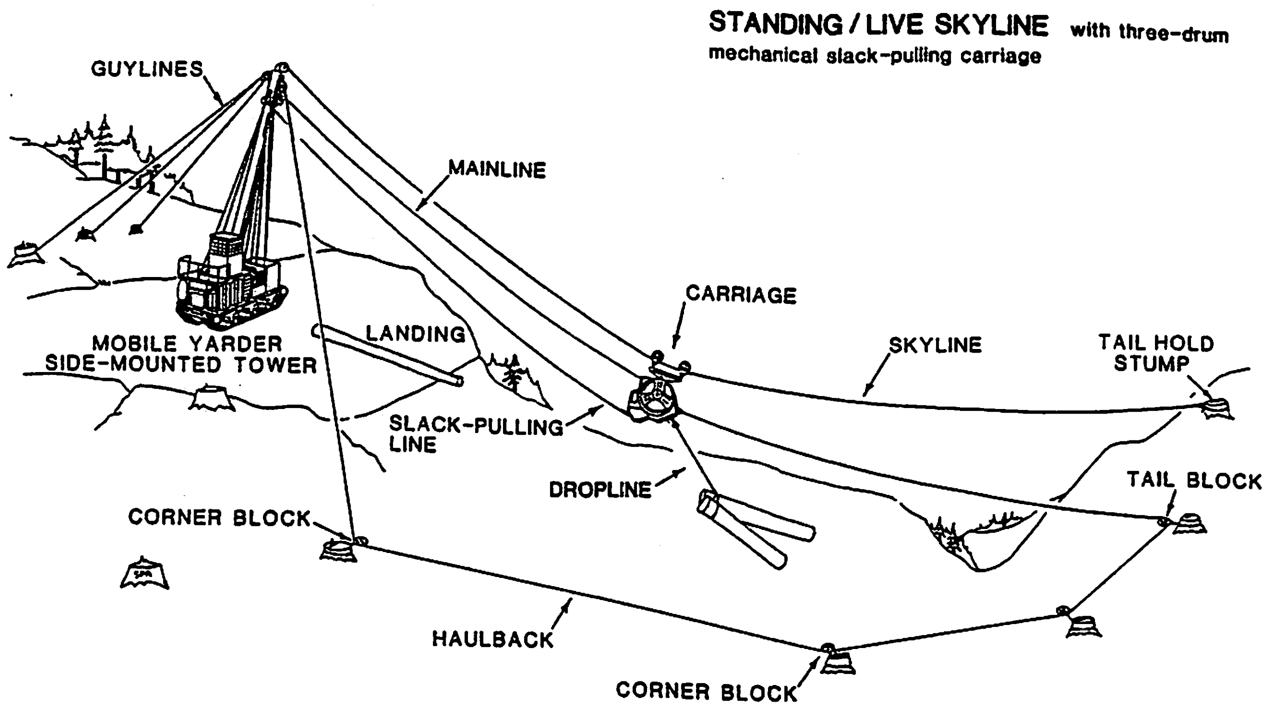

Figure 7. Live Skyline with Three-Drum Mechanical Slack-Pulling Carriage.

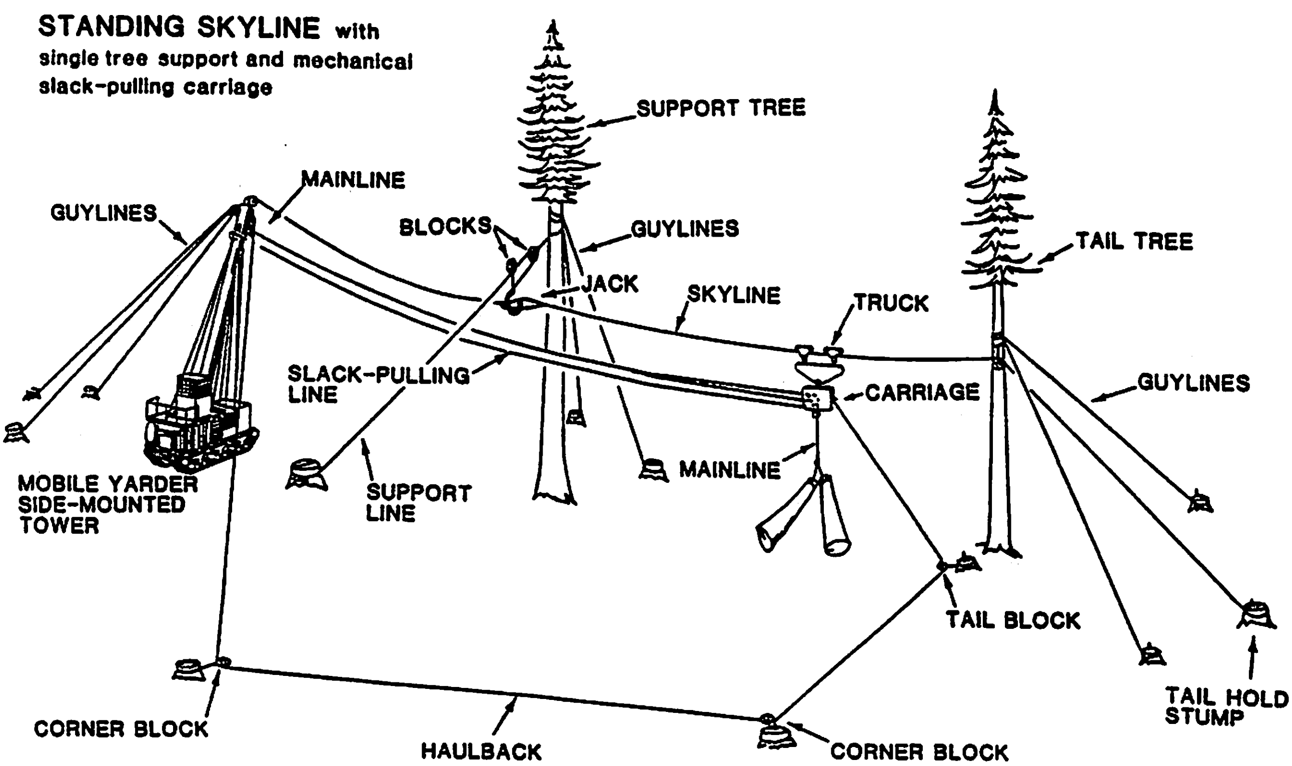

Figure 8. Standing Skyline with Single-Tree Support and Mechanical Slack-Pulling Carriage.

A detailed outline showing the steps in implementing cable logging systems into Papua New Guinea was also provided. Steps in the implementation process included requirements in the areas of harvest and transportation planning, crew training, and equipment selection and acquisition.

SOUTH CAROLINA

In November 1988, Forest Engineering Inc. investigated and evaluated the feasibility of utilizing cable systems in the swamps of South Carolina.

The current skidding methods utilize rubber-tired skidders and FMCs. Chokers, as well as grapples, were being used. Timber is either hand-felled or cut with track-mounted feller-bunchers. The cost to build roads into the swamps is high.

The timber stands are mixed hardwoods, pine, and cypress. Stem counts can be as high as 740 per hectare (300 per acre). Some stands are heavy to sawlogs, but hardwood pulp can run to 135 tonnes per hectare (60 tons per acre).

Two cable methods have a possibility of success in the swamps. Since the topography is flat, there is little or no deflection available. The multispan system described previously (Figure 8) could be used to yard distances of 600 meters (2,000 feet). Several intermediate supports would have to be rigged and therefore the availability of adequate trees would have to be investigated. Another option would be to singlespan short distances of approximately 150-200 meters (500-700 feet) with a running skyline grapple system (Figure 9).

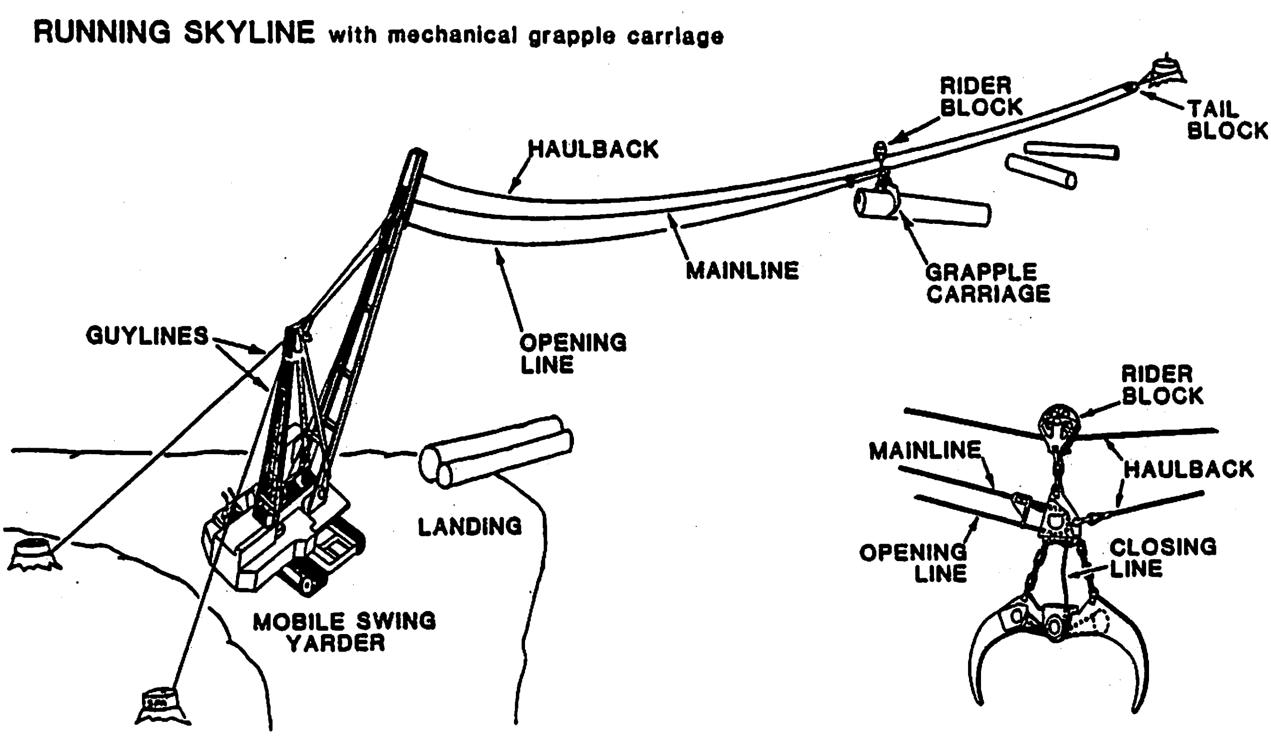

Figure 9. Running Skyline with Grapple Carriage.

This would reduce or eliminate the amount of time workers have to wade through water trying to set chokers under logs. There are some considerations when evaluating cable logging with grapples. If piece size varies and there are a large number of smaller stems, grapples have a difficult time building a optimum turn size. Bunching of small stems is therefore desirable. Since the grapple is very limited in lateral yarding, road changes are made more often than when using a choker carriage. Mobile tailholds might be possible to decrease road changing times as long as there is enough deflection to clear the lines and the system is operating in a clearcut.

Grapple logging productivity is also influenced by the visibility of the yarder operator to see the logs being grabbed. It is important that the operator has good depth perception and can place the grapple accurately.

CONCLUSIONS

Cable systems can be used to harvest wetlands. Special care and attention to anchors and structures are required since the ground is normally saturated. Several cable systems can be used depending upon the conditions encountered.

Because of limited deflection, multispans are a useful tool. As with any harvest system, the need for careful planning is essential for success.

REFERENCES

Aulerich, D. Ed, 1983: Evaluation and recommendations for harvest and transport of Carton de Colombia operations. Forest Engineering Project Report 80.01, Carton de Colombia, Cali, Colombia. 30p.

Aulerich, D. Ed, 1988: Evaluation of harvesting alternatives in the wetlands of South Carolina. Forest Engineering Project Report 138.01, Stone Forest Industries, Orangeburg, South Carolina. 15p.

Aulerich, D. Ed, 1988: Evaluation of harvesting operations for Beechwood Pty. Ltd., Southern Highlands Province, Papua New Guinea. Forest Engineering Project Report 133.01, Alliance Training Association Ltd., Lae, Papua New Guinea. 41p.

Aulerich, Stephen P., 1984: Training of cable logging crews in Ontario wetlands. Forest Engineering Project Report 94.02, R.K.M. Wood Products, Tiverton, Ontario, Canada.

Aulerich, Stephen P., 1987: Training of crews on cable harvesting equipment. Forest Engineering Project Report 80.04, Carton de Colombia, Cali, Colombia. 20p.

Aulerich, Stephen P., 1990: Field test and evaluation of a small cable machine to harvest the lower Columbia River fiber farm. Forest Engineering Project Report 154.02, James River Corporation, Clatskanie, Oregon. 27p.

Cost of Wetland Protection Using Cable Logging Systems

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ABSTRACT

Forest managers, loggers, land-use planners, and other decision makers need an understanding of estimating the cost of protecting wetlands using cable logging systems to harvest timber products. Results suggest that protection costs can range from $244.75 to $489.50 per acre depending on the degree of protection desired.

Keywords: Harvesting costs

INTRODUCTION

Wetlands and wet areas are among our most important natural areas. From a biological perspective, forested wetlands are the most productive wildlife habitat on the continent (Dept. of Fish and Wildlife Resources, 1990). In addition to providing habitat for a wide range of game and non-game wildlife species, these areas also rank as some of the most productive sites for the production of high-quality wood products. Protection of forested wetlands is a top priority with most state and federal conservation agencies. It needs to be a priority in the private sector as well. Protecting forested wetlands involves tradeoffs of wood utilizaton, protection costs, returns to the landowner, and logging costs.

Cable logging technology has been used in the Eastern United States to remove timber from environmentally sensitive steep-slope forest sites. The technology can be used to protect wetlands while removing wood products. Results of time- and-motion studies have provided the production rate and cost estimates for cable logging systems over a range of operating conditions and sites. General costing packages have been developed and integrated with wood value and growth- and-yield projection systems for use in forest planning and decision making. Research also has shown that cable logging systems can minimize timber harvesting effects on forest sites (Patric and Gorman, 1978). Although much work has been completed and reported, decision makers, loggers, managers, and planners need to understand, and have methods for, estimating the cost of wetland protection when using cable logging systems. The challenge is greater for eastern cable logging operations where loggers are operating in a wide range of site and stand conditions in which operating conditions can change not only from site to site but within a given logging chance.

In this study, the costs of protecting a wetland area are estimated for harvesting a mixed hardwood stand using a Christy[1] cable yarder (Figure 1). The Christy is a small, low-priced cable yarder, and the results can be applied to other yarders of the same class in similar applications.

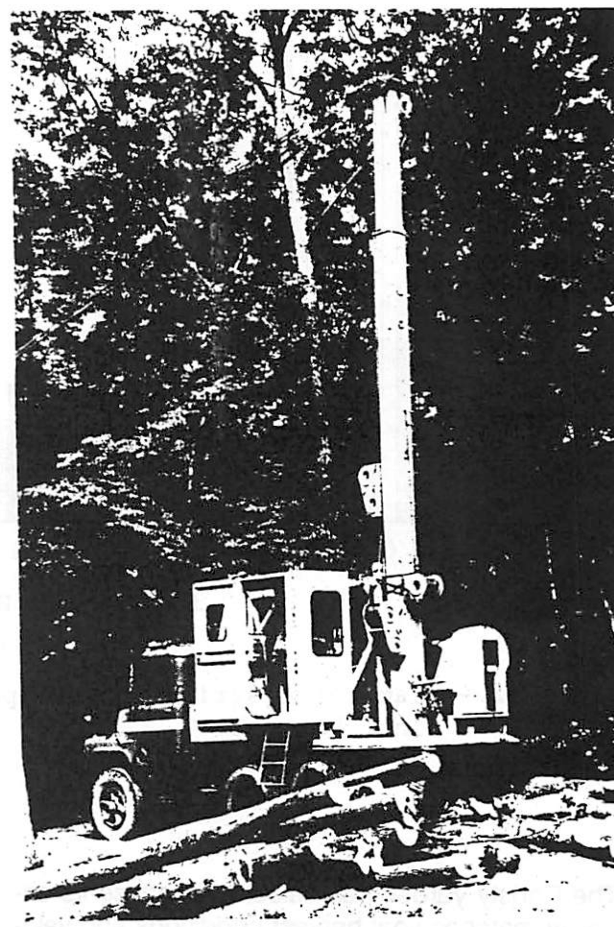

Figure 1.--Christy yarder.

Stand Conditions

The initial stand is a 40-acre mixed hardwood stand that averages 195 trees per acre. The prinicpal species components are red maple, red oak, white ash, hickory, and white oak. The stand has a site index of 60, is 90 years old, with an average tree d.b.h. of 10.2 inches (trees 5-inches d.b.h. and above are included in the average). The stand at age 90 contains 4.5 Mbf/acre of sawlogs and an additional 27 cords/acre of fuelwood and pulpwood (3,317 ft³ total).

The desired silvicultural treatment is to grow the stand to optimal rotation length of 110 years and then conduct a regeneration harvest of the stand. The rotation length is based on maximizing present net value. The stand at age 110 contains 8.7 Mbf/acre of sawlogs and an additional 28 cords of fuelwood and pulpwood (4,290 ft³ total). The distribution by species and 2-inch diameter classes for the 110-year-old stand is shown in Figure 2. The stump-to-mill logging costs were estimated with ECOST (LeDoux, 1985) and time study data for a Christy yarder (LeDoux, unpublished). ECOST is a microcomputer program that can be used to estimate the stump-to-mill cost of cable logging eastern hardwoods.

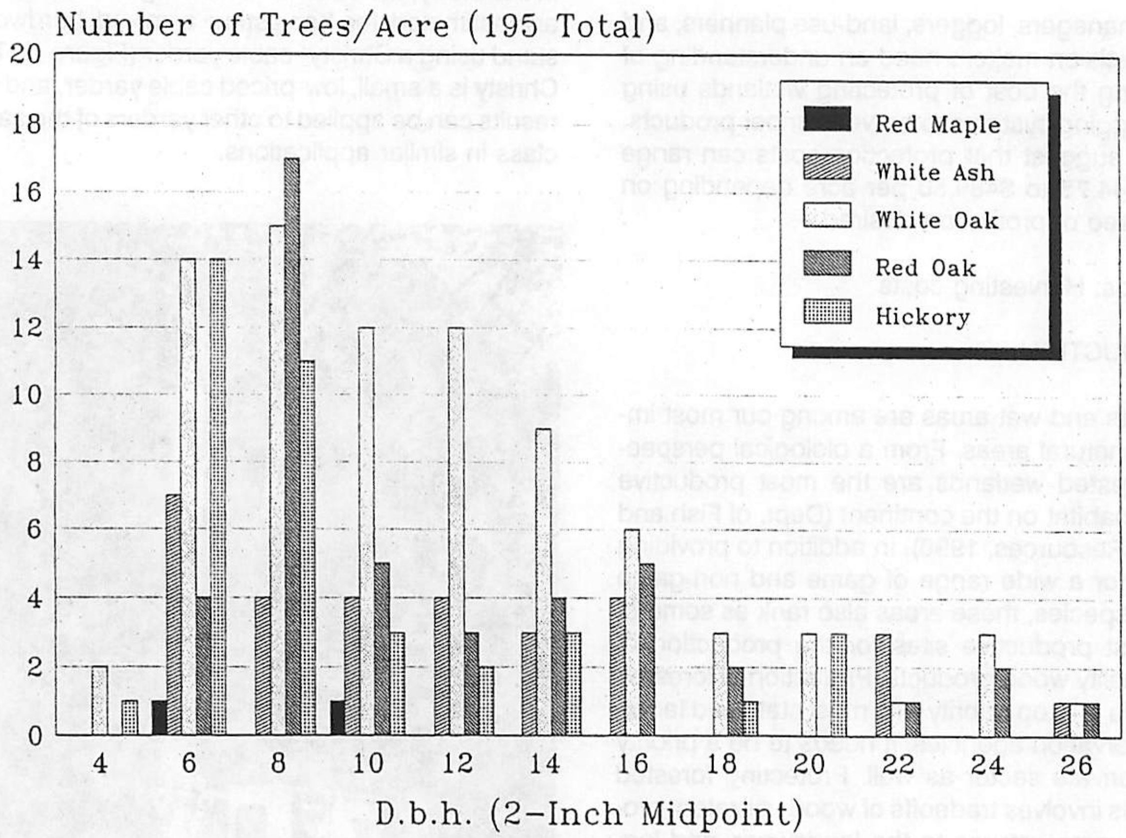

Figure 2.--Diameter distribution by species for the 110-year-old stand at final harvest.

The Christy yarder was selected because its capacity matches final harvest conditions and valuable time study data were available (Sherar and LeDoux, 1989; LeDoux, unpublished[2]). The growth and yield projections, volume estimates, and optimal rotation were estimated with MANAGE

(LeDoux, 1986). MANAGE, a computer program written in FORTRAN V, 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. The model can be used to develop optimal management guidelines for eastern hardwoods. The delivered prices for sawlogs and pulpwood were obtained from Forest Products Price Bulletins and Coastal Lumber Company, Hopwood, PA (Ohio Agric. Stat. Serv., 1989; Pa. State Univ., 1989; Tenn. Div. For., 1989) and are shown in Table 1.

Table 1.--Delivered prices for sawlogs and fuelwood/pulpwood by species.

	Product			
Species	Large[1] Sawlogs	Medium[2] Sawlogs	Small[3] Sawlogs	Fuelwood/[4] Pulpwood
	----------$/Mbf (Doyle Rule)----------			$/Cord
Red maple	210	160	80	30
White ash	500	300	100	30
White oak	500	300	100	30
Red oak	600	350	100	30
Hickory	210	160	100	30

[1]Minimum small-end diameter ≥ 13 inches, length ≥ 10 feet.

[2]Minimum small-end diameter ≥ 11 inches, length ≥ 8 feet.

[3]Minimum small-end diameter ≥ 10 inches, length ≥ 8 feet.

[4]89 ft^3/cord, minimum small-end diameter ≥ 4.0 inches that will not make large, medium, or small sawlogs.

The 40-acre stand is located on both sides of a wet area that includes 10 acres adjacent to a live stream as shown in Figure 3. The objective was to remove timber from both sides of the stream to a landing on the truck road while simultaneously protecting the stream and adjacent wetlands.

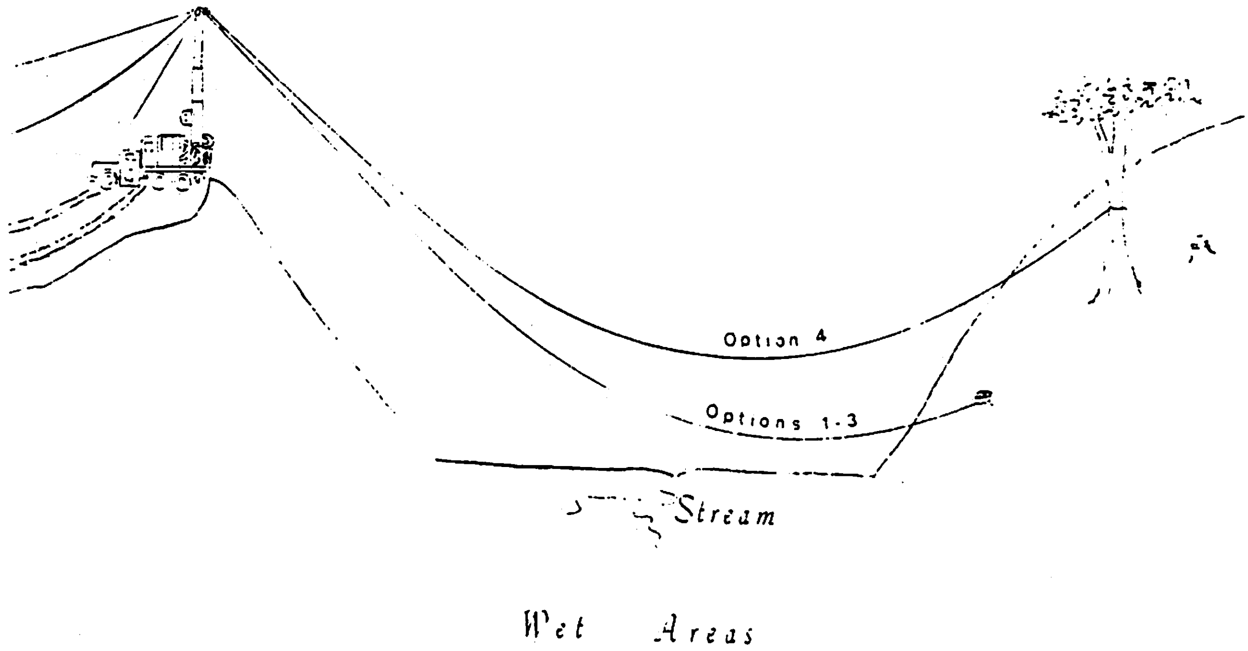

Figure 3.--Harvesting options offering different levels of stream protection.

Stream/Wetland Protection Options

The area would be harvested under an even-aged management plan, harvesting all merchantable timber at the optimal rotation age of 110. The protection options evaluated include: (1) no protection, clearcut the stand and take all the timber; (2) leaving the wet area as a buffer zone on both sides of the stream and not removing any wood from this zone; (3) leaving a buffer zone on both sides of the stream, but selecting some timber from within the buffer zones (approximately 50% of the volume) and allowing logs to drag across the stream and wet areas; and (4) option 3, and requiring full suspension of the logs across the stream and wet areas. A wetland is defined as an area that is periodically wet and flooded, but which dries up during periods of low rainfall, thus allowing trees and other vegetation to grow on the dry soil.

Option 1 affords the least protection to the wet-area and stream but results in the most net revenue to the land owner (Table 2) and the highest utilization of wood in the stand (Table 3). Leaving a portion of the stand as a buffer zone, option 2, removes 42,900 ft³ less wood and results in $19,580 less revenue than option 1. Option 3 removes more wood from the stand and returns $9,790 more to the land owner than option 2. Although option 4 removes the same amount of wood as option 3, the logging cost increase of about 11% reduces the net revenue by $7,977. The increase in estimated logging cost is due to additional bucking of logs to meet full-suspension payloads, smaller payloads, and the additional rigging required to attain full suspension. It is beyond the scope of this paper to detail the bucking, payload, and additional rigging costs incurred. The intent is to illustrate a method that can be used to estimate wetland protection costs and provide representative protection costs for the options specified.

If the value lost to the landowner is interpreted as the cost of wetland protection, then the treatments evaluated result in protection costs that range from $489.50/acre for option 2 to $244.75/acre for option 3 (Table 3). The additional protection of fully suspending the logs over the stream and wet areas, option 4, results in a protection cost of $444.18, which is only $45.33/acre or about 9% less than option 2. However, option 4 takes 21,450 ft³ more wood than option 2. The tradeoffs of wood removal, return to the landowner, protection costs, and logging costs must be evaluated carefully for each specific set of conditions.

Table 2.--Effect of protection option on logging costs.

Item	Protection option 1	2	3	4
	Dollars			
Fell, Buck, Limb	6,530	4,903	5,720	6,892
Yarding	27,221	20,415	23,820	25,773
Loading	6,996	5,248	6,122	7,183
Delay	6,864	5,147	6,005	7,065
Move In and Out	6,863	5,142	5,998	7,729
Haul	28,406	21,305	24,855	25,855

Table 3.--Costs and revenues by protection treatment for harvest of a 40 acre stand at optimal rotation age of 110.

Protection Option	Volume removed (ft^3)	Cost Logging	Revenue Gross	Net	Percent change (Net revenue) From Option 1
1	171,600	$82,880	$161,200	$78,320	0.0
2	128,700	62,160	120,900	58,740	-25.0
3	150,150	72,520	141,050	68,530	-12.5
4	150,150	80,497	141,050	60,553	-22.7

Although MANAGE evaluated only one mixed hardwood stand, cable logging technology, and four protection treatment options, the results show that protection costs can be substantial depending on the level of protection desired. Protection costs also will change with other protection objectives, product values, yarding systems, market locations, crew efficiencies, and many other factors. However, protection scenarios could be easily evaluated by projecting existing stands to optimal rotation age, estimating logging costs and revenues for final or intermediate harvests, and then focusing on the tradeoffs of protection costs, returns to the landowner, and the logging costs necessary to achieve the desired objective. The results can be used to assist decision makers, loggers, managers, and planners in understanding the costs involved in protecting wet areas for several treatment options. The tradeoffs to wood utilization, costs, and returns to the landowner depend on the objectives chosen.

The final decision and end results are up to the decision maker.

Literature Cited

Department of Fish and Wildlife Resources. 1990. Wildlife and Wetlands. Kentucky Happy Hunting Ground. 46 (1): 14-15

LeDoux, C.B. 1985. Stump-to-mill timber production cost equations for cable logging eastern hardwoods. Res. Pap. NE-566. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.

LeDoux, C.B. 1986. MANAGE: A computer program to estimate costs and benefits associated with eastern hardwood management. Gen. Tech. Rep. NE-112. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 7 p.

Ohio Agricultural Statistics Service. 1989. Timber Prices. Columbus, OH: Ohio Agricultural Statistics Service, February, 2 p.

Patric, J.H.; Gorman, J.L. 1978. Soil disturbance caused by skyline cable logging on steep slopes in West Virginia. Journal of Soil and Water Conservation. 33(1):32-35.

Penn State University. 1989. Pennsylvania woodlands timber market report. Pensylvania State University. University Park, PA: April-June. 3 p.

Sherar, J.R.; LeDoux, C.B. 1989. Shift-level analysis of cable yarder availability, utilization, and productive time. In: Proceedings of the 12th Annual Meeting of the Council of Forest Engineering. 1989. August 27-30; Coeur d'Alene, ID, p. 37-40.

Tennessee Division of Forestry. 1989. Tennessee Forest Products Bulletin. Nashville, TN. April-June. 13 p.

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[1]The use of trade, firm, or corporation names in this paper is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

[2]LeDoux, C.B. Production rates and costs of group selection harvests with a Christy cable yarder. Unpublished report on file at the Northeastern Forest Experiment Station, 180 Canfield St., P.O. Box 4360, Morgantown, WV 26505.

DEVELOPMENT OF A RAIL CAR AND WOODYARD FACILITIES

FOR SHIPMENT OF BOTH TREE LENGTH AND CUT-TO-LENGTH WOOD[1]

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ABSTRACT

A rail car and related equipment have been developed for shipment of tree length or cut-to-length wood. This new transportation option extends the flexibility of trucking into rail zones, allowing procurement of wood in the most economical forms. The combination tree length/long log car, developed during a four year program, is now operational and fully approved by the American Association of Railroads and Federal Department of Transportation.

[1] Presented at the Council on Forest Engineering Annual Meeting, Kill Devil Hills, NC, August 12-16, 1990.

INTRODUCTION

Strategic security in the vertically integrated forest products industry relies on consistent planning horizons, technical programs, and management development in a wide range of disciplines. Silviculture, harvesting, pulp and paper technology, and converting operations receive regular attention. Transportation, which forms one-fourth to one-half of delivered wood cost, is seldom addressed with a similar level of intensity.

In the Eastern US, a wood transport infrastructure has developed which operates largely outside the area of influence or control of the forest industry. Services of truck, rail, or barge operators are obtained at arms length, under little if any immediate or long term control of the forest industry managers.

Relatively low transportation costs have been maintained, however, and seldom have perceived risks justified intervention into the system. In fact, forest products adheres to the universal rule in manufacturing: Never enter the transportation business directly, as long as the marketplace provides adequate service. With few exceptions, a surplus of competitive, flexible transport services has been available to meet the changing needs of this industry.

How then, did we justify a four-year development project and tentative plans for a multi-million dollar system of rail yards and specialized cars? The following review of history explains our concern with the current course of rail transportation, and permits weighing the risks of doing nothing against creating a change in course.

HISTORY OF WOOD TRANSPORTATION

Our mill sites have traditionally been selected to provide truck, rail, and water transportation, where possible. Barging, inherently the most cost-effective mode of shipment, extended procurement capability to the limits of navigation, well before modern roads or adequate rail equipment existed (Table 1). Indirect subsidies for highway construction and development of modern heavy trucks during WWII, along with rail rate discounts such as the Roanoke Rapids agreement literally dried up most barging operations.

Railways were called on to furnish large numbers of wood racks for use at numerous small woodyards in the early 1950's. The Southern RR alone turned out over 8,000 units, using lightweight trucks and underframes salvaged from retired gondolas and boxcars. They overbuilt, based on historical car utilization and an expanding market. The resulting car surplus allowed wasteful, inefficient practices to develop in loading, switching and moving, and unloading. As demand continued to increase, intermittent car shortage resulted, largely from poor car management. By 1970, all salvageable components had been consumed, much of the fleet was over 40 years old, in bad need of replacement, and additional cars were needed to meet a backlog of demand.

Facing massive investment costs, it was evident to the railways that substantial rate increases were necessary to meet the additional shipping demand. Some segments of the paper industry resisted these increases and the ICC suspended them. The roads took the stance that rates were then below variable costs, profits were non-existent, and any new equipment investment would be lost.

Under Federal regulations, individual railways could not negotiate rates independently with paper companies which were willing to accept increases. With no other alternative, improved utilization of existing equipment became the focus. Individually and as a unified industry, assigned cars and unit trains were attempted. Car assignment were transferred from a few, overworked railway employees to paper company personnel who could react quickly to production, inventories, and consumption.

Increases were inevitable, and a few railways built

	Truck	Rail	Barge
Fuel Consumption (Gal/Ton-Mi)	0.016	0.003	0.006
Total Freight Cost ($/Ton-Mi)	.07 - .10	.04 - .05	.025 - .03

Table 1. Relative fuel efficiency and approximate cost (1990) of shipping modes.

new, high capacity cars, based on projections of increasing demand and the assumption that profitable rates could be sustained. In 1972, when the roads announced that all traffic must be profitable, the resulting $23 million annual freight increase drew a mixed reaction, including shock from the pulp and paper industry.

Tactics varied from region to region. In the Lake States, 3 to 4 week turn times had become common. Rate increases were viewed as leverage to hasten the demise of rail wood. Car maintenance programs were curtailed, and units were withdrawn from service whenever maintenance was required. Increasingly, the railways viewed shipment of unsecured and often poorly loaded shortwood as a risky and unprofitable business. They began to withdraw. As early as 1969, the Penn Central refused rack cars on its main line.

Some of the South continued to mechanize around 5-foot wood and rack cars, with a shift from numerous small woodyards to high volume concentration yards with slashers. Located on lines with frequent switching service, these yards held inventory to assure consistent shipments, and used bundle buckers, sling loaders, and car toppers to prepare and load racks quickly, securely, and safely. Double handling was reduced by loading set-out slasher trailers in the woods. Later, tandem diesel trucks replaced single-axle gas burners and large grapple loaders replaced the sling loader and car topper. The resulting system is still hard to improve on, where shortwood must be produced in rail zones, if all the required equipment still exists in good, useable condition.

Other Southern mills quickly turned to trucks, abandoning rack cars whenever possible. These mills modernized to accept longwood and tree lengths, first with deck slashers and later with tree length debarking drums. Direct trucking displaced rail shortwood within 100 miles or so. Tree length debarking made this option even more attractive, eliminating the waste, cost, and chip quality loss associated with shortwood handling and slashing.

While this became the most practical and cost-effective option for many mills, which can be supplied solely from a radius of about 100 miles, others consume more wood, or have overlapping procurement zones, where the common drain forces longer hauls. This number continues to grow, as mill expansions are more cost-effective than greenfield construction, and the few remaining greenfield sites are merely areas of low drain.

Several responses have been made by mills in this situation. Many mills have retreated from rail, choosing to truck longer distances, or overcut their traditional truckwood zones. Some built satellite chip mills in rail zones, and others expanded sawmill residue chip procurement. Together, they compete for a limited, heavily utilized chip hopper fleet.

Attempts were made to slash and load 10' wood on rack cars or longer bulkhead flatcars. We found that the slight woodyard savings is approximately offset by a loss of payload, since the stacked bulk density declines with increasing length. In addition, 10' wood causes some glitch in the flume or jackladder of every mill woodyard.

In 1971, Weyerhaeuser found 10 log cars in the N&W fleet, ran successful trials with log length pulpwood, and ordered fifty 65' triple deck cars from Ortner. They hoped to achieve 100-ton payloads, but averaged only 84 tons per load. Nevertheless, this started a trend to haul random length wood and long logs in open-end cars. The American Association of Railroads approved this loading configuration, with publication of Figure 15 in its Open Top Loading Rules. Today, there are approximately 1,500 such cars in fleets of International Paper, Georgia-Pacific, Federal, Potlatch, and leasing companies. Rail lines consider this a "specialty" car, and generally require shippers to provide them through direct ownership or leasing arrangements. Further expansion of the concept has been limited by several reasons, including the following:

- Capital cost per ton for processing equipment is similar for "long logs" and shortwood.
- Operating cost is also similar, unless headcount is reduced.
- The lower bulk density of log lengths results in a very high center of gravity. At 65', a Plate F car must be built of high tensile steel and ballasted with concrete in the center sill to haul 100 tons.
- Integrating long log handling systems with tree lengths or shortwood is clumsy.
- Cars which were designed for long logs are not suitable for tree length wood.
- Tiedown systems are marginal for long log cars, and cushion devices are not used in the underframes.

- Logs occasionally shift due to impacts in transit and may slip by the sideposts.

Since then, the high cost of new railcars coupled with these concerns have deterred shippers from further acquisition of long log cars. Old cars are once again being converted for wood service; this time by refurbishing old bulkhead flats and adding side posts, rather than by salvaging components. Shippers and leasing firms are cooperating to acquire and modify cars, supporting railway fleet reduction objectives.

Back in 1973, International Paper and Pullman Standard initiated a three year development project for a 3-in-one car, called the Blue Ox. The 75' long unit, weighing 84,900 pounds, could move up to 87.5 tons of chips, shortwood, or roundwood up to 50' in length. Although the transportation segment of the concept looked promising, mills were unwilling to commit to the expensive, high volume unloading and sorting facilities required for rapid discharge of the multiple products.

In 1982, Jim Johnson, Director of Customer Service for the Southern RR wrote that the major questions facing the railroads were projected reductions in shortwood and possible transition to longwood. The advantage of expanding longwood drain areas into rail zones, and its market potential for the railways was understood, but not pursued.

The future of our rail service has since become tied to either ownership or leasing of chip hoppers, an aging fleet of technically obsolete rack cars, or second-hand salvage. Meanwhile, our harvesting, trucking, and millyard systems have converted to tree lengths, and European cut-to-length systems are rapidly proving to be competitive and environmentally sound. There has been no concerted, successful effort to extend the flexibility of trucking into the rail zones with "combination" cars which can accommodate both wood forms.

How will this loss of full-service rail capability affect the forest industry? The decline in rail shortwood capability is certain to be most critical when compounded by a construction downturn, when residue chips are in short supply. Meanwhile, pending environmental constraints on logging and increased regulation of trucking operation and safety are likely to dramatically reduce the production consistency of our truckwood. The cumulative cost of doing nothing in preparation for these upcoming changes is anyone's guess.

Satellite chip mills are the popular answer, not that they are always the least cost solution, but because they utilize the only proven technology. It should be noted that with chip mills, someone must also provide new cars, since the utilization of existing hoppers has held constant and high for nearly a decade. In addition, chip mills and rollover dumps run into the millions, while the tree length cars can be loaded at any convenient rail siding with conventional knuckleborns and unloaded along with trucks using a portal crane, by the addition of a sidetrack under the crane. Lower cost facilities are partially offset by the additional cost of combination cars, however, which may be greater than for rollover dump cars.

DEVELOPMENT PROGRAM

In mid-1986, my first involvement in this program was a feasibility study of shipping tree length wood in converted 50' wood racks. Our Wood Harvest Schedule model of plantations showed that the height to a 3" top averages only 37.4 to 37.6' and only 5% of the stems are over 50'. The volume above 50' was only 0.3% of total merchantable volume (Table 2).

A woodyard survey was conducted to determine the same data for wood obtained from various sources. Over 7,600 stems were measured at three rail yards. Five to 15% of stems were over 50'; as shown in Table 3, however, the volume above 50' was less than 0.5% in all cases. This loss compares favorably with slashing 5' wood, where 1 to 2% is lost to kerf and short ends.

Periodically, however, we encounter longer wood, which is topped at 58 - 60', to meet 75' length limits for highway trucks. Here, the use of 50' cars would result in much higher waste. In addition, rack cars

Av. Ht to 3" Top	37.4 - 37.6"
Percent of Stems > 50'	5%
Percent of Vol. > 50' Cutoff	0.3%

Table 2. Average Height of Pine Plantations and Volume above 50' Cutoff

	% Of Stems Over 50'		% Of Volume Lost In Topwood >50'	
	Pine	Hdwd.	Pine	Hdwd.
Swainsboro	4.5	15.4	0.2	0.4
Waynesboro	8.5	11.4	0.5	0.4
Lavely	8.3	0.3	0.5	0.0

Table 3. Percent of stems over 50' and topwood volume above 50' cutoff.

are narrow, have relatively low and light bulkheads, and many have 70 ton load limits.

We considered widening and raising bulkheads and installing three or four pairs of posts, mounted to the sloping floor with widening brackets. Railway personnel felt that chains and tensioners must be used between the tops of each pair of posts to maintain the integrity of side sills and underframes. The necessity for personnel to work atop the loads ruled out this option.

During this time, the centerbeam lumber car began to appear in the South, and rapidly gained acceptance. The railway equipment register confirmed that there were numerous 58' bulkhead flatcars in lumber service which might soon be displaced by centerbeam cars.

Working with the Norfolk Southern, we modified a 58' bulkhead car and ran trials into the Savannah mill. We now had data to show that tree length wood loads to a bulk density of around 25 lbs./cu. ft. versus 35 lbs./cu. ft. for shortwood. A rack car with an effective volume of 4,500 cubic feet could accommodate 80 tons of shortwood, but almost 6,500 cubic feet were required for 80 tons of tree length wood.

Theoretical capacity of the 58' car, at 25 lb./ft., was 67 tons. We achieved 66 tons with hardwood and 72 tons with pine, for a range of 24 - 27 lb./ft. Calculations showed the loaded CG to be around 87" above the rail, 11" below the 98" limit which maintains adequate rolling stability. Norfolk Southern modified another car to Plate F, with posts and bulkheads 15" higher for 18% greater capacity.

While the second conversion was occurring, we learned that unloading 58' cars was a problem. Two dead-stacked tiers could not be separated during unloading with a log stacker or portal crane. Separators reduced payload, occasionally broke, or shifted outside the clearance line, presenting a serious danger to bridges, personnel, and other rail equipment. Since we did not want to limit unloading options to knucklebooms or other mobile grapple loaders, a longer car with greater lifting clearance was required.

The logical choice was a 65' open-end car of the style used to haul 20' and 40' wood. We noted initially that two pairs of stanchions must be removed and the bottom tier limited to 50' or less for unloading this car with a portal crane. Trials with the car achieved loads up to 84 tons, averaging in the upper 70's. Loading was most convenient with the loader on the rail, working through the end of the car. Tall, well-formed wood often resulted in lighter loads than shorter wood, as the center of the car reached the height limit relatively early. The lift point of the top tier was still too close to the bottom tier, indicating the need for an even longer car.

A series of impact tests were conducted with open end cars to determine whether a bulkhead was required to safely contain wood that might shift in transit. Tests followed the AAR procedure of successive 2, 4, and 8 mph impacts, then reversing the car for a final 8 mph impact. The test car was impacted into a buffer car coupled to a string of cars having a specified minimum total weight, all with brakes locked. Results were at first marginal. We removed rubber bearing blocks, which had been installed for pole transport, from the load bolsters. This left a sharp edge which gripped the stems along the bottom of the pile somewhat better. In a "worst case" trial, the top tier of both pine and hardwood loads slid beyond the end of the car upon the 8 - 9 mph impact. Our last hopes for the open-end car concept ended with this test.

A skeleton-frame bulkhead car seemed the next logical choice. Manufacturers advised that it would be impractical due to weight and cost, that the frame could not withstand bulkhead forces, and that the design was a new and untried concept. If declared "new and untried" by the AAR, the design, construction, and mandatory testing of a sample car would cost $750,000 to $1 MM, with no guarantee of success. In addition, there were fears that years of empty miles at slow speed with the bulkheads wagging would create latent fatigue in the "fish belly" sill ends resulting in massive frame failures. When we confirmed that the concept was actually new and untried, it was obvious that the time, cost, and risk of structural failure ruled out this option as well.

It is apparent that a conventional, fully-floored car with center sills and full length side sills was the remaining option. Up to this point, proposals for a fully-floored car were considered suboptimal, on the basis that a full floor and side sills added unnecessary weight and vulnerability to grapple damage during unloading.

In order to gain operational experience and loading approvals for this configuration, we requested assistance from CSX to refurbish and modify four old 70' bulkhead flats. CSX agreed to support our development work and provide cars. With their expertise behind the project, cars were soon in service between our Nashville, NC woodyard and Franklin, VA mill. In addition, nine test loads were shipped over 500 miles from Georgia to Virginia. AAR personnel documented the load positions at each end to determine the extent of load settling and shifting. No unsafe exceptions were noted, and the loading configuration was approved in February, 1990.

For convenience of construction, posts were installed on the CSX cars at locations of existing crossmembers. As a result, the configuration allowed loading with tree length wood, but not random lengths.

Our next objective was to develop and prove a combination car. Two railcar manufacturers, Gunderson and Bethlehem, offered to design and build a prototype car according to our configuration and dimensions. Ultimately, Bethlehem Steel Freight Car Division and Union Camp entered into an agreement for construction of a car for delivery in early 1990.

Preliminary design work showed that full length side sills and floor actually minimize weight and cost, as well as the risk of structural failure or wood falling through to the rail. The floor acts as a top flange for the center sill in this design, as well as acting as a web between the side sills forming a channel beam, thereby controlling both vertical and side loading. The full length side sills also control bulkhead forces, balancing them with static loads in the span between trucks. Full length side sills also carry much of the draft and buff forces away from the center sill.

Our prototype included features and accessories which address every concern raised during the conceptual phase of design. Full bulkheads and floor, wrap-around bulkhead sheets, constant tensioning winches to accumulate and lock in slack that forms as loads settle, remote hook releases for tiedowns, bulkhead caps designed for use as a loading bench, hourglassed geometry for maximum load space, and a configuration suitable for both tree length and log shipment. Three patents related to the car, constant tension winch, and remote hook release are pending. The car design has been fully approved by the AAR and Federal DOT. Light weight of the car is 79,300, providing a load limit of 183,700 based on the normal 263,000 gross rail limit for 100 ton trucks.

RESULTS AND EXPERIENCES

Payloads with the modified cars have ranged from 27 to 28 cords (81 to 84 tons). The prototype, with slightly more cubic volume, has ranged from the low 80's to over 100 tons, averaging in the upper 80's, or around 30 cords.

Loading with a Prentice 410 or equivalent machine generally takes about 40 minutes. Unloading with a portal crane takes 6 to 8 minutes. A net lifting capacity of 47 to 50 tons and a grapple with 75 - 80 sq. ft. of area are ideal to consistently unload in two lifts. With our 40-ton crane and 70 sq. ft. grapple at Franklin, we occasionally can't reach around or lift an unusually big tier.

At first we had problems with intermingled tops pinching when lifting the upper tier. A temporary shipping point was set up in the mill railyard, wood was loaded, shuttled, and unloaded continuously for two days. A separator of heavy conveyor belting, chained to the car at one end, was tried. No significant problems were encountered with or without it. We learned to lift before closing the grapple and "boiling" the wood when possible, and pinching has not been a problem since.

Our four modified cars have been in operation almost 1-1/2 years, and the prototype 6 months. In addition, we are looking at existing cars which could be modified. Design engineering and a finite element stress analysis have just been completed for modification of a group of 100 ton bulkhead flat cars which have substandard bulkheads. Color plots were generated by a CAD system, mapping stress levels in the bulkhead and frame at four stages in the design of structural reinforcements. The final design has been accepted and is being submitted to the AAR for approval. Purchase of the sample car is progressing, and a contract is being prepared for the modification.

EXPECTATIONS AND CONCERNS

An extensive transportation analysis was conducted prior to making sourcing decisions for our recent mill expansion at Eastover, SC. This included satellite chipping, shortwood, and tree length wood, by truck or rail. Tree length rail appears to have a cost advantage over other modes at several locations, generally beyond 120 miles, and on the CSX, where rolling stock must be provided by the shipper. These sites which favored the tree length rail option tend to be the most distant, however, with comparatively high freight cost by all modes. It may be difficult to justify sustained shipments from some such points, in order to maintain high car utilization.

It is also probable that the tree length rail system is at greater risk than rail shipment of chips from a satellite mill. Many mills cannot substitute tree length truckwood for chips, due to limited millyard capabilities. In many cases, however, direct truckwood can be substituted for tree length rail, at a significant "direct cost" savings. If this is allowed to happen, and car utilization declines significantly, freight cost per ton will increase due to fixed costs of ownership or leasing. This can have a domino effect, further reducing the utilization, if procurement strategy is based on minimizing variable costs, rather than total cost.

Will the ROI and benefits from this system justify the risks of the venture for the shipper who developed it? Return on equity for railways has averaged 5.9 and 5.7% for the last two years, far below forest industry hurdle rates for capital investment. Can it weather the uncertainties of rail service? Will the continuing shift from rack cars to direct truckwood result in a surplus of serviceable wood racks at a bargain basement price which washes out our ROI? Will we shift to managing transportation by total cost and achieve good car utilization, or continue managing by direct cost and use these cars intermittently?

The "combination" car has the highest tare weight of any wood car ever built, other than the Blue Ox. It is a fairly labor intensive design, and while volumes are low, it's unit cost may be greater than it's chief competitor, the chip hopper. Will savings in other areas of the system offset these disadvantages? How will car maintenance compare with bottom drop hoppers and rollover dumps?

SUMMARY

From a fledgling innovator's point of view, development of a railcar by a shipper has been a rather interesting and frequently puzzling experience. You are an individual designing for a committee, requiring that everyone's concerns are somehow addressed. The only direct and clear guidance comes from those whose opinions, however well intended, don't control the destiny of the project. In today's world of liability, no railway or railcar personnel can provide direct guidance beyond interpretation of industry standards and regulations, lest some unpredictable event leave "blood on his hands". They can only tell you what not to do. Sometimes no alternative remains, and you must bet on achieving a majority vote of the ruling committee, over a minority concern. An extremely conservative and thorough approach is required, stressing high degrees of reliability and safety. While it may look simple, railway equipment is developed and operated in an extremely complex, formal environment. Reducing this complexity to the simplicity of a serviceable, durable car is quite an exercise.

FORESTRY SYSTEMS ANALYSIS AND MANAGEMENT

THE ROLE OF GIS IN INDUSTRIAL FOREST RESOURCE INFORMATION MANAGEMENT

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ABSTRACT

During the 80's, forest industry in the U.S. has steadily increased its use of and reliance on geographic information systems (GIS) for providing accurate, up-to-date resource information for making a variety of forest management decisions. Integrating the spatial dimension into their inventory and planning is vital to stay abreast with the current demands made by the public for multiple use planning and compliance with state and federal laws governing landuse and environmental protection. Use of GIS is the most efficient tool for managing the large amount of site-specific resource information, and is sometimes the only means by which complex environmental analyses can be made. This paper presents the results of a survey of GIS use by U.S. forest industry and describes several GIS-based applications currently being used.

Key Words: Geographic information systems (GIS), Forest industry.

INTRODUCTION

For the forest industry in the U.S. and Canada, geographic information systems (GIS) are playing an expanding role in woodlands resource information management and planning. During the 80's, GIS was thought to be just another fad or "buzz word" that would quickly fade. Today, however, "the entire forest industry is moving toward incorporating the spatial dimension into inventory and planning" (Wientzen, 1990). Lower hardware costs, improvements in GIS software, and increased availability of digital data have contributed to the increased use of GIS technology, but the real reason for the rapid growth of GIS-based resource information systems is its ability to deal with the changing resource planning environment. Traditional tabular database systems simply can not handle the complex spatial analyses required for comprehensive planning. In the 90's, the demand for multiple use planning and compliance with a variety of state and federal laws regulating land use and environmental protection will only increase.

For many forest-based industries, GIS is already a vital tool for handling the large volume of detailed inventory data and other stand-related information needed for more intensive forest management. The justification for investment in and the initial use of GIS for some companies was based solely on map production. However, shortly after the land base is digitized and the database constructed, the process of developing more sophisticated GIS applications begins. The development process will continue to grow as GIS becomes an integral part of the firm's decision support process. Sieg and McCollum (1988) argue that integration of GIS with other decision support software makes justification of these systems easier and improves their overall usefulness.

Unfortunately, complete integration of GIS and with the existing information management system is an ongoing process that can and usually does take many years to complete. For Weyerhaeuser, integration over the past 15-20 years has become so complete that GIS and Forest Inventory are "inextricably linked . . . for the simple reason that it provides the most efficient and effective means of collecting, storing and distributing the timberlands management information demanded by the total organization" (Wakely 1987). For Great Southern Paper Company, Read and Raber (1989) state that the benefits of GIS "reside in four categories of work that are now mainly manual functions." These can be summarized as: mapping, record keeping, planning, and special projects. Although the mapping and record keeping functions are vital to the overall system, the most important applications of GIS are in the areas of planning and special projects.

The realization that GIS is much more than "automated cartography" has caused many diverse groups to take notice, particularly in the field of natural resource management. Successful applications of geographic information system (GIS) technology are, in essence, decision support systems (DSS). This important difference is underscored by Cowen (1988), who states, "GIS can best defined as a decision support system involving the integration of spatially referenced data in a problem solving environment." Others suggest that GIS must evolve from an inventory tool to an analysis tool, and then ultimately to a management tool (Crain and MacDonald 1983). This process of evolution and integration of GIS into the existing decision support system is currently taking place for many forest-based companies using GIS.

This paper presents the results of a recent survey of GIS use by U.S. forest industry which highlights the trend of integrating the spatial component into the traditional information management systems. Several applications of how these companies are using GIS are also presented.

FOREST INDUSTRY SURVEY

A survey of 30 major U.S. forest industries was conducted in mid 1990 to determine how GIS fits into their companies' resource information management system. The survey focused on large forest-based companies owning 100,000 acres or more that were known to have existing or recently acquired GIS systems. Collectively, the American Forest Council lists 81 companies owning more than 100,000 acres and estimates that the total forest industry ownership is approximately 69 million acres in the United States (American Forest Council 1988). The combined ownership for the 30 companies in this survey amounts to 49.7 million acres, or approximately 72 percent of the total industrial ownership. Several companies, however, have not completed digitizing all of their land base. Roughly 59.6 percent of the forestland owned by these companies is currently included in a GIS database. Recent mergers/land acquisitions, new installations of GIS systems, conversion to new software, and hardware upgrades have slowed the process of digital database construction.

Some of the 30 companies in this survey have separate subsidiaries or regional locations that operated independently from the main corporate computing facilities. Consequently, some companies provided data on GIS involvement for the whole corporation rather than broken down into regional facilities. Whenever a subsidiary or regional facility operated separately, the survey data provided were listed as a separate company. Although the main purpose of the survey was to determine how GIS was integrated into their resource information management system, specific GIS applications using GIS, and general background information about their GIS system was also obtained. This included:

1. Years of Experience with GIS;
2. Full-Time Personnel involved with GIS;
3. Hardware specifications;
4. Software specifications; and
5. Current applications of the GIS system.

The survey results, summarized in Table 1, indicate a broad range of GIS use. Although grouping was subjective, three distinct classifications became apparent when the 30 companies were compared in terms of how completely GIS is integrated with other inventory/resource information and decision support software. As shown in Table 1, the three classifications are fully integrated, partially integrated, and no integration.

Fully Integrated

Nine of the companies surveyed indicated that their GIS system was fully integrated into the resource management information/decision support environment of the company's operations. Forest ownership averaged 2.9 million acres for these nine companies. Typically, the companies in this category had more years of GIS experience (9.9 years); more personnel working with the GIS system (12 full-time individuals); one or more minicomputers (DEC VAX, Data General or Prime) and several microcomputers with graphics capabilities; and more sophisticated GIS software (Arc/Info, Intergraph, or software developed in-house).

Well-developed applications, sophisticated analyses, and full integration into the management information/decision support process distinguished these nine companies from the others surveyed. These companies also appeared to be continually

Table 1. Integration of GIS/DSS for 30 forest-based industries.

	Degree of Integration		
	Fully	**Partially**	**None**
Number of companies	9	11	10
Average GIS experience (yrs.)	9.9	4.7	1.2
Average number GIS personnel	12.2	3.9	1.7
GIS hardware	mini & micro	micro & mini	micro & mini
GIS software*	Arc/Info Intergraph In-House	Arc/Info GeoBased Intergraph	Arc/Info GeoBased

*Mention of trade names is for information only and does not imply endorsement by Virginia Polytechnic Institute and State University.

developing new macros/applications for a variety of in-house clients ranging from field foresters to upper management. In addition to the routine GIS functions of map production and inventory maintenance/update, many of these companies have developed specific macros in the following areas:

- Harvest Planning/Scheduling
- Forest Management Planning
- Long-Range Inventory Growth and Yield Projections
- Transportation Planning
- Road Maintenance and Design
- Wildlife Habitat Evaluation
- Environmental Risk Assessment
- Soil Type Mapping
- Machine Operability Guidelines
- Strategic Planning (i.e., Land Acquisitions, New Mill Locations, and International Supply/ Demand Analyses)
- Corporate Accounting
- Tax Record Maintenance
- Stand History on Fee Lands
- Integration with SPOT/LANDSAT Imagery

Partially Integrated

Eleven companies indicated that their GIS system was partially integrated with their company's resource information system. Quite often, companies in this category were preoccupied with digitizing the balance of company ownership, converting to a new software system, redesigning their tabular databases, or upgrading their GIS hardware. Average ownership for the eleven companies was 710,000 acres of forestland. As Table 1 indicates, these companies typically have less experience with GIS (5 years); fewer full-time personnel (3.9); hardware configurations tended more toward microcomputers (Compaq 386) for primary processing and minicomputers; and a slightly different mix of GIS software (Arc/Info, GeoBased, and Intergraph) than the companies classified as fully integrated.

Most of the companies in the partially integrated category were aggressively integrating GIS into their other resource management system and developing decision support linkages. In addition to map production and inventory maintenance/update functions, the GIS was used for:

- Harvest Planning/Scheduling
- Forest Management Planning
- Soil/Fertilization Mapping
- Strategic Planning
- Environmental Assessment

No Integration

Many of the ten companies in this category have recently acquired a GIS and were heavily involved in digitizing the new land base, constructing the database, and learning how to use their system. In terms of size, the average acres of forestland (i.e., 686,000) owned by these companies was only slightly less than the previous category. These companies have fewer years of GIS experience (1.2); fewer number of GIS personnel (1.7); utilize more microcomputers (Compaq 386) than minicomputers; and use more PC-based software (Arc/Info, GeoBased, etc.) than the companies in the previous two categories. At least initially, map production and database maintenance/update functions are the primary uses of the GIS system, and will obviously take precedence over development of specific applications.

CONCLUSION

The results of the forest industry survey highlight the trend toward expanded use of GIS by the forest industry. In addition, the rate of GIS acquisition by forest-based companies that has occurred in the past three years indicates the importance of GIS to their resource information system. In the past year, over one-third of the 30 companies surveyed have or are currently in the process of upgrading either the software or hardware supporting their GIS system. To successfully integrate GIS with existing company inventory databases and other decision support models requires (1) a long-term commitment of several years; (2) financial commitment for development personnel and the hardware/software configuration capable of sophisticated analyses; and (3) management commitment, at all levels, to using a GIS-based decision support system.

If the last decade is any indication, it is obvious that forest industry will continue to operate in a "changing environment," and forest resource planning in the 90's will be both interesting and challenging times. I feel GIS will play an important role in resource planning because it allows us to evaluate large amounts of site-specific data and perform complex spatial analyses. GIS is not the solution to our problems. It is simply a powerful tool that can help to better analyze the problem and improve the quality of forest industry's resource planning effort.

REFERENCES

American Forest Council. 1988. National survey on forest management and remote sensing. American Forest Council, 16 pp.

Cowen, D.J. 1988. GIS versus CAD versus DBMS: What are the differences? *Photogrammetric Engineering and Remote Sensing* 54(11):1551-1555.

Crain, I.K. and C.L. MacDonald. 1983. From land inventory to land management. The evolution of an operational GIS. *Proceedings, Auto Carto VI,* Vol. 1, pp. 41-50.
Read, J. and B.R. Raber. Developing a cost effective multi-resource base map for forest management applications. *Proceedings, GIS/LIS '89,* Nov. 26-30, Orlando, FL, Vol. 1, pp. 211-220.

Sieg, G.E. and M.P. McCollum. 1988. Integrating Geographic information systems and decision support systems. *Proceedings, GIS/LIS '88,* Nov. 31-Dec. 2, San Antonio, TX, Vol. 2, pp. 901-910.

Wakely, R. R. 1987. G.I.S. and Weyerhaeuser - 20 years' experience. *Proceedings, GIS'87.* Oct. 26-30, San Francisco, CA, Vol. II, pp. 447-455.

Wientzen, B. 1990. Great Northern Paper: Managing a forest with GIS. *GIS World* 3(2):31-33.

ESTIMATES OF LOGGING EQUIPMENT SALVAGE VALUES

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ABSTRACT--Prices for used logging equipment were collected from various sources and compared with the original sales price based on equipment age, condition, and geographic region. The data were summarized in tabular form, and used to estimate regression equations for overall salvage value percentages by age of equipment. Salvage values were generally greater than those which are commonly reported and used in the literature.

INTRODUCTION

Equipment salvage values are often used to help estimate overall machine costs for timber harvesting equipment and trucks. Salvage values of forest harvesting equipment influence many of the purchase/replacement/budgeting decisions made in the logging industry. The residual value of a piece of equipment, whether at the end of its useful life or at some age before, will affect cash flows, rates of depreciation, maintenance and repair decisions and new and used machine purchase decisions.

Estimates of the residual value of machines usually rely on rules-of-thumb developed by a number of authors or on expert judgement. These estimates usually range from 15 to 25 percent of the original sales value of the machine. The values represent a machine's value at the end of its useful life, generally around 4 to 6 years depending on the type of equipment. However, machines often last beyond the expected life or are resold before their normal economic life has ended. Additionally, costs for new equipment have increased substantially in recent years, which may affect salvage values as well. Salvage values also only estimate the value of equipment at the end of a specified life span. More information on resale values in other years or by condition of equipment or by geographic region also would be useful. Accordingly, this study estimated current resale values for logging equipment based on price data gained from various sources.

PRIOR ESTIMATES

Most authors have used a constant rule-of-thumb to estimate the salvage value of a piece of equipment, based on its life and orignal purchase price. Warren (1977) and Hypes and Stuart (1979) used varying percentage rates for estimating equipment salvage values, which were also relied on by Cubbage (1981). Miyata (1980) recommended that salvage values should be 20 percent of the initial price. Based on the higher new equipment prices, which made used equipment more valuable, Werblow and Cubbage (1986) recommended that 25 percent be used as an estimate of salvage value. In 1989, Brinker et al. published a summary table on the typical salvage

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values for forest harvesting equippment and life spans (Table 1), based on the Warren (1977) and Hypes and Stuart (1979) and Cubbage (1981) salvage value estimates. They too, however, relied on an average salvage rate of 20 percent for all the machine rates calculated in their bulletin.

DATA

Data on used equipment sale prices were obtained from annual summary books published by various equipment cost auction houses and data sources (Green Guide 1987-1989, Forke Brothers 1980-1988). Data were compiled from publications from 1986 through 1989. Individual equipment information was recorded concerning the type of machine, used sales price, age, equipment options, region of sale, and general condition of equipment for machines 20 years of age and younger. The data were separated into five equipment categories--cable skidders, grapple skidders, feller-bunchers, loaders, and combined--and sorted by year of manufacture. Information on other classes of equipment such as dozers, chippers, and slashers was not sufficient for analysis.

The Green Guide and prior machine rate estimates (Cubbage 1981, Werblow and Cubbage 1986, Dorris and Cubbage 1987, Burgess and Cubbage 1989) provided data on the original sales prices for the make, model, and year of manufacture for each individual piece of equipment. Machine serial numbers were used when available to substantiate the year of manufacture reported in the auction house reports. Equipment prices included all standard original equipment with additional options noted at the time of resale. Those machines having non-original options or lacking options generally found on original equipment had their value increased or decreased accordingly by the estimated average price of the option in that particular year of manufacture. Older equipment that had newer, upgraded options such as a new grapple, winch, shear, or tires also had their prices adjusted accordingly.

Once this data had been recorded, the percentage of original cost represented by the salvage value was calculated for each individual machine. This was done for all machines having complete records (a total of 451 machines) and for all categories of equipment. Salvage percent yearly averages were determined for each machine category for equipment 1 to 10 years of age and for all those machines with an age greater than 10 years.

These percentage resale values were then averaged by class and by year (Table 2). Figures of values versus age were made for each class of equipment and for the combined class data as well. These salvage value curves represented the estimated average yearly decline of value of used machinery over a ten-year life span.

ANALYSIS

The equipment sales data were used to estimate average values of classes of equipment, and multiple regression was used to examine the contribution of three variables--age, physical condition of machine at the time of sale, and region of purchase--on average resale value. Age, five states of equipment condition (poor, fair, good, very good, and excellent), and five regions (Southeast, Northeast, Central, Midwest, West) were examined in linear models. These variables were used alone and in combination.

Table 1. Machine Life and Salvage Value Estimates

Machine category/description	Life (years)	Salvage Value[1]
Chainsaw	1	20
Tree shear, without carrier	5	50
Feller-buncher, small, rubber-tired	3	20
Feller-buncher, medium-large, rubber-tired	4	20
Feller-buncher, large, tracked, boom	5	15
Cable skidder, less than 80 horsepower	4	20
Cable skidder, medium, 80-100 horsepower	4	20
Cable skidder, medium, 101-120 horsepower	5	15
Cable skidder, more than 120 horsepower	5	10
Grapple skidder, 70-90 horsepower	4	20
Grapple skidder, more than 91 horsepower	5	25
Grapple skidder, large, tracked, bunk	5	15
Forwarder, shortwood	4	21
Slasher/loader, multi-stem	4	20
Delimber, iron gate	5	0
Harvester, combine	4	20
Loader, bigstick	5	10
Loader, small, hydraulic	5	30
Loader, medium, hydraulic	5	30
Chipper, small-medium, 12-18 inches	5	20
Chipper, large, over 22 inches	5	20
Crawler tractor, less than 100 horsepower	5	20
Crawler tractor, 101-200 horsepower	5	20
Crawler tractor, more than 201 horsepower	5	20

[1] Percent of purchase price at end of life span.

Source: Adapted from Brinker et al. (1989).

Table 2. Summary of Harvesting Equipment Salvage Value Data by Machine Type and Age

Equipment Class	Equipment Age										
	1	2	3	4	5	6	7	8	9	10	11+
Feller-Bunchers:											
Number of Sales	0	0	8	21	10	8	5	8	7	4	4
Percentage of Original Price											
Mean	na	na	0.375	0.278	0.250	0.227	0.265	0.226	0.218	0.309	0.144
Standard Deviation	na	na	0.103	0.074	0.043	0.073	0.067	0.081	0.149	0.070	0.048
Minimum	na	na	0.202	0.158	0.205	0.170	0.188	0.068	0.054	0.188	0.077
Maximum	na	na	0.540	0.373	0.355	0.391	0.382	0.335	0.456	0.355	0.201
Grapple Skidders:											
Number of Sales	5	9	8	12	23	13	18	23	26	13	27
Percentage of Original Price											
Mean	0.639	0.463	0.413	0.349	0.282	0.288	0.250	0.242	0.231	0.246	0.283
Standard Deviation	0.032	0.143	0.131	0.099	0.093	0.098	0.098	0.098	0.086	0.104	0.088
Minimum	0.577	0.196	0.272	0.149	0.159	0.175	0.111	0.097	0.107	0.131	0.145
Maximum	0.662	0.765	0.702	0.546	0.518	0.497	0.429	0.594	0.407	0.429	0.508
Cable Skidders:											
Number of Sales	1	2	8	11	9	4	22	18	30	23	55
Percentage of Original Price											
Mean	0.635	0.508	0.446	0.350	0.281	0.387	0.340	0.280	0.307	0.265	0.352
Standard Deviation	na	0.035	0.059	0.097	0.071	0.115	0.116	0.085	0.098	0.070	0.143
Minimum	na	0.473	0.342	0.188	0.189	0.224	0.145	0.152	0.083	0.158	0.121
Maximum	na	0.543	0.496	0.506	0.405	0.551	0.684	0.416	0.618	0.465	0.665
Knuckleboom Loaders:											
Number of Sales	2	3	4	5	4	8	4	12	19	3	9
Percentage of Original Price											
Mean	0.780	0.563	0.473	0.599	0.465	0.444	0.335	0.321	0.323	0.361	0.357
Standard Deviation	0.053	0.071	0.067	0.208	0.150	0.143	0.074	0.148	0.166	0.086	0.145
Minimum	0.726	0.504	0.397	0.306	0.242	0.132	0.261	0.073	0.077	0.327	0.162
Maximum	0.833	0.663	0.559	0.875	0.663	0.650	0.458	0.596	0.701	0.533	0.573
All classes:											
Number of Sales	8	14	28	49	46	33	49	61	82	43	95
Percentage of Original Price											
Mean	0.647	0.491	0.420	0.334	0.290	0.323	0.299	0.270	0.227	0.268	0.319
Standard Deviation	0.071	0.126	0.104	0.141	0.103	0.136	0.111	0.109	0.125	0.086	0.134
Minimum	0.577	0.196	0.202	0.149	0.159	0.132	0.111	0.068	0.054	0.131	0.077
Maximum	0.833	0.765	0.702	0.875	0.663	0.650	0.684	0.596	0.701	0.465	0.665

Analysis indicated a very weak relationship between the salvage value percentage and the region of sale for all models, with an overall addition to the multiple coefficient of determination (R^2) of generally less than 2 percent of the predicted value for all classes of machines. Condition was coded from 1 (poor) to 5 (excellent) for the analyses. The condition variable contributed moderately (up to 11 percentage points) in the two variable linear model [value = f (age + condition)]. None of these untransformed linear models yielded a R^2 greater than 0.35. Age was the most significant independent variable determining salvage values for all equipment classes.

Various data transformations and regression models were examined. The salvage value percentages generally sloped downward rapidly and then leveled off after five or six years. Various transformations of the data were examined for use in linear regression estimation. The transformations and models tested included:

Salvage %	= Age
Salvage %	= Age + Condition
Salvage %	= Age * Condition
Salvage %	= ln (Age)
Salvage %	= 1/Age
Salvage %	= $1/Age^{0.5}$
Salvage %	= ln (Age)
Salvage %	= Age + Age^2
Salvage %	= $1/Age^{0.5}$ + Condition
(ln)Salvage %	= ln (Age)

The regression analyses generally indicated that the transformation of age = $1/Age^{0.5}$ proved most useful for use in predicting salvage values. Condition code also was useful in some regressions. The predictive power of the regressions and the age and condition variables depended on the number of years for which salvage values were estimated. The coefficients of determination were modest, ranging up to 0.55, but all the prediction equations selected were significant (Table 3) and the predicted salvage values were close to the actual salvage values. For equipment that was up to five years old, the inverse transformed age variable alone served as the best predictor of the salvage value percentage. The equipment condition code contributed only two or three percentage points to the multiple coefficient of determination for each equipment category, and usually was not statistically signficant. For the regressions for equipment ranging from one to ten years old, the addition of equipment condition usually contributed significantly to the salvage value prediction equations. Condition added about 2 to 10 percentage points to the multiple coefficient of determination, depending on the equipment class. No prediction equations proved very worthwhile when equipment older than 10 years was included in the regression models.

DISCUSSION

The results of the data collection and statistical analyses are revealing. First, it seemed clear that a considerable amount of timber harvesting equipment was being used and retained its value beyond the conventional four to five year depreciation period. Regression analyses indicted that some types of equipment were more predictable in their decline in value over time than other types. The prediction equations for feller-bunchers and loaders indicated that age and condition explained only about one-fifth to one-third of the variability in resale price. The feller-buncher data had no observations for the first two years, which probably contributed to poor estimation. Cable skidder and grapple skidder resale price variability was

Table 3. Regression Equations Selected to Predict Salvage Value as a Percent of Original Purchase Price by Year

Model: Salvage % = $\alpha + \beta_1(1/Age^{0.5}) + \beta_2$ Condition

Equipment Class/ Age Span	n	α	β_1 estimate	β_1 standard error	β_1 t value	β_2 estimate	β_2 standard error	β_2 t value	R^2	Sy•x
Feller-Bunchers										
1 to 5 years	39	-0.199	0.976	0.282	3.45	-	-	-	0.24	0.078
1 to 10 years	71	0.038	0.270	0.133	2.02	0.042	0.014	3.02	0.19	0.088
Grapple Skidders										
1 to 5 years	56	0.018	0.633	0.090	7.07	-	-	-	0.48	0.109
1 to 10 years	149	-0.051	0.532	0.058	9.09	0.046	0.011	3.88	0.49	0.096
Cable Skidders										
1 to 5 years	31	-0.019	0.737	0.138	5.32	-	-	-	0.49	0.084
1 to 10 years	128	0.056	0.403	0.083	4.66	0.041	0.011	3.91	0.31	0.091
Loaders										
1 to 5 years	18	0.290	0.446	0.228	1.95	-	-	-	0.19	0.161
1 to 10 years	63	0.023	0.685	0.139	4.94	0.035	0.025	1.44	0.33	0.155
All Classes										
1 to 5 years	145	-0.013	0.709	0.074	9.52	-	-	-	0.39	0.120
1 to 10 years	415	0.000	0.494	0.047	10.44	0.041	0.008	5.43	0.31	0.114

Note: All regressions are significant at alpha = 0.05. Condition codes are: 1 - poor; 2 - fair; 3 - good; 4 - very good; 5 - excellent.

explained better by the prediction equations.

One can use the regression equations selected in Table 3 to compute average resale values by year, for average condition machines. These can be compared with the common salvage value rules-of-thumb as well (Table 4). These comparisons clearly indicate that used timber harvesting equipment has kept its value considerably better than most rules-of-thumb have assumed. It also indicates that the salvage estimates based on five-year or ten-year old equipment data sets are reasonably close for the first five years. The largest differences occur in the first year, for which there was little data available.

One also could compute two-factor tables relating salvage value percentages to age and condition class. Table 5 presents such a summary for combined equipment class table from ages 1 to 10, and very poor (1) to excellent (5) states of condition. These data indicate that equipment condition is likely to affect resale price significantly, at about 4 percentage points difference per change in condition class. Most equipment was classed as fair to very good in the auction sale reports, however. Thus this would translate into practical differences of only eight percentage points usually. The largest drops in value by year occurred in the first through third years, and tapered off quickly after that.

CONCLUSIONS

The salvage values and resale values found in this analysis were generally quite large. Of the three factors examined that could contribute variability in equipment resale prices, age was by far the most significant. The region of the country made little difference in equipment resale prices. Equipment condition was statistically significant in predicting resale values when the data included equipment of up to 10 years old, but not for equipment up to five years old.

The averages of the equipment sale data and the regression equations do indicate that salvage values tend to drop sharply in the first year, losing over a third of their value. The recent data also indicate that the old rules-of-thumb for equipment salvage values are too conservative now. At the end of their traditional "life" spans, feller-buncher values were 29 percent rather than 20 percent of the original price; grapple skidders 30 percent instead of 25 percent; cable skidders 35 percent rather than 20 percent; and loaders 49 percent rather than 30 percent (based on the five-year salvage value prediction equations). Feller-bunchers lose resale value most rapidly, and loaders maintain their values best (Figure 1). This confirms what one would expect, since use in the woods will wear out equipment faster than at the landing. Resale values remained high even after the commonly cited life spans for depreciating equipment. They leveled off after about 5 years, at values of 20 percent to 35 percent of the original sale price. Even equipment that was up to 10 years old maintained a value of about one-quarter to one-third of its original sale price.

The data indicate that there is a slight jump or smaller drop in salvage values in the sixth year. This may be due to an equipment overhaul after its initial depreciation period has expired. From that point on the original trend in resale value seems to continue.

The analysis indicates that salvage value rules-of-thumb generally under-value used machine salvage

Table 4. Selected Equipment Salvage Percentages by Year and Source

Equipment class	Age 1	2	3	4	5	6	7	8	9	10
	resale value as a percent of original sales price									
Feller-Bunchers										
1 to 5 year regression	78	49	36	29	24	-	-	-	-	-
1 to 10 year regression	43	35	32	30	28	27	27	26	25	25
rules-of-thumb	-	-	-	20	-	-	-	-	-	-
Cable Skidders										
1 to 5 year regression	65	47	38	33	30	-	-	-	-	-
1 to 10 year regression	62	46	39	35	32	30	29	28	26	26
rules-of-thumb	-	-	-	-	25	-	-	-	-	-
Grapple Skidders										
1 to 5 year regression	72	50	41	35	31	-	-	-	-	-
1 to 10 year regression	58	46	41	38	36	34	33	32	31	31
rules-of-thumb	-	-	-	20	-	-	-	-	-	-
Knuckleboom Loaders										
1 to 5 year regression	74	61	55	51	49	-	-	-	-	-
1 to 10 year regression	81	61	52	47	43	41	39	37	36	34
rules-of-thumb	-	-	-	-	30	-	-	-	-	-
All Equipment										
1 to 5 year regression	70	49	40	34	30	-	-	-	-	-
1 to 10 year regression	62	47	41	37	34	32	31	30	29	28
rules-of-thumb	-	-	-	-	20	-	-	-	-	-

Note: All 10-year regression percentages computed using good condition class (code 3).

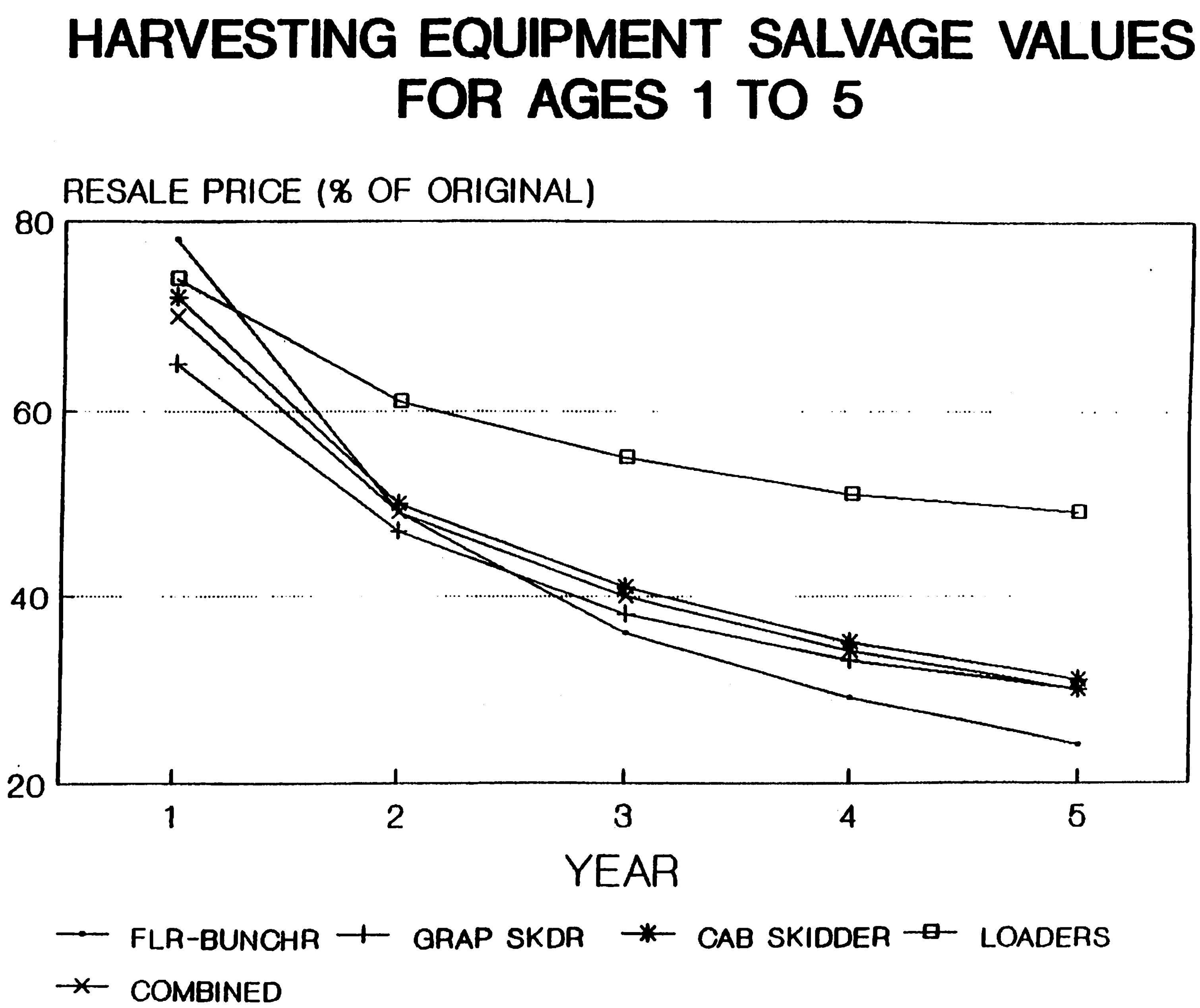

Figure 1. Comparisons of Equipment Salvage Values by Machine Class.

Table 5. Average Equipment Salvage Values by Age and Condition, Combined Data Set

Condition Class	Age									
	1	2	3	4	5	6	7	8	9	10
	---- resale value as a percent of original sales price ----									
Poor (1)	54	39	33	29	26	24	23	22	21	20
Fair (2)	58	43	37	33	30	28	27	26	25	24
Good (3)	62	47	41	37	34	32	31	30	29	28
Very Good (4)	66	51	45	41	38	37	35	34	33	32
Excellent (5)	70	55	49	45	43	41	39	38	37	36

prices. The analysis also provides a means to estimate salvage values for other years. The prediction of salvage values by this or any other model cannot be exact, however. Many factors influence residual value for a particular piece of equipment. The factors used in the regression equations estimated by this study could not explain all the variation in used equipment prices, as indicated by the low coefficients of determination. Equipment prices depend on market competition--the needs of buyers and sellers. Prices may vary within a region because of local economic or harvesting conditions. Original equipment may be removed and newer equipment added to a machine.

Overall, the historical data and the regression this models selected here are more accurate than the traditional rules-of-thumb. The coefficients of determination and statistical tests do indicate that the regression equations are good predictors of salvage values. Increasing the number of machines surveyed, particularly newer machines, would increase the accuracy of the resale value equations.

LITERATURE CITED

Brinker, Richard W., Douglas Miller, Bruce J. Stokes, and Bobby L. Lanford. 1989. Machine rates for selected forest harvesting machines. Circular 296. Alabama Agricultural Experiment Station. Auburn University. 24 p.

Burgess, Joseph and Fred Cubbage. 1989. 1988 timber harvesting costs. Technical Release 89-R-12. American Pulpwood Association. 2 p.

Cubbage, Fred W. 1981. Machine rate calculations and productivity rate tables for harvesting southern pine. Staff Paper Series 24. Department of Forest Resources, College of Forestry and the Agricultural Experiment Station, University of Minnesota.

Dorris, Jason and Fred Cubbage. 1987. 1986 Timber harvesting costs. Technical Release 87-R-13. American Pulpwood Association. February. 2 p.

Forke Brothers. 1980-1988. Blue book of current market prices of used heavy construction equipment. Lincoln, Nebraska.

Green Guide. 1987-1989. Green Guide auction reports, annual issue. Dataquest, Inc. San Jose, California.

Hypes, Trenor L. and William B. Stuart. 1979. Preliminary analysis of harvesing cost by diameter class. Industrial Forestry Operations Program, School of Forestry and Wildlife Resources, Virginia Polytechnic Institute and State University. Mimeo. 41 p.

Miyata, Edwin S. 1980. Determining fixed and operating cost of logging equipment. General Technical Report NC-55. USDA Forest Service, North Central Forest Experiment Station. St. Paul, MN. 16 p.

Warren, B. Jack. 1977. Analyzing logging equipment costs. In: Logging Cost and Production Analysis. Timber Harvesting Report No. 4. LSU/MSU Logging and Forestry Operations Center. Long Beach, MS. p. 37-61.

Werblow, Dennis A. and Frederick W. Cubbage. 1986. Forest harvesting equipment ownership and operating costs in 1984. Southern Journal of Applied Forestry 10(1):10-15.

PROCESSING ROUNDWOOD FOR PULP CHIPS[1]: DEBARKING, CHIPPING AND SCREENING

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ABSTRACT
The chipping of roundwood for pulp chips consumes a large proportion on the South's timber harvest annually. Some details of the key components of the process are detailed incorporating the results of a recent wood yard survey.

KEY WORDS

Chipping, roundwood, chip quality, debarking

INTRODUCTION

To many in the forest industry involved in woods operations the mill gate forms a major barrier. Often the only opportunity to see what happens behind the high wire fence and guarded gates is on chaperoned tours. This limited access to the mill and its wood yard also limits the opportunity to gain a through comprehension of activities within the yard. Yet the demands of the wood yard and pulp mill have a major impact upon woods operations so the needs of the mill should be understood.

A project instigated at Mississippi State University's Department of Forestry enabled a glimpse at some of the workings of mill facilities across the southeastern USA. A survey of roundwood chipping facilities was undertaken, and samples of chips made within the yards collected to allow the relating of chip quality to equipment variables.

The survey, undertaken in the Fall of 1989, covered 12 southeastern States from Virginia to Texas, and included 76 wood yards, 53 integrated with pulp mills, and 23 satellite facilities (Figure 1).

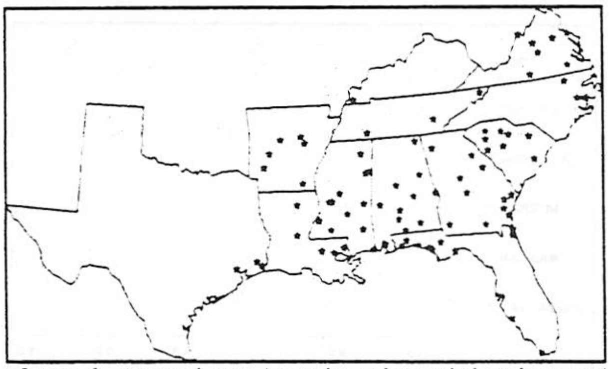

Figure 1. Approximate location of participating wood yards

The purpose of a roundwood chipping yard is to convert stems into chips in the quality and quantity desired by the pulp mill. While there are number of steps in this process, the quality of the product is altered in three main activities: debarking, chipping and screening. These three processes will be discussed in further detail using the results of the survey to illustrate yard operations.

DEBARKING

Bark is removed from the logs before chipping as it has several undesirable properties in the pulping process. For example, in the alkaline process, bark lowers pulp yield, raises alkali consumption, lowers pulp strength and increases bleach consumption. Mills therefore have a low tolerance of bark, usually requiring it to be less than 1% of the digester feed.

Debarking is accomplished in several ways including using drum debarkers, ring debarkers, rosser head debarkers, hydraulic debarkers or chain flailing debarkers.

While all of these forms of debarking exist within the United States, by far the most dominant approach for debarking pulpwood logs in the South is drum debarking. The advantages of drums are that they can efficiently handle smaller and irregularly shaped logs, they require relatively little manpower to operate, and they can process substantial wood volume. A disadvantage with drums is that when processing short logs end 'brooming' or fraying occurs.

Drum debarking is the most common method of removing bark within the surveyed yards. Of the 76 yards recorded, 69 used rotating drums, 3 used ring debarkers, while 4 did not remove the bark prior to chipping.

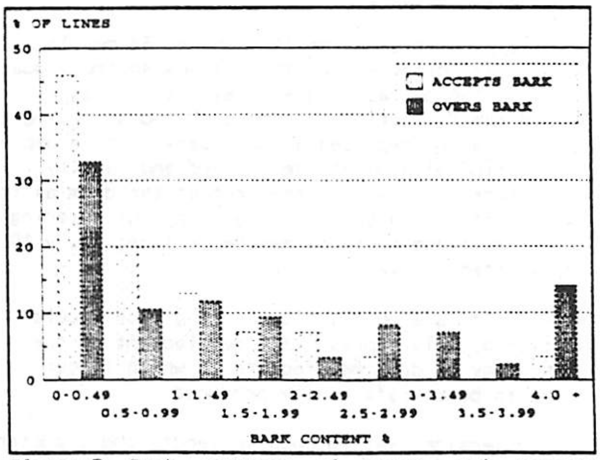

Figure 2 Bark content of overs and accepts fractions from chipper samples

Parallel vs tumbling debarking

Debarking within the drum was assumed to be by log tumbling if the average log length into the drum was less than the drum diameter. Of the 126 drum

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recorded in the survey, tumbling debarking occurred in 100 drums, while parallel debarking occurred in 26 drums.

Parallel debarking systems, where the log length is longer than drum diameter, are being almost exclusively installed in new wood yards. This method can accommodate tree lengths up to approximately 18 metres (55 feet). The advantages of this system are that raw material storage is simplified, and the drum can be fed directly, without the need for logs to pass over a slashing facility. Advantages in chip quality are also attributed to the system because fewer ends are presented to the chipper.

Drums using parallel debarking were commonly 24-27 metres (80-90 feet) in length, longer than many of the tumble drums. This additional length increases retention time within the drum to maintain debarking quality.

In some wood lines a mixture of both long and short wood is introduced into the drum. A mixture of both long and short logs can result in a higher flow rate through the drum than either short or longwood used exclusively.

Yards with multiple lines, processing both hardwood and softwood varied in their separation of the two wood types. Often both softwoods and hardwoods are fed through the same lines, however some dedicated a line to one or the other of the fiber types. Many yards with a single line separated the fiber types by running the two in batch mode.

Most wood yards were very effective in removing the bark from logs. The bark content of the chip samples collected after chipping was commonly less than 1%, (see Figure 2).

Drum specifications

Drums are built of 25 mm (1 inch) to 38 mm (1½ inch) steel plate either in sections so individual sections can be replaced as they wear, or as a single shell. Sectioned drums are used so a single section can be replaced as necessary. For example, the section of drum at the in-feed end usually wears more quickly than the rest of the drum as it is subjected to higher loading from logs entering the drum. These sections may be replaced every 10, or as often as every 5, years.

Newer drums are more typically single or double sectioned. This represents a development in the technology of drum manufacture in which longer drums to be satisfactorily produced.

Drum dimensions varied both in length and diameter, (see Figure 3). Diameters ranged from 9 feet to 16½ feet, while length ranged from 45 feet to 100 feet. Certain drum dimensions however were more prevalent than others, particularly 12 feet x 67 feet, and 14½ feet x 80 feet.

Drum revolutions fell within the range of 3 rpm to 21 rpm, with a rate from 5 to 8 rpm being most common. No major trends were detected that might indicate a rationale for selection of drum speed, apart from the feature that the smaller drums

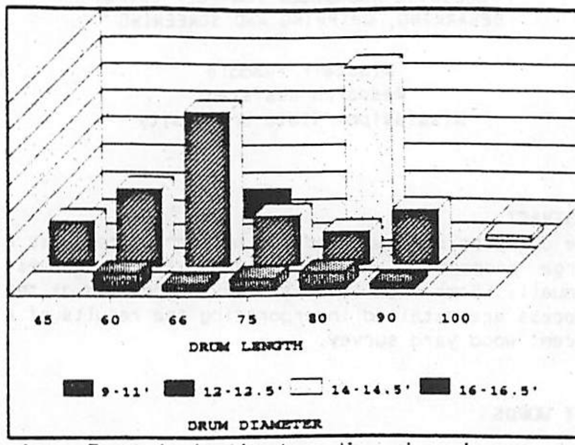

Figure 3 Variation in drum dimensions in surveyed yards

tended to operated at higher revolutions. Illustrating this variation in drum speed, the set of 12'x 67' drums in the survey operated at speeds ranging from 3 rpm up to 20 rpm with apparently similar operating conditions.

The 14½'x 80' drums were more commonly operated at 6 to 8 rpm, although there were examples of speeds up to 18 revolutions in this drum size.

Drum Manufacturers

One manufacturer dominates construction of drums, (see Figure 4). Fiber Making Process (FMP) manufactured 50% of the 126 drums included within the survey. The next major manufacturer was Manitowoc with a 17% share of the market, while no other vendor had over a 10% share. Six manufacturers had less than 5% of the installed drums recorded. These included Carthage, Hooper, Ingersoll Rand, Mississippi Tank, Modomeken and Price.

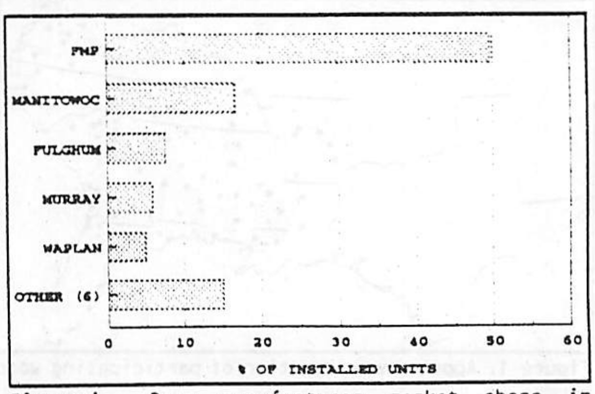

Figure 4 Drum manufacturer market share in surveyed yards

CHIPPING

The chipper is the point where chip dimensions are formed that the pulping processes will utilize.

While screening may later ameliorate defects in a portion of the chip flow, the majority of the chips used in pulping are raw from the chipper.

Roundwood chippers come in three designs: disc, drum, and V-drum. Disc chippers are used almost exclusively for roundwood chipping in the South.

Disc chippers use a series of radially mounted knives on a circular disc to comminute the log. Logs are fed in at an angle to the disc and a knife blade severs a wood disc from the log. The wood disc breaks up both in width as it discharges from the disc slot, and thickness in the course of the chipping action.

As the knife wedge passes through the stem bole, splits form in the partially severed block of wood as it is forced into the chip slot by the front of the knife. These splits form the thickness dimension, and are partially a property of the wood (density, moisture content etc.), and partially a function of the wedge angle of the blade.

While chip thickness is very important to pulp quality, it cannot be directly manipulated in disc chippers. However, as chips form, their length to thickness ratio is about 5:1; therefore, by controlling chip length, chip thickness is also defined.

Chip length is a function of the gap between the disc wear plate and the knife tip, and the angle the log presents to the disc. The former parameter is often called the Y-dimension, while the latter is known as the spout angle, (see Figure 5).

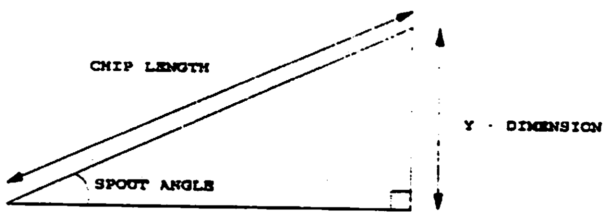

Figure 5. Derivation of chip length

Desired Chip Size

Disc chippers unavoidably produce a variety of chip sizes which are commonly grouped into four main categories; overs, accepts, pins and fines.

Overs are chips which are overlong and/or overthick. For length the limit is around 45 mm while for thickness the normal limit is 8 mm. **Pins** are chips which may be of acceptable length but small in thickness or width, looking more like short match sticks. They are classified as being able to pass through a 7 mm round hole in a chip classifier. **Fines** are all of the small material which passes through a 3 mm round hole in a chip classifier. The **accepts** fraction, usually the bulk of chips, falls between the overs and pins.

Chip length is set in the chipper, thereby indirectly also specifying chip thickness. Three factors govern the desirable size for pulp chips: the need for the cooking liquor to fully impregnate each chip, and the need to minimize fiber damage and the production of pins and fines.

The decision on the choice of a suitable chip length is a result of several compromises. To maintain pulp strength a long chip is preferred as proportionately fewer fibers are severed. Also cutting long chips creates fewer pins and fines, which are undesirable in the pulp furnish.

Although a long chip has its benefits, as chip thickness increases with chip length, and most pulp process prefer a chip only 2 mm to 4 mm thick to ensure a complete cook, the length of chip cut must be limited.

For kraft pulping typical preferred chip dimensions are 15-25 mm long and 2 to 4 mm thick, while chip width is not important.

Chipper Dimensions

A total of 101 chippers was recorded in the survey. These chippers produced 63.6 million tons of chips in the 12 month survey period; on average, therefore, each chipper produced about 630,000 tons of chips. In some mills, however, individual chippers produced about 1¼ million tons of roundwood chip material.

Disc dimensions of chippers varied from 75" to 130", and the number of knife sets in the discs from 4 to 15. Bigger discs had more knife sets. The most common disc/knife combinations were a 112" disc-15 knife, and a 116"-12 knife, although there was also a variety of other combinations, (see Figure 6).

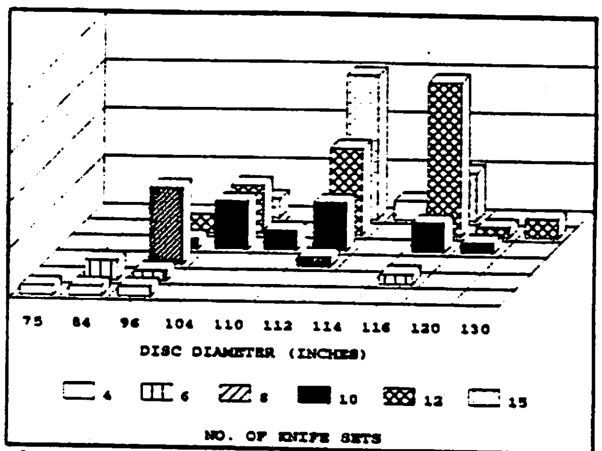

Figure 6 Disc/knife combinations on surveyed chippers

Chipper Power

Over the whole range of disc sizes recorded, bigger discs had larger power motors; however within disc dimensions there was considerable variation. For example 112"-15 knife discs ranged from 2500 hp down to 800 hp. Similar variation was also found in the common 116"-12 knife discs.

Of the chipper motors greater than 1500 hp, 87% were synchronous units. In contrast 62% of the chippers below 1500 hp used wound rotor motors.

Large synchronous motors allow chipping productivity to maintained without compromising disc rpm. When a large log enters a chipper with a synchronous motor, the motor can draw additional horsepower to maintain disc speed. However, a wound rotor motor does not have this ability, but rather relies on disc inertia to cope with larger logs. If disc speed falls below a critical level the motor will cut out to prevent damage, thus halting production.

Operating Speed

The speed of cutting wood during chipping affects chip quality. High disc speed boosts throughput but at the expense of an increase in production of fine material. An advisable target cutting speed of 20 to 25 metres per second is therefore an acceptable compromise between production and quality (Hartler, 1986).

The mid-disc operating speed of chippers in the survey was either in this appropriate operating range or above it slightly. The highest operating speeds noted were at 31 m/sec, by smaller discs, 96" and 104", at high revolutions, above 450 rpm.

Disc revolutions of the chippers varied from 257 to 512 rpm. Most operated at around either 300 rpm or at 360 rpm. Those chippers operating at 400 rpm or greater had the smaller disc sizes.

Log Feed

Disc chippers are fed by either of two methods: horizontal or drop. The drop (or gravity) feed method, where logs fall down a chute on to the disc surface at an angle of 30° to 40°, are more appropriate for shortwood systems. In horizontal feed systems, logs are belt or chain driven to the chipper throat.

Horizontal feed systems chipping long length logs should produce the best quality as the log axis can be kept more correctly positioned to the chipper spout axis, and log speed can be kept equal to the feeding speed of the chipper (Hartler, 1986). In addition long logs present fewer ends to the chipper per unit volume of wood. Chip quality of log ends is lower than that for the rest of the log.

While horizonal chipping of long logs produces high chip quality, chipping of especially short logs (4 feet) in a horizonal fed chipper produces poor quality chips because the short logs cannot be sufficiently stabilized in the horizontal spout (Robinson, 1989).

Because of the dominance of tumble debarking systems in the wood yards surveyed, shortwood (4'-10') chipping systems dominate. Of the 101 chippers in the survey, 56% are gravity-fed. The remaining 44 are horizontal-fed units. All 23 of the satellite yards used horizontal feed systems, as well as several other yards chipping longer shortwood (8-10'), although some yards were feeding horizontally with log length down to 5 feet.

Chip Discharge

After being severed from the bole, chips passing through the disc slots are expelled from the chipper casing. The chips are forced from the casing by blowing vanes mounted on the back of the disc and blown to a storage location, or they may passively drop out of the bottom of the casing and are conveyed away from the chipper.

The blowing discharge method is a much more "aggressive" technique as the chips are forced from the chipper housing. The chips are likely to be struck by the vanes or driven against surfaces along the discharge path thereby causing additional breakage and the creation of pins and fine material. Blowing chippers also impose heavier power requirements, even if the chipper is under 'no-load' conditions, because of the force required to move large volumes of air.

The key advantage of blowing chippers is that they can be situated closer to the ground level as there is no need for a conveying system under the chipping unit such is used for bottom discharge units. The feed systems to the chipper can therefore also be lower which can decrease initial capital outlays.

Bottom discharge chippers constituted nearly two-thirds of the surveyed chippers, with blowing type chippers making up most of the remainder. The exception was one survey response which indicated the use of a horizontal discharge chipper.

Chip Set-up Length

Since most pulping processes require a reasonably similar chip size, and the Kraft process dominated as the final source of most of the yard chips, the variation in chipper length set-up is not great, (see Table I).

Table I Variation in chip set-up length

CHIP SET-UP LENGTH (MM)	% OF CHIPPERS
13(½")	1
14($^{9}/_{16}$")	1
16(⅝")	30
19(¾")	36
22 (⅞")	21
25 (1")	1

There is some tendency for chippers which are chipping hardwoods only to be set at slightly shorter chip lengths as hardwoods produce a slightly thicker chip than do softwoods at the same chip length.

Chipper Manufacturers

In the wood yards included within this survey, Carthage is the major chipper brand used, with 44% of the 101 chippers being from this manufacturer. Murray have about one-quarter of the chippers, followed by Fulghum and Black Clawson each having 10% of the units.

Six other chipper manufacturers: KMW, Kockums, Precision, Progress and Soderhamn share the remaining 10% of installed chippers, (see Figure 7).

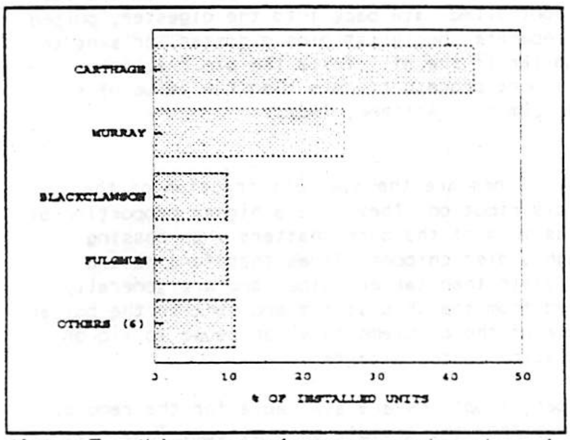

Figure 7. Chipper manufacturers market share in surveyed yards

Chip quality

The overall averages for all yard samples combined is displayed in Figure 8. The base of information used in deriving these figures included the summation of the three samples received over the life of a knife set for each chipper.

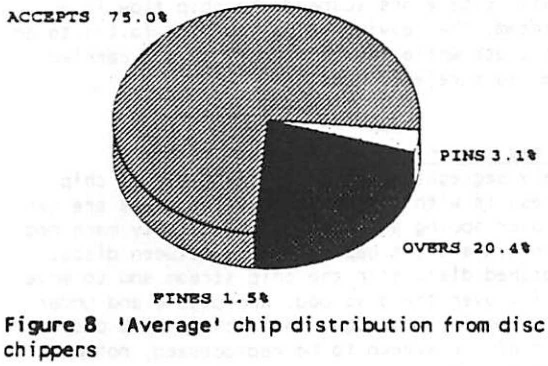

Figure 8 'Average' chip distribution from disc chippers

The overall average, while constituting some form of 'industry average' for roundwood chipping operations in the South, masks considerable variation caused by differences in various aspects of operation within the yards.

Figure 9 displays the range of accepts for all of the summed chipper samples, (accumulation of three samples over the life of a knife set before resharpening). Most accept proportions cluster between 70% and 85%, but the range extended from a high of 89% to a low of 43%. The other chip fractions showed matching variations.

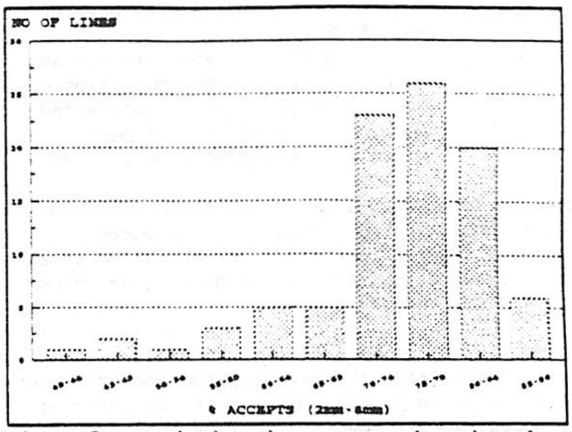

Figure 9 Variation in accepts fraction from chipper output

The quality of the chips formed from a disc chipper, or rather the proportion of undesirable chip sizes produced, is a function of several variables including; species, chipper disc rpm, chip set-up length, and chip discharge method.

Using the data collected from the chippers in the wood yard survey, the impact of some of these variables on the most undesirable chip fractions (pins and fines) was assessed. An example of the relationships developed are shown in the pins model in Figure 10.

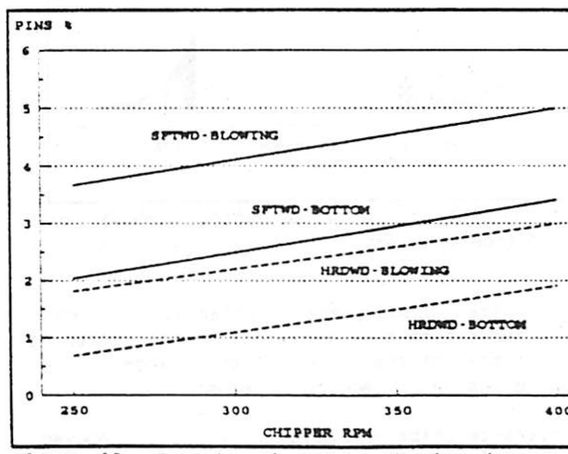

Figure 10 Example of models showing impact of various variables on pins production

The analyses made suggested that a bottom discharge chipper saves about 1.6% in pins creation with softwoods and about 0.7% in hardwoods. They also indicated that softwoods are more responsive to changes in chipper rpm and chip set-up length than are hardwoods.

CHIP SCREENING

The purpose of a screening system is to remove components of the chip distribution that are undesirable in the downstream pulping process. Generally recognized as undesirable are the following;

1. over-thick chips, usually greater than 8 mm,
2. over-long chips, length is not as a critical dimension, but chips over 50 mm (2") are not preferred,
3. and undersize chips or fines, which are less than 3 mm to 5 mm.

The goal is to produce a uniform digester loading, so that a consistent pulp quality is produced continuously. Having consistent uniform-sized chips in the digester allows for better packing of chips and for a more consistent pulping liquor usage.

The screening system must therefore remove extremes in size from the raw distribution from the chipper, and allow for the discard or reprocessing of the undesirable elements. The final chip flow will then more closely conform to the desired size.

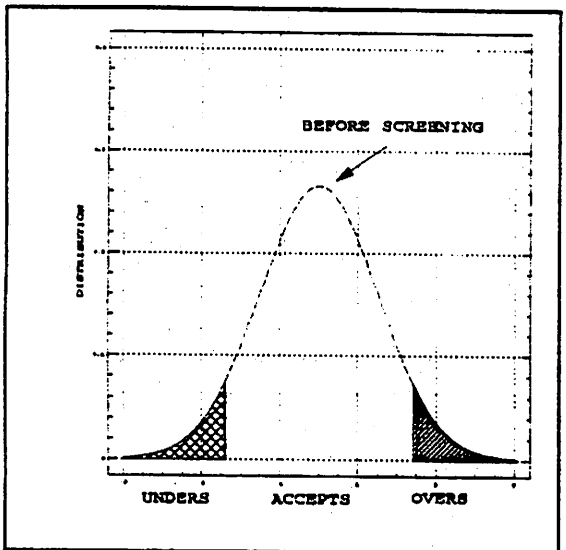

Figure 11 Objective of screening: removal of distribution extremes

Gross Oversize. Gross oversize material is often removed from the chip stream early in the screening process to prevent the chance of this large material plugging or jamming screens.

Gross oversize chips are relatively easily removed by the use of a scalping disc screen set with an interfacial opening of 2 to 4 inches. This screen can also remove other gross contaminants from the chip stream before the main screening system.

Over Length. Over length chips are usually correspondingly over thick, and therefore are removed from the chip stream and reduced to a more appropriate size. Because of the direct proportional relationship between length and thickness, correct length screening can give a measure of control over chip thickness, (McCauley, 1985).

Over-length chips are removed by passing the chips stream across a moving deck which has holes in its surface. Hole shape is most often round, but square and rectangular hole dimensions are also used. Acceptable and undersized chips fall through, while the over-length remain on the surface and eventually pass off the end.

Pins. Pins are short thin chips which contain valuable fiber but can present processing problems, particularly in continuous digesters where they can plug pulp screening systems.

Pins can be separated from the chip stream and feed at a controlled rate back into the digester, pulped in a separate specialist pins digester, or sent to the boiler if the mill feels the pin fraction causes more process trouble than the value of its fiber, (Smith & Artiano, 1987).

Fines. Fines are the smallest fraction of the chip distribution. They have a higher proportion of bark as much of the bark shatters when passing through a disc chipper. Fines therefore have a lower yield than larger chips, and are generally removed from the chip stream and sent to the boiler because of the problems they can cause to liquor circulation in the digester.

A number of options are available for the removal of fines from the accepts chip stream. They fall into three methods; moving deck, rolling disc or drum, and pneumatic, (Smith and Golgert, 1988).

The moving deck options are commonly a horizontal gyratory deck with various mounting arrangements. Other versions use a flexing bottom plate.

Rolling discs or drums come in two versions. One is similar to the scalping screen but with a much smaller gaps, down to 1.5 mm to 2 mm. The roll screen has rolls mounted with 1.5 mm to 2 mm gaps between each roll. Small grooves on the roll surface capture and pass the fines.

Pneumatic separators suspend the chip flow in an air stream. The heavier chips and pins fall into an accept chute while the lighter fines are carried further to a reject chute.

Thickness Screening. The main method of actively segregating chips on the basis of chip thickness is with a disc screen. The discs are set in an overlapping arrangement and closely machined to maintain a tight gap tolerance between discs. The notched discs stir the chip stream and to move the chips over the disc bed. Acceptable and under sized chips fall through, while over-thick pass off the end of the screen to be reprocessed, normally in a chip slicer.

Disc screens are of two types. One is a flat bed where the chip stream is moved down the bed by a series of discs, while the other is a V configuration which churns the chips up the sides of the trough formed by the sets of disc assemblies.

Screening - Before/after Storage

For various reasons different facilities choose to handle their chips in different ways. While it might be expected that the screening of chips should be undertaken just before final consumption to remove material degraded from handling, several yards screen only before storage. These yards did not appear to have any different processing characteristics than those which screened after storage.

Half of the satellite yards also had screening ability, using either a drum or a gyratory system. Four of the five satellite yards with gyratory screens screened for both overs and unders, while the fifth screened only for unders. Conversely six of the seven yards with drum screens screened only for unders, while the seventh also screened for overs.

Final Screening Systems

Because of the variety of final screening systems used in yards they are grouped into broad categories for ease of classification. These systems are all associated with the final screening received by the chip flow before pulping. The chips may have received a previous screening, for example at a satellite mill, or before storage.

The predominant final screening system uses a gyratory screen, either alone, or in combination with a disc screen, (see Table II). Eighty-four percent of the mill yards which screen use a gyratory screen in the final screening of the chip stream.

Table II Mill yard chip screening systems

SCREENING SYSTEM	NO OF YARDS
GYRATORY	31
DISC	6
GYRATORY → DISC	2
DISC → GYRATORY	10
OTHER	2

Disc screens were also prevalent with 35% of the yards having a disc screen somewhere in their final screening process. Disc screens were of either the flat deck type or of a V configuration. Six of the yards with disc screens had the V configuration, while the remainder used flat decks.

Two screening types not falling within the bounds of either a gyratory or disc method were one each of a vibratory and louvered system.

Thickness Screening

The merits of screening for thickness in sulfate pulping has received considerable attention in the last decade, (Jönsson, 1981, Porter, 1981). The technology to separate over-thick chips and efficiently reduce them to acceptable dimensions appears to be well developed, (Artiano, 1986). However of the 53 mill yards only 16 (30%) now screen specifically for thickness, (see Table III). Between 7 mm and 8 mm is the most common thickness target in these yards, but one yard producing bleached sulfate chips screens for a 12 mm chip.

Table III Number of mill yards using various dimensioned thickness screens

THICKNESS SCREENING (MM)	NO OF YARDS
6.5	1
7	3
7.5	1
8	8
10	2
12	1
NONE	39

Overs Screening

Screening for overs showed considerable variation both in hole dimensions and shape. Top screen hole sizes varied from 5", down to ¾" (which would have removed a considerable quantity of fiber). Both round, square and rectangular hole sizes were reported.

Sixty percent of the yards screening for overs used a hole size between 2" and 1¼". Overall, the most common screen sizes in order were; 2", 1½", 1¾", and 2½".

Treatment Of Oversize

After overs are separated from the main chip stream, two options are available for their subsequent treatment, disposal or reduction. Most yards do not take the disposal option because oversize chips can represent a substantial volume of valuable fiber. Rather they reduce the chips to a more acceptable size by comminution.

Reduction of chips can be accomplished in three ways: feeding them back into the main chipper, using a separate rechipper, or using a slicer. The use of chippers, either the main unit or a separate specialist unit, to reduce chips will result in the creation of a significant proportion of extra pins and fines material. Slicers also create additional fines but to a lessor extent than chippers. Slicers have the additional advantage that the chip they produce has better dimensions than those from rechippers.

Using rechippers was the most common method of oversize chip reduction, with 26 of the 53 processing site yards using a separate rechipper. Slicers were the next most common oversize treatment, with 16 mill yards having this system. All but one of the yards which screened specifically for thickness (using disc screening) used a slicer to treat over-thick chips. Only two mill yards returned oversized chips to the main chipper for size reduction.

Only three of the 23 satellite yards used any form of retreating overs, with all three using a rechipper.

Fines Screening

While fines screens ranged in size from 2 mm to 10 mm, most (42%) of the yards screening for fines used hole sizes of 5 mm or 6 mm, (see Table 23).

Those yards screening for fines accomplished the task mainly with the use of gyratory screens, either as part of a single or double deck screen. In most cases (40 of 49) the gyratory, disc or vibrating screen separating fines received either the raw chip flow or chips which had passed a scalping screen. In the remaining 9 systems the fines screen was the final screen.

SUMMARY

The purpose of presenting the information above is not to provide any exhaustive description of wood yard operations. Rather it was to give some background information on the main processing activities within roundwood chipping yards, using data collected from a recent survey on southeastern facilities so that those unfamiliar with the more important components of the yard operations may gain some insight into some of the key activities in the yard.

LITERATURE CITED

Artinano, A. (1986). Chip slicer - state of the art. TAPPI Jl., Vol. 69(2), pp 38-40.

Hartler, N. (1086). Chipper design and operation for optimum chip quality. TAPPI JL., Vol. 69(10), pp 62-66.

Jönsson, L. (1981). Experiences in chip thickness screening system at SCA Östrand. TAPPI 1981 Pulping Conference, Conference Proceedings, pp 21-28.

McCauley, W.N. (1985). Chip-grading - the use of conventional screening for thickness screening. TAPPI 1985 Pulping Conference, Conference Proceedings, pp 503-508.

Porter, J.B. (1981). Chip thickness screening system improves medium output, quality. Pulp & Paper, Vol. 55(6), pp 76-79.

Robinson. M.D. (1989). Optimizing chip quality through understanding and controlling chipper design characteristics and other variables. TAPPI 1989 Pulping Conference, Conference proceedings, Book 1, pp 325-338.

Smith, D.E. & Artiano, A. (1987). Various equipment configurations for chip thickness screening and slicing. TAPPI 1987 Pulping Conference, Conference Proceedings, pp 345-351.

Smith, D. & Golgert D. Jr. (1988). State-of-the-Art in fines removal. TAPPI 1988 Pulping Conference, Conference Proceedings, pp 439-449.

ANALYSIS OF TRUCK WEIGHT MODIFICATIONS FOR SOUTHERN TIMBER HAULING OPERATIONS

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ABSTRACT

Light-weight haul trucks used by a southern logging contractor were studied to determine whether this vehicle configuration improved returns from hauling operations. Load data were compared to determine if weight related changes to truck and trailer components affect truck load characteristics. Resulting estimates of load weight were used to measure the economic potential of these modifications. Comparison of net weights for pulpwood and chip'n'saw loads suggest that weight related modifications can significantly improve net load weight, regardless of the type of product being carried. An incremental investment comparison of the light-weight and conventional vehicles indicates that significant increases in yield can be realized from light weight haul trucks. The incremental internal rate of return for a light-weight truck-trailer configuration was estimated at 243 percent annually over returns provided by the conventional vehicle.

INTRODUCTION

Large capacity truck-trailer combinations capable of legally hauling 40 ton gross payloads are used throughout the South to haul harvested timber from the forest to the mill or woodyard. Advantages of this truck configuration include a large payload capacity, low transport costs, and greater transport efficiencies. However, constraints placed on truck transport operations limit their efficiency and payload (Beardsell 1986). Legal restrictions limit total truck weight in most states and, as a result, restrict net load capacity and the profits associated with truck transport of logs and tree-length wood.

Weight is a major concern to the contract logger or hauler travelling on public roads in the South. In most southern states, state transportation agencies monitor and enforce state and federal limits on allowable loaded vehicle weights. Heavy fines are often imposed by these agencies to encourage contractors to keep their payload below the legal limit.

Contractors hauling directly from the woods site have begun using on-board truck scales to monitor their loads before reaching public highways. This allows them to maintain full capacity loads on their haul trucks and minimize the possibility of being fined for an overweight load. A recent study of on-board scale applications for southern timber transport found that these scales reduce load variability, increase average payload in areas where truck weight limits are vigorously enforced, and have the potential to generate financial rates of return approximating 20 percent annually (Shaffer et al. 1987).

This paper reports on a study of light-weight haul trucks and trailers operated by a southern logging contractor. The study objectives included the documentation of weight related modifications, comparison of these newly designed vehicles with conventional truck and trailer configurations to detect differences in net load weight, determination of the impact of vehicle design changes on net load capacity, and estimation of the incremental investment value of these light-weight vehicles.

STUDY METHODS

The contractor participating in the study had previously used conventional truck-trailer combinations with tare weights ranging between 13 and 14.5 tons. To reduce truck and trailer weight, three truck-trailer units equipped with lightweight aluminum components were purchased and placed into service in the Fall of 1988.

Purchased trucks were modified by the manufacturer to include 55 gallon aluminum fuel tanks (replacing standard 75 gallon steel tanks), aluminum cab protectors, aluminum front bumpers, and aluminum wheels and rims to replace standard steel rims. These changes reduced truck weight by approximately 0.35 tons, while increasing the purchase price of the truck by nearly $2,000, from $58,000 to $60,000.

Purchased trailer modifications included super-wide single tire and rim configurations to replace commonly used dual tandem tires and rims - including longer axles, aluminum rims, fewer bolsters - three instead of four - to hold the load, light-weight landing gear, and the use of 14 inch I-beams throughout the trailer to replace commonly used 16 inch I-beams. The weight of these light-weight trailers averaged 4.35 tons, a reduction of 1.40 tons when compared with conventional trailers weighing 5.75 tons (Trevitt, 1989). Trailer prices are typically based on trailer weight and the final cost of the light-weight trailers, approximately $10,500 per unit, were comparable to the price associated with conventionally equipped trailers. The cost per trailer was increased somewhat by adding the super-wide single tire configuration.

The overall reduction in truck and trailer weight averaged 1.52 tons, from a mean combined weight of 13.83 tons for conventional units to a mean combined weight of only 12.31 tons for the light-weight units. Total cost of a light-weight truck/trailer at the time of purchase (Fall-1988) was approximately $70,500 per unit. The cost of a conventionally equipped truck/trailer combination at that time averaged $68,500.

Weight related data for light-weight and conventional truck configurations were obtained from randomly selected weight scale tickets for pulpwood and chip'n'saw product loads hauled off a tract in middle Georgia. Loads were measured by permanent weight scales located at the mill woodyard and operated by mill employees.

Data from each weight scale ticket provided gross, net, and tare weight in pounds. Weight tickets for each vehicle configuration were randomly selected from two different product groups, pulpwood and chip'n'saw material, to determine if the weight characteristics associated with these products affected net load weight for either configuration.

Statistical analysis was conducted to determine if significant differences in delivered weight could be detected for gross, tare, and net weights for all loads and for the different product types. Economic comparisons were made to quantify the financial differences associated with the conventional and light-weight vehicles. The economic analysis incorporated mean weight data from the study with cost and revenue data provided by the contractor to quantify the financial attraction of investing in weight modified haul vehicles.

RESULTS AND DISCUSSION

A summary of observed net load weights for conventional and light-weight haul vehicles is provided in Table 1. Mean net load weight increased by an average of 2.07 tons when using the light-weight vehicles. Comparison of the relative frequency distributions indicates a definite placement shift to the right for loads delivered by the light-weight vehicles (Fig. 1).

Changes in mean gross weight for the light-weight units were significant at the 0.005 level with a computed t-value of -3.89 (Table 2). Significant differences in mean net load weight were also measured for both the pulpwood and chip'n'saw products at an alpha level of 0.005.

A financial analysis comparing the revenue from conventional and light-weight truck/trailer investments was conducted to quantify potential investment returns (Table 3). Analysis assumptions included a 10 percent hurdle rate on the investment, an average haul rate of $3.50 per loaded ton ($0.07 per loaded mile and averaging 50 miles per haul), an average of 2.75 hauls per day, estimated mean net load per haul of 25.83 tons for the conventional haul vehicle and 27.90 tons for the light-weight vehicle. Gross revenues estimated from this data averaged $65,792 per year for the light-weight vehicle and $60,910 per year for the conventional vehicle. These revenue differences resulted from differences in net load capacity.

Costs considered in the analysis included variable costs such as fuel, oil and lube, tires, and maintenance. Fixed costs included the purchase cost, taxes, interest, and insurance. Cost estimates were developed through discussions with several logging contractors.

Table 1: Summary of weight observation data.

Observations	N	Min	Max	Mean	S.D.
		(Tons Per Load)			
GROSS:					
Conventional	96	36.50	42.92	39.66	1.146
Light-weight	111	38.16	41.60	40.21	0.785
TARE:					
Conventional	96	13.37	14.27	13.83	0.226
Light-weight	111	11.78	13.10	12.31	0.215
NET:					
Conventional	96	23.00	29.37	25.83	1.166
Light-weight	111	25.75	29.96	27.90	0.788
NET PULPWOOD:					
Conventional	41	23.00	29.37	25.80	1.343
Light-weight	80	25.67	29.44	27.81	0.818
NET CHIP'N'SAW:					
Conventional	55	23.37	28.93	25.86	1.013
Light-weight	31	26.78	29.96	28.13	0.653

Fuel costs were estimated by assuming a mileage rate of 6.0 mpg (average of loaded and unloaded travel), an assumed cost of $0.80 per gallon of diesel fuel, and an annual mileage of 75,375 miles. Mileage was based on 245 days of hauling per year, 2.75 hauls per day, and a 50 mile average one-way haul. The computed haul mileage estimate of 67,375 miles per year was increased by 8,000 miles to 75,375 miles per year to account for travel to and from home base and other miscellaneous travel, such as moving equipment between sites.

Lube costs were estimated at 10 percent of fuel costs. Tire expenses were estimated at $3,600 per year for the light-weight unit and $3,000 per year for the conventional truck, with the difference accounting for the higher price of super-wide singles mounted on the light-weight unit. Maintenance costs were assumed to be 60 percent of annual depreciation and averaged $8,220 per year for the conventional vehicle and $8,460 per year for the light-weight unit.

Fixed costs included taxes of $2,475 per year and insurance, estimated at $2,500 per year. Purchase price for the units varied slightly, with the conventional vehicle costing $68,500 and the light-weight vehicle costing $70,500.

Incremental analysis was used to analyze the investment value associated with purchasing a light-weight haul truck. Cashflows were estimated over a five year investment period for the conventional and light-weight vehicles. The additional costs and revenues associated with the light-weight vehicle were then separated and financially analyzed to determine the

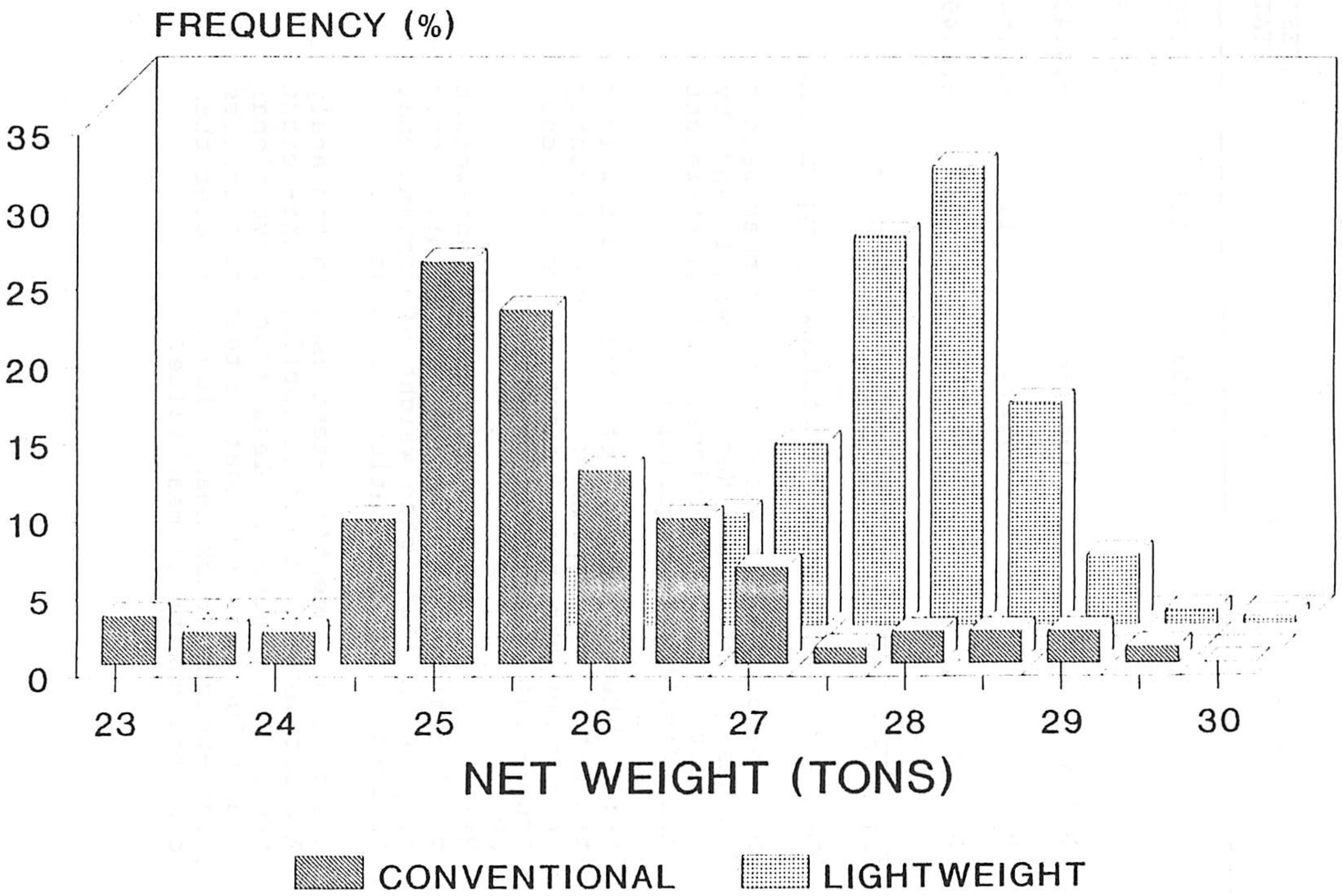

Figure 1: Frequency distribution of net load weight data for conventional and light-weight truck-trailer combinations.

Table 2: Statistical analysis results comparing weight data for conventional and light-weight haul truck configurations.

COMPARISON[1]	S_p	D.F.	TEST STAT
GROSS WT	1927.85	205	- 3.89[a]
TARE WT	438.52	205	+47.18[a]
NET WT	1952.88	205	-14.43[a]
NET-PULP	2032.35	119	-12.54[a]
NET-CNS	1780.61	84	-18.49[a]

[a] Significant at the 0.005 level.

[1] Comparisons made under the following hypotheses:

Ho: No difference exists between mean weight (Gross, Tare, and Net - overall and by product) for conventional and light-weight truck/trailer configurations.

Ha: Mean weight of the light-weight truck-trailer combination is significantly less than the mean weight of conventional truck-trailer combination (Tare).
OR
Ha: Mean weight of the light-weight truck-trailer combination is significantly greater than the mean weight of conventional truck-trailer combination (All others).

One tailed Student's t-test used in the analysis. A positive test statistic implies light-weight truck mean value is less than conventional mean value, while a negative test stat implies light-weight truck mean value is greater than conventional truck mean value.

Table 3: Incremental investment analysis to determine added investment value of light-weight haul vehicles.

COST/REVENUE FACTOR	CONVENTIONAL	LIGHT-WEIGHT	DIFFERENCE
	(Cost/Revenue)		
Fixed Costs:			
Purchase Price	$68,500	$70,500	($ 2,000)
Taxes	$ 2,475	$ 2,475	0
Insurance:	$ 2,500	$ 2,500	0
Variable Costs:			
Fuel[2]	$10,067	$10,067	0
Oil, Lube[2]	$ 1,007	$ 1,007	0
Maintenance[1]	$ 8,220	$ 8,460	($ 240)
Tires	$ 3,000	$ 3,600	($ 600)
Labor @ $7.35/SMH	$15,000	$15,000	0
Revenue:			
Gross per year[3]	$71,194	$76,899	$ 5,705

Incremental Investment Values:	
Internal Rate of Return (IRR):	242.7 percent
Net Present Value (NPV) at 10 percent hurdle rate and 5 yr investment period:	$16,442

[1] Assumed 60 percent of annual straight-line depreciation to estimate maintenance expenses. No salvage value assumed.

[2] Fuel and oil/lube consumption estimated using mileage estimate for deliveries, adding 8,000 miles for travel to and from home base, and a 6.0 mile per gallon fuel efficiency value. Annual mileage estimated to be 75,500 miles per year.

[3] Revenue Assumptions:
Haul rate = $0.07 per ton-mile
Average haul distance = 50 miles (one way)
Average loads per week = 2.75 loads
Assumes 5 day work week and 49 week work year.
Mean net weight per load - Light-weight: 27.90 tons
Conventional: 25.83 tons

incremental internal rate of return (IRR) and net present value (NPV). Under the assumptions detailed previously, the incremental IRR associated with investing in a light-weight haul truck was estimated at 242.7 percent annually. Incremental NPV associated with the investment at a 10 percent hurdle rate was estimated at $16,442.

CONCLUSIONS

The results suggest that substantial increases in investment return can be attained through a conscious effort to reduce truck and trailer weight. While the actual returns from an investment in a light-weight haul vehicle may not reach the rates estimated in this analysis, the results indicate that substantial benefits do exist. For the contract logger or hauler who must replace an aging haul truck, these results strongly suggest that weight light-weight haul trucks equipped with on-board electronic scales provide far greater return on investment than conventionally fitted haul trucks. Contract loggers or truckers interested in increasing the return associated with log hauling operations should seriously consider similar truck and trailer weight reduction efforts, where appropriate.

LITERATURE CITED

Beardsell, M. 1986. Decreasing the cost of hauling timber through increased payload. VPI & SU School of Forest Resources, Blacksburg, VA. 133 p.

McNeel, J.F. 1988. Super-wide singles on timber haul trucks. APA tech. release 88-R-44. 2 p.

Shafer, R., J. McNeel, P. Overbow, and J. O'Roarke. 1987. On-board scales: Application to southern timber harvesting. S.J. of Applied Forestry 12(1):37-41.

Trevitt, D. 1989. Personal communication.

ECONOMICS OF A CUT-TO-LENGTH HARVESTING SYSTEM IN SECOND THINNINGS

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ABSTRACT

A Norcar 600H harvester and a 490 forwarder have been in operation in south Alabama since October, 1989. These machines have been tested in second-thinnings. Productivity has ranged from 3.8 to 27.4 cords per PMH in tree sizes of 4.5 to 15.4 inches DBH. These machines have been able to produce wood on a trailer at roadside for less than $15.00 per cord.

KEYWORDS: Harvesting, Thinning, Forwarding

INTRODUCTION

During the Fall of 1989 and the Spring of 1990, data were collected on a mechanized cut-to-length harvesting system performing second thinnings. The system consisted of two separate machines, a Norcar 490, 7.5 tonne capacity forwarder and a Norcar 600H single-grip harvester with computerized length and diameter sensors. These machines were powered by Perkins 85-hp and 120-hp engines respectively, with power transferred through an eight-wheel hydrostatic drive power train. Operator cabs were ergonomically designed with air conditioning, electronically actuated hydraulic joystick controls, AM/FM stereo, and lighted for night operation.

Data on thinning for the Norcar 600H harvester were collected under two different conditions:

1. 325 observations were collected in stand 1, which was a second thinning with a trained Finnish driver as the operator, and
2. 436 observations were collected in Stand 2, a second thinning with a US operator-in-training.

The timber stands being thinned were loblolly pine (*pinus taeda*) plantations aged 19 and 20 years old. Individual stem sizes ranged from 5 to 15 inches diameter breast high (DBH), with volumes ranging from 0.78 to 38.23 cu. ft. per stem. Site index on both stands was approximately 95 at base age 25.

Overall objectives for the study were:

1. to determine productivity of the system in second thinnings, and
2. obtain a preliminary estimate of system operating costs.

DATA COLLECTION TECHNIQUES

Data for the harvester were collected by a two-person team. One person rode inside of the cab and read diameters and lengths of each piece cut, as displayed on the harvester's computer display, into a microcassette audio recorder. This information was used to determine volume of each piece harvested. Reference points were read into the recorder at frequent intervals.

The harvester operation was video taped by the second person, to collect data for the elemental time study. These elements consisted of: 1) select and cut, 2) process first piece, 3) process remaining pieces, and 4) move. These elemental times were extracted from the video tape in the office and combined with the individual tree measurements into a data file for analysis.

Data from the forwarder operation were collected in two phases. The first phase required two persons. Each piece was numbered and the length and two end diameters were measured. The distance from the center of each piece to the centerline of the forwarder trail was also measured. The time to load each numbered piece was then taken with an electronic stopwatch. The second phase was accomplished by one person who collected the time in the field with an eletronic stopwatch on the individual forwarder elements. These elements were: 1) travel empty, 2) load (each grapple swing), 3) move during loading, 4) travel loaded, and 5) unload.

DATA ANALYSIS

The objectives of the data analysis for the harvester were to determine the effect, if any, of tree DBH and volume, and the number of pieces cut from each tree on the times to select and cut, process the first piece, process the additional pieces, total process time, total time to harvest the tree and the observed productivity.

The independent variables used in the analysis were tree DBH, merchantable volume, the number of pieces cut from each tree, and the interactions between DBH and volume, DBH and number of pieces, and volume and number of pieces.

Observed productivity for each tree was calculated by determining the cords per tree and dividing by the time to process the tree. Conversion factors of 54 lbs./cu. ft. of wood and bark and 5,350 lbs./cord were used to convert the merchantable volume per tree to cords per tree.

Statistical analyses involved calculation of Pearson product-moment correlation coefficients to determine the linear relationships between the dependent and independent variables. Multiple linear regression analyses were then used to develop models to predict the dependent variables in terms of the independent variables. The Stepwise Procedure was used to develop initial models and determine the amount of variability described by each dependent variable in the model. Models containing multiple independent variables were also analyzed for multicollinearity.

RESULTS

Harvester

A regression model was developed for each stand to predict the volume in cubic feet and the number of pieces harvested per tree by DBH. These variables were then used to predict harvester productivity by DBH. These models are:

Stand 1:

$$VOL = -7.813 + 1.869*DBH + 0.052927*DBH^2$$
$$R^2 = 0.887$$

$$PIECES = -0.86630 + 0.6282*DBH - 0.2462*DBH^2$$
$$R^2 = 0.429$$

$$PROD = -1.961 + 0.5502*DBH + 1.871*VOL - 0.04502*DBH*VOL - 0.1786*PCS*VOL$$
$$R^2 = 0.809$$

Stand 2:

$$VOL = 6.904 - 3.852*DBH + 0.7203*DBH^2 - 0.02530*DBH^3$$
$$R^2 = 0.917$$

$$PIECES = -1.517 + 0.7495*DBH - 0.02987*DBH^2$$
$$R^2 = 0.532$$

Table 1. Merchantable volume per tree and number of pieces per tree by stand.

DBH	Volume Stand 1	Volume Stand 2	Pieces Stand 1	Pieces Stand 2
	(cu. ft.)			
5	2.86	2.49	1.66	1.48
7	7.86	6.56	2.32	2.27
9	13.29	12.14	2.79	2.81
11	19.15	18.01	3.06	3.11
13	25.43	22.97	3.14	3.18
15	32.13	25.80	3.02	3.00

$$PROD = -1.539 + 0.6683*DBH + 0.9754*VOL - 0.1257*PCS*VOL$$

$$R^2 = 0.873$$

where:

VOL = volume per tree (cu. ft.),
PIECES = number of pieces per tree, and
PROD = productivity (cds/hr).

The volume per tree and number of pieces per tree by stand are shown in Table 1. As can be observed, the average tree size of Stand 2 was smaller than Stand 1.

The average time to select, cut and process a tree in Stand 1 was 24.6 seconds or 2.4 trees per minute, and in Stand 2 was 26.2 seconds or 2.3 trees per minute. The average time to select and cut a tree was about 11 seconds in each of the two stands; so, the differences in times for the two operators were due primarily to differences in times required for each operator to process a tree.

As shown in Table 2, predicted productivity ranged from a low of 3.8 cords per productive machine hour (PMH) in the 5-inch DBH class to a high of 27.4 cords per PMH in the 15-inch DBH class. Since the machine can process about two trees per minute the primary determinant of productivity is tree size.

Productivity was calculated on a productive machine hour basis, with no allowance for mechanical or non-mechanical interruptions. Productivity was calculated for each tree DBH class based on the merchantable volume processed from the tree.

The relationship of productivity and dbh was almost linear in both stands up to a tree size of approximately 12-inch DBH. As the tree size increased above 12- inch DBH, for the Finnish operator, productivity increases were minimal.

Table 2. Norcar 600H harvester predicted productivity per PMH by stand by DBH.

DBH	STAND 1	STAND 2
	(cords)	
5	4.64	3.77
7	10.86	7.67
9	15.85	12.03
11	19.95	16.33
13	23.63	20.38
15	27.40	23.91

Table 3. Basic assumptions used in machine cost calculations.

	HARVESTER	FORWARDER
Purchase price ($)	295,000	150,000
Amt. borrowed (%)	90	90
Machine life (yrs)	5	5
Salvage Value (%)	20	20
Fuel Cons. (gal/hr)	2	1.3
Oil & Lube (gal/hr)	0.1	0.08
PMH/yr.	1404	1512
Insurance ($/yr)	13,275	6750
Maint. & Repair ($/hr)	40.00	20.00

Table 4. Harvester costs and total system costs by DBH and stand.

	Harvester Costs Stand		System Costs Stand	
DBH	1	2	1	2
	$/cd.			
5	24.31	29.97	32.34	38.00
7	10.39	14.72	18.42	22.75
9	7.12	9.38	13.98	16.24
11	5.66	6.91	12.52	13.77
13	4.78	5.54	11.64	12.40
15	4.12	4.72	10.98	11.58

Forwarder

Forwarder productivity was based on forwarding distances of 200 to 900 feet. Travel speeds empty ranged from 1.27 to 3.31 MPH. Loaded speed ranged from 1.09 to 2.71 MPH.

Capacity of the forwarder was 7.5 tonnes, or approximately 3 cords. On a productivity basis, the forwarder was able to produce 8.87 cds/PMH when forwarding chip-n-saw (C-N-S) and 7.58 cds/PMH forwarding pulpwood. Average cycle time for the study distances was less than 24 minutes per cycle.

Production Costs

Production costs were calculated on an after-tax cash flow basis, using the Cash Flow & Machine Rate Comparison Program (Burgess and Cubbage, 1990). A discount factor, to account for inflation and opportunity costs, of 8 percent and an interest rate, which repesented the cost of borrowing, of 12 percent were used in the calculations. Assumptions used in the operation costs for both machines are shown in Table 3.

Cost of operation for the harvester was $112.87/PMH, which included $40.00/PMH maintenance cost, based on experience during the past eight months. After-tax cash flow cost for the forwarder was $60.84/PMH. On a production basis, the cost of forwarding C-N-S logs was $6.86/cd and $8.03 /cd for pulpwood.

Harvester costs by stand and DBH are shown in Table 4. Harvester costs per cord for the Finnish operator ranged from $24.31/cd in the 5-inch DBH class to $4.12/cd in the 15-inch DBH class. Harvester costs for the US operator ranged from $29.97/cd in the 5-inch DBH class to $4.72/cd in the 15-inch DBH class.

Total system cost for a perfectly balanced system was $173.71/PMH. Cost of wood delivered to roadside ranged from a high of $38.00/cd for the 5-inch class to a low of $10.98/cd for the 15-inch class.

SUMMARY

Although the initial capital investment for this mechanized cut-to-length system appears to be high, the production cost on a unit basis appears to be cost competitive with conventional mechanized tree-length systems. Further research is needed to determine the additional value received from the capability to merchandise small sawlogs out of second thinnings with the computerized length and diameter sensing capability of the harvester. Also, additional work is needed to evaluate the visibly improved environmental impact to the residual timber stand and site.

LITERATURE CITED

J.A. Burgess and F.W. Cubbage. 1990. Fixed and operating cost analysis system. Electronic spreadsheet template. Univ. of Georgia. Athens, Ga.

MACHINERY SYSTEMS IN THE USA AND ABROAD

MECHANIZED LOGGING IN THE USSR

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ABSTRACT

The USSR contains twenty-five percent of the world's total volume of timber. However, the current Soviet machines require higher levels of technology to sustain effective and efficient mechanized logging processes. Wasteful over-cutting, lack of reforestation, limited transportation, and economic constraints prohibit the steady growth of the Soviet forest products industry.

Key Words: Mechanized, Technology, Constraints, USSR, Prohibit, Timber.

INTRODUCTION

The forest products industry in the Union of Soviet Socialist Republics (USSR) has the potential for unbounded expansion if given the proper support to overcome the industry's constraints. Caterpillar's previous involvement with the Soviet Union has given Cat an interest in the Soviet forest machinery market. As a country, the USSR owns a significant amount of untapped timber resources. Several million Soviets are already part of this major industry. However, with the current harvesting machines and techniques, no one will be able to take advantage of these abundant resources. The objective of this paper is to discuss Caterpillar's involvement, the USSR as a country, the Soviet forest products industry, and the current Soviet machines to better understand the vast potential of the forest products industry in the USSR.

CATERPILLAR'S INVOLVEMENT

Caterpillar's involvement with the USSR is through the Geneva and Moscow offices. Caterpillar's efforts in the USSR have been pipelayers, mining equipment, and forest road construction equipment. Their biggest set back in the Russian market was in the late 70's when the Carter administration activated an embargo and would not issue licenses to do business with the Soviets. This embargo carried on into the Reagan administration era and significantly affected our company, in particular, the pipelayer sales. Since the embargo has been lifted, Cat has been trying to reestablish its position in the Soviet market place. We are now interested in supplying forest harvesting systems to help efficiently and effectively retrieve some of the untouched timber.

In the USSR, Caterpillar tractors are kwown to be excellent for construction and earthmoving functions. The forest road construction involvement has been assisted by the KS agreements which are trade agreements for Japan to supply Caterpillar tractors to the USSR for logs from the USSR. The KS acronym stems from the first letter of the surname of each negotiator of the agreement. In a period of thirteen years the USSR will receive 3050 D6D's.

Current Soviet forest harvesting methods lack the necessary technology to be effective and efficient. Logging is the least developed process of any USSR forest industry branch. Only twelve percent of the timber is felled by machine, twenty-one percent is grapple skidded, and fifteen percent is delimbed mechanically. Cat would like to provide them with complete mechanized logging systems to increase productivity.

THE USSR AS A COUNTRY

The general features of the country are conducive to a possible wide spread forest industry. The USSR covers 8.6 million square miles which is 2.5 times the size of the United States (U.S.). It stretches 6800 miles across two continents and has fifteen internal republics with the Russian Soviet Federated Socialist Republic being seventy-six percent of the territory. Eleven time zones cover in longitude from twenty degrees east to 170 degrees west and thirty-five to eighty degrees north in latitude. The population at 280 million people is only slightly larger than the U.S. Moscow is the country's largest city with 8.6 million people (Black, 1988).

The geography of the Soviet Union can be divided into three distinct regions. The Western region, the European Industrial Heartland, has been the country's significant timber supplier. Overcutting has occurred in this area, causing the depletion of forest resources. On the other side, the Far East has enormous timber reserves but is not a major supplier. Scarce labor and high development costs are major constraints to accessing this timber. In between these two regions, there is Central Asia. No significant timber reserves exist in this area. However, explosive population growth exists with an average of four to five children per family.

Many different types of people exist in the Soviet Union. The four major ethnic groups are the Russians, Ukrainians, Uzbeks, and Byelorussian. Many of these people rely entirely on the forest resources in the Western region which are quickly becoming scarce. Limited Western timber means that these people will need the technology necessary to access the timber in the Far East.

Russian is the official language of the country, however, over 100 other languages are spoken. Eighteen of these are spoken by groups of more than a million people (Black, 1988). French, German, and English are the next most frequently spoken languages. This many languages is an example of the country's diversity.

Below is a picture of the Saint Baisles Cathedral (figure 2.1). The principal religions would include

Figure 2.1: SAINT BAISLES CATHEDRAL.

Russian (Eastern) Orthodoxy, Islam, Roman Catholicism and Protestantism. Compared to the U.S., religion is a suppressed institution in the USSR.

Below is one type of car in the Soviet Union. It is a Lada (figure 2.2). This particular one is a

Figure 2.2: SOVIET LADA.

"sporty" two door model with the luggage rack included. These cars are usually painted black or green.

The value of Soviet exports exceeds that of imports by ten billion U. S. dollars. The Soviets export 95 billion U.S. dollars and import 85 billion U.S. dollars worth of goods. Fifty-six percent of the trade is with communist countries while thirty percent is with Western nations. The Federal Republic of Germany is the largest Western trade partner. Non-Communist developing countries comprise the other fourteen percent of the trade (Black, 1988). Surprisingly enough forest products are only five percent of the total exports.

Below is a Russian Pepsi logo which signifies that American corporations are not new to the USSR (figure 2.3). Also, McDonald's has opened a restaurant in Moscow, which indicates that the Soviets are willing to accept American products. Furthermore, in 1989 the Soviet industry business declined by one percent after several years of reported growth. They lack the technology to maintain steady industry growth particularly in the forest industry.

Figure 2.3: PEPSI LOGO.

The Soviets also have a wide variety of natural resources. They are world leaders in iron ore, coal, and oil. The land resources are primarily the forests. Table 2.1 shows the breakdown of the top three minerals in which the USSR is the leading supplier. It is clear that the Soviets have a significant advantage over the U.S. in iron ore and oil. Both countries produce nearly an equal amount of coal (Editors of Time-Life Books, 1986).

Iron Ore (Million Metric Tons)	
U. S.	75
Brazil	92
USSR	2245
Coal (Million Short Tons)	
China	738
U. S.	785
USSR	789
Oil (Thousand Barrels/Day)	
Saudi Arabia	5062
U. S.	8680
USSR	11864

Table 2.1: USSR A WORLD LEADER IN MINERALS.

THE USSR FOREST PRODUCTS INDUSTRY

Some amazing facts about the forest products industry indicate its potential. Thirty-three percent of the world's standing softwood volume and twenty-five percent of the world's total volume of timber exist in the Soviet Union. Fifty-one billion cubic meters of wood are available, but they only harvest 370 million cubic meters per year, which breaks down into 280 million cubic meters used commercially, and 90 million cubic meters used for fuel. One third of the country's total area, or 746.8 million hectacres is forests (Barr & Braden, 1988).

Figure 3.1 illustrates the logging production patterns from 1913 to 1984. The unstable pattern since 1960 (Barr & Braden, 1988) demonstrates the inability of the Soviet machines to increase productivity every year.

By knowing the types of trees available in the forests, the proper techniques for harvesting the spe-

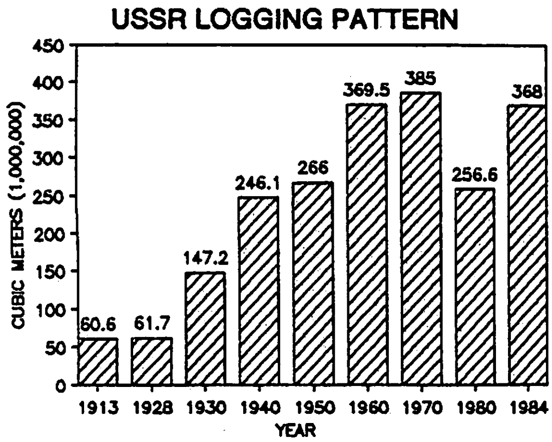

Figure 3.1: USSR LOGGING PATTERN 1913-1984

cific species can be implemented. Conifers comprise 78.3 percent of the trees available. The major conifers include Larch (40.5%), Pine (17.4%), Spruce (12.0%), Stone Pine (6.0%), and Fir (2.3%). The majority of hardwoods are shade intolerant hardwoods (SIH) which make up seventeen percent of the accessible wood. Birch (13.0%), Aspen (2.8%), Basswood (0.8%), and Alder (0.8%) are the significant SIH species. The shade tolerant hardwoods (STH) account for 4.7 percent of the usable timber. Oak (1.4%), Beech (0.4%), and Ash (0.1%) are the notable species (Barr & Braden, 1988). Figure 3.2 represents the species distribution.

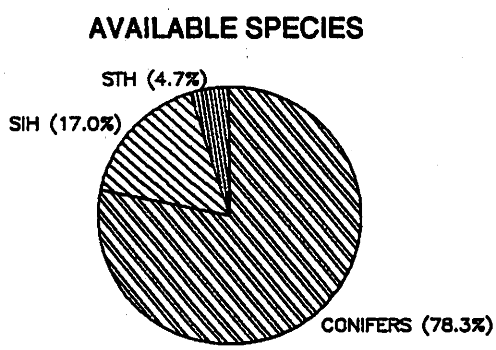

Figure 3.2: USSR SPECIES DISTRIBUTION

The structure of the Soviet forest products industry is very extensive. At the top, GOSPLAN is the state planning commission. MINLESPROM, the ministry of forestry, reports to GOSPLAN. Under MINLESPROM, 2.3 million Soviets are employed. Twenty-eight sub-enterprises known as LESPROMS are subordinate to MINLESPROM. Many branches of loggers are governed by each LESPROMS. MINLESPROM works with several Foreign Trade Organizations (FTO) to import and export products. TRAKTOROEXPORT controls machine trade and EXPORTLES monitors forest product trade. Table 3.1 portrays the industry's structure.

Of the twenty-eight sub-enterprises, DALLESPROM is the major Far East forestry headquarters located in Khabarovsk. It employes 30000 people and has forty branches under it. Sixteen and a half million cubic meters of timber are cut annually by DALLESPROM with six million cubic meters exported to Japan.

Roundwood and lumber are the leading exported wood products from the Soviet Union. Japan (36%), Finland (20%), and China (14%) are the three major importers of the roundwood as shown in figure 3.3 (Barr & Braden, 1988). The problem with exporting to China is that the railroad gauge changes between Russia and China. It takes a significant amount of time and money to change the wheels from the Soviet's gauge to China's.

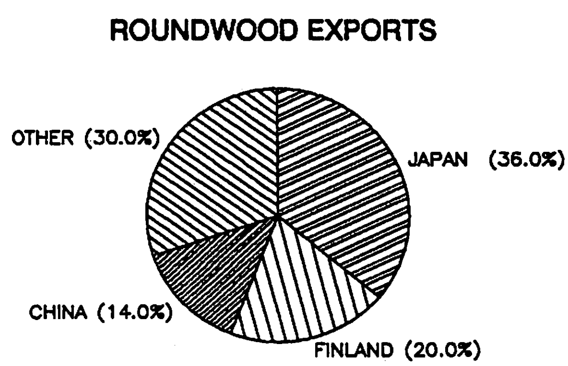

Figure 3.3: USSR ROUNDWOOD EXPORTS

The USSR forest products industry faces several dilemmas. The major concern is that they have plenty of wood available, but they are over using the supply in the West because

GOSPLAN

MINLESPROM - - - - FTO

LESPROM	HEADQUARTERS
KARELLESPROM	PETROZARODSK
MURMANSKLES	MURMANSK
ARCHANGELSKLESPROM	ARCHANGELSK
VOLOGDALESPROM	VOLOGDA
KIROVLESPROM	KIROV
PERMLESPROM	PERM'
BASHLESPROM	UFA
OMSKLESPROM	OMSK
TOMLESPROM	TOMSK
KRASNOJARSKLESPROM	KRASNOJARSK
ZABAIKALLES	ULAN-UDE
JAKUTLES	JAKUTSK
DALLESPROM	KHABAROVSK
SAKHALINLESPROM	JUZSHNO

LESPROM	HEADQUARTERS
LENLES	LENINGRAD
NOVGORODLESPROM	NOVGOROD
KOMILES	SYKTYVKAR
KOSTROMALESPROM	KOSTROMA
GORKLES	GORKIJ
UDMURTLES	IZJEVSK
SVERDLESPROM	SVERDLOVSK
T'UMENLESPROM	T'UMEN
KEMEROROLES	KEMEROVO
IRKUTSKLESPROM	IRKUTSK
CHITALES	CHITA
AMURLESPROM	BLAGOVESHINSK
PRIMORSKLESPROM	VLADIVESTOK
KAMCHATLES	KAMCHATSKY

Table 3.1: USSR FOREST INDUSTRY ORGANIZATION

of the lack of transportation between the East and West. It is very difficult to get the timber out of the East. The BAM (Baykal-Amur Mainline) was initially intended to help people move to the East and provide a means of transporting goods from the East. However, it has never been completed and has been extremely expensive.

The industry is challenged with several constraints to compliment the dilemmas. Wasteful overcutting exists in the West. They do not completely benefit from what is harvested. Lack of reforestation means that negligible second growth timber will be present in the future. Effects of this already present themselves in the Western region. As expressed earlier, the virgin forests are in the East and the customers are in the West. The foreign markets are limited due to currency problems. Low levels of technology concern the industry.

The lack of transportation contributes to the problems. The timber is usually transported by railways, inland waterways, and trucks. However, they have not developed enough in the East to make it cost effective to ship the timber to the West.

The currency of the Soviet economy is detrimental to trade with the U.S. and other foreign countries. The monetary system owns no convertible hard currency. So, the Soviets make their own inefficient harvesting machines and seek joint ventures in hopes of gaining higher levels of technology.

The technological problems prohibit the productivity of the harvesting process. Low levels of mechanization and lack of machine deliveries result from these problems. It is common for only fifty-one percent of the skidding tractors to be ready at one time. The low levels of technology cause wasteful tree cutting practices. Every year, 2.7 million cubic meters are wasted. Logging and Sawmilling exhibit the lowest levels of technology in the industry. The entire process from the forest to the millyard is inefficient. The lack of technology appears to be the root of all concerns dealing with the forest products industry.

The USSR acquires a significant amount of technology from other countries. Figure 3.4 shows that Finland (44.4%) contributes the largest amount, with West Germany (12.8%), Poland (10.5%), and Japan (10.0%) following (Barr & Braden, 1988). The U.S. does not significantly contribute technology to the Soviet forest products industry.

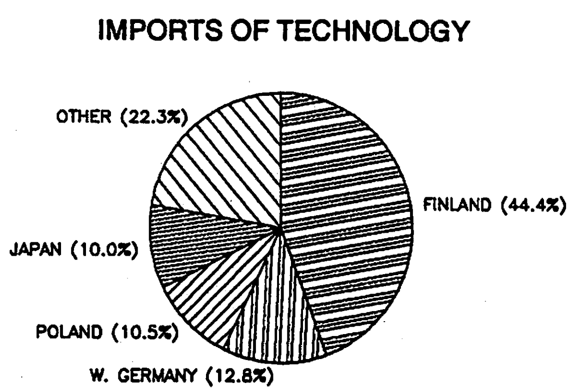

Figure 3.4: USSR IMPORTS OF TECHNOLOGY

Table 3.2 illustrates the comparison between the forest products industry in the USSR and North America which consists of the U.S. and Canada. The USSR has a notably larger portion of the world's forested land and coniferous timber (Economics and Statistics Directorate Forestry Canada, 1989; "Forestry Today", 1989). However, they harvest approximately two thirds the amount of timber harvested by North America. North America produces 1.5 times the industrial timber, 1.7 times the commercial roundwood, 9.4 times the plywood, 8.0 times the chemical pulp, and 2.8 times the fiberboard (Barr & Braden, 1988). These obvious variations can be attributed to the different levels of technology between the industry in each country.

SOVIET MACHINES

Caterpillar has recently made two significant trips to the Soviet Union concerning forestry. In December of 1988, members of the Forest Machinery Unit went to Khabarovsk and a woods site in Mukhen to recommend equipment and see the Soviet equipment. The next trip was to confirm Caterpillar's commitment to the industry. In September 1989 they went to LESDREVMASH which means forest timber machine and is a machine expo in Moscow. Cat also held a seminar for MINLESPROM during this visit to the USSR. The trips provided extensive insight to the Soviet harvesting machines and their problems.

The following pages concentrate on the Soviet machines (USSR Exhibits, LESDREVMASH, 1989). These machines exhibit low productivity and low

	USSR	NORTH AMERICA
PERCENT OF WORLD'S FORESTED LAND	25%	17%
PERCENT OF WORLD'S CONIFEROUS TIMBER	53%	23%
PERCENT OF WORLD'S DECIDUOUS GROWING STOCK	8%	7%
TOTAL FOREST OUTPUT (MILLION CUBIC METERS)	370	600

Table 3.2: USSR vs. NORTH AMERICA (U. S., CANADA).

availability. The vehicles usually use a common chassis designed for the TT4M skidding tractor. The TT4M chassis is adaptive to all types of machines. Skidders, fellers, delimbers, overloaders, and manipulators are all made with this chassis. The TT4M skidder (figure 4.1) weighs 31000 pounds, has 130 hp, and travels up to 6.1 miles per hour (mph).

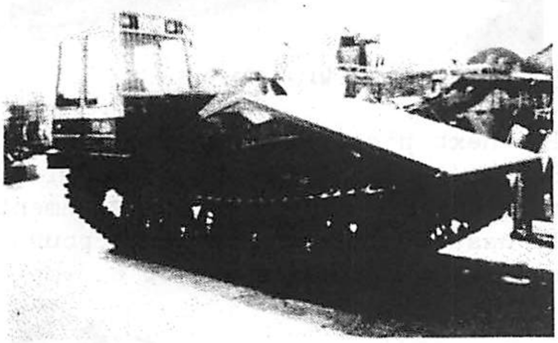

Figure 4.1: TT4M TRACK SKIDDER.

Figure 4.2 is a section of the TT4M undercarriage showing the track and wheels. This undercarriage is also used on many military machines.

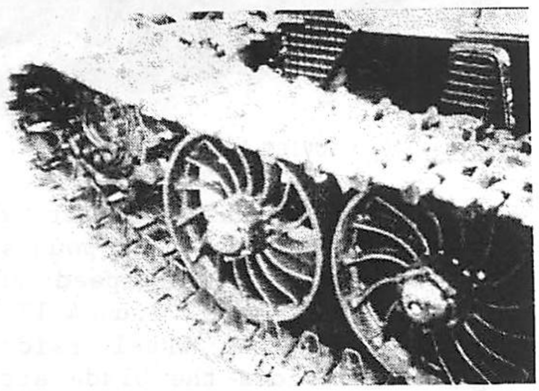

Figure 4.2: TT4M UNDERCARRIAGE.

The machine in figure 4.3 and 4.4 is a Soviet track feller forwarder. It has 165 hp, weighs 57000 pounds, and has a maximum speed of 2.5 mph. It can handle trees with a maximum diameter of twenty-three inches.

The next machine (figure 4.5) is a HEX feller buncher that is similar to the previous feller forwarder with the exception of the undercarriage. It consists of six wheels instead of five.

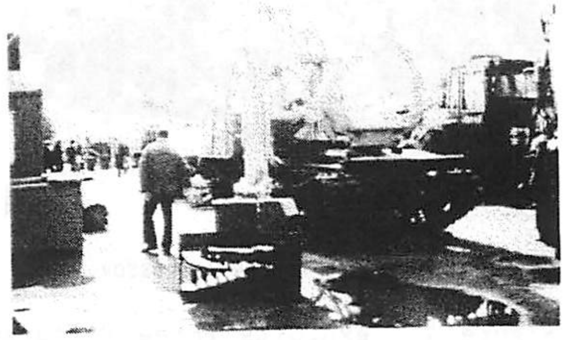

Figure 4.3: TRACK FELLER FORWARDER.

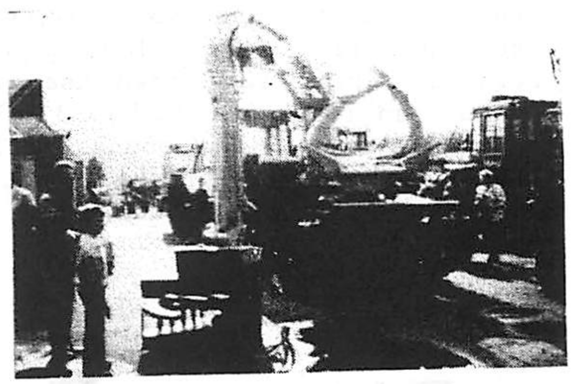

Figure 4.4: TRACK FELLER FORWARDER.

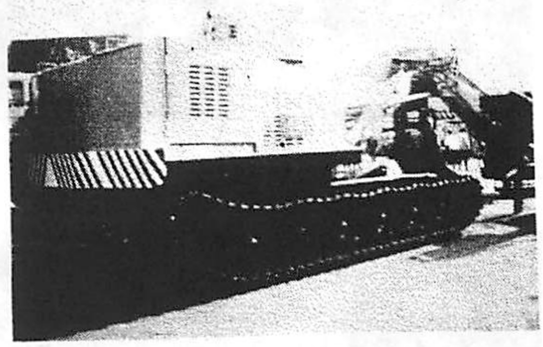

Figure 4.5: HEX FELLER BUNCHER.

This is a Soviet wheel feller processor (figure 4.6). This wheel machine has a higher maximum ground speed than the track machines with all other specifications remaining nearly the same.

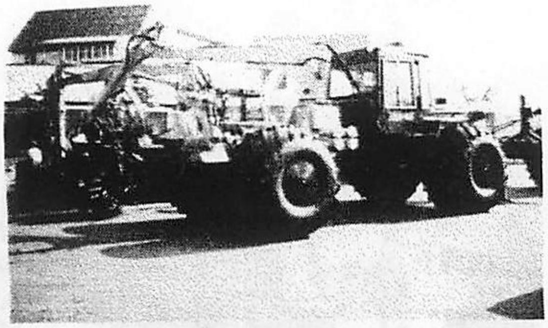

Figure 4.6: WHEEL FELLER PROCESSOR.

Figure 4.7 exhibits three different types of Soviet felling heads to be used with the previously mentioned machines. A processor, bar saw, and disc saw are shown. Figure 4.8 shows the chain saw often used by the Russian loggers. It has 3.5 hp and weighs twenty-one pounds. The felling machines are presently not a major competitor of the chain saw.

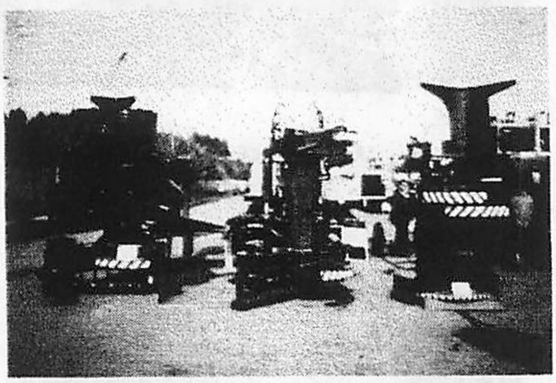

Figure 4.7: SOVIET FELLING HEADS.

Figure 4.8: SOVIET CHAIN SAW.

Figure 4.9 shows the TT4M track skidder with a grapple attachment.

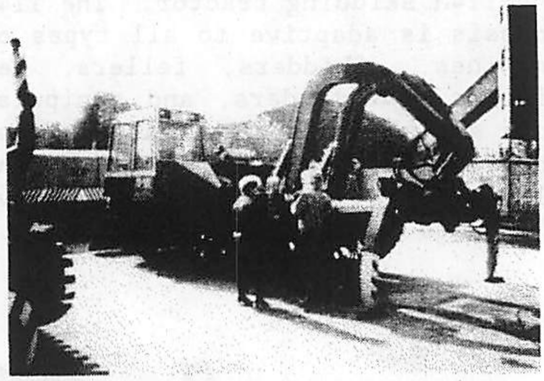

Figure 4.9: TT4M WITH GRAPPLE.

The next picture (figure 4.10) is a Soviet track skidder with a multipurpose manipulator attachment. It has 100 hp, weighs 31500 pounds, and has a maximum speed of 6.7 mph.

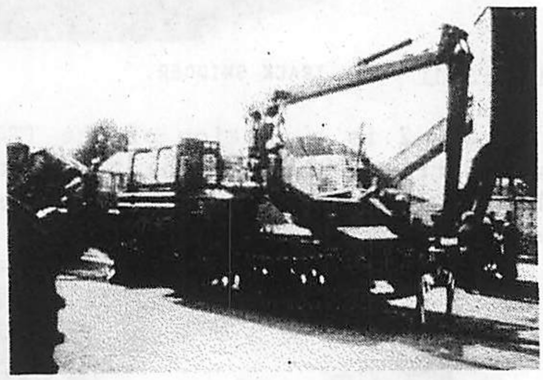

Figure 4.10: SOVIET TRACK SKIDDER.

Figure 4.11 shows a Soviet wheel skidder that weighs 36500 pounds and has a maximum travel speed of 24 mph. Figures 4.12 and 4.13 are pictures of other wheel skidders. Figure 4.13 shows the blade attachment on the front of the machine.

Figure 4.11: SOVIET WHEEL SKIDDER.

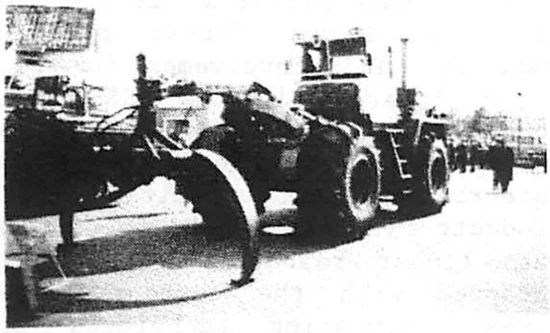

Figure 4.12: SOVIET WHEEL SKIDDER.

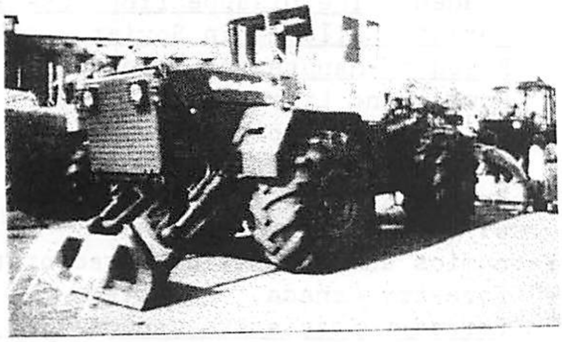

Figure 4.13: SOVIET WHEEL SKIDDER.

Figure 4.14 shows a delimber machine which has 110 hp, weighs 38000 pounds, and can handle trees up to nineteen inches in diameter. Figure 4.15 is a smaller delimber that has seventy-five hp and can handle trees of eighteen inch maximum diameters. The delimbers work with the trees perpendicular to the machines.

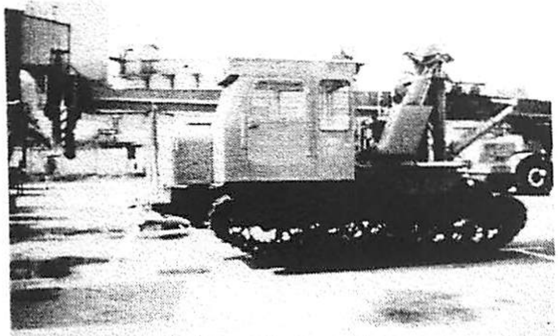

Figure 4.14: SOVIET DELIMBER.

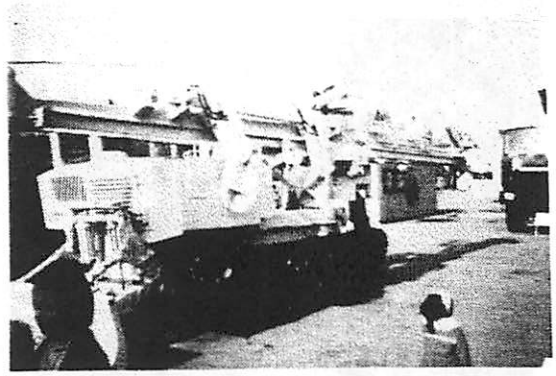

Figure 4.15: SOVIET DELIMBER.

The Soviet rafting an transportation rig in figure 4.16 is designed to assemble short wood bundles of round logs into rafts on the river bank and transport them. Its has a maximum travel speed of twelve mph and weighs 52000 pounds. It can handle logs with a maximum length of 36 feet.

Figure 4.16: RAFTING AND TRANSPORTATION RIG.

The last two pictures are of Soviet overloaders (figure 4.17, 4.18). This machine loads trucks by lifting the trees over itself from the ground to the truck.

Figure 4.17: SOVIET OVERLOADER.

Figure 4.18: SOVIET OVERLOADER

The Soviet operators have expressed dissatisfaction with their machines. Cold start ability, slope limitations (twenty-two degrees), soft ground limits, and ground disturbance are the four primary areas of concern. In DALLESPROM it is common to have one third of the fleet down because of lack of parts. Right now Caterpillar is working on a consignment of parts agreement with the Soviets. In the USSR, no product support systems, managed parts inventories, or dealers exist. They rely almost entirely on cannibalization.

CONCLUSIONS

The changes in the USSR that have taken place recently are PERESTROJKA which means re-structuring and GLASNOST which means openness. These two very positive changes have enabled Caterpillar's involvement with the Soviet forest products industry. This involvement has lead to an interest in the USSR as a country and the practicality of Soviet machines. The USSR has the potential for an unlimited forest products industry. However, the vast timber resources will remain untapped with the current Soviet forest harvesting techniques and machines.

LITERATURE CITED

Barr, Brenton M. and Kathleen E. Braden. The Disappearing Russian Forest a Dilemma in Soviet Resource Management. Totowa: Rowman and Littlefield, 1988.

Black, George. "Big Business for U.S. Business in the USSR." Business Marketing. Nov. 1988: 69-80.

Economics and Statistics Directorate Forestry Canada. Selected Forestry Statistics Canada 1988. Minister of Supply and Services Canada, 1989.

Editors of Time-Life Books. Library of Nations the Soviet Union. Alexandria: Time-Life Books, Inc., 1986.

"Forestry Today." Forests and Forestry in the U.S.A. 1989:11.

USSR Exhibits, LESDREVMASH. Vneshtorgizdat, 1989.

Observations on the Logging Labor Forces of the Nordic Countries and the U.S.

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ABSTRACT

Describes characteristics and structures of the logging labor forces of the Nordic countries relative to the U.S. Demographic variables, ergonomic developments, safety and health relationships, and selection and training are discussed. Working conditions are compared.

INTRODUCTION

The Nordic countries (or more correctly Fenno-Scandanavia) are known for their high levels of forestry practice. Norway, Sweden, Finland, and Denmark intensively practice forestry with modern equipment and technologies, but it is the labor force which operates the machines and carries out the technological operations. Less is known about the labor force policies and organization and their contributions to progress. While a full comparison is beyond the scope of this paper, some observations are useful on the Nordic and U.S. labor forces.

Material for these observations come from a year's sabbatical at the Norwegian Forest Research Institute and study of the topic in the other countries. These observations are extracted from a soon to be published book on The Logging Labor Force: Some Perspectives by the author.

A Strategy for Thinking

Space does not permit every possible comparison of the Nordic labor force and the regional labor forces in the U.S. Thus, readers might form a mental image of the typical logger in their region and use that image to compare to what is described here. In some places, specific data are provided for the labor forces of Oregon and Norway to illustrate ideas. There are differences between the labor forces in the various logging regions of the U.S. which can be as great as those between the U.S. and the Nordic countries. The labor forces of the Nordic countries are more similar than different.

There are many similarities of the logging labor forces that will not be much discussed but which are the essence of human relationships. Nordic loggers love to hunt and fish. They work hard compared to the rest of the population. They have a deep knowledge and respect for the forest in which they spend their working lives. They have families and social obligations. They are interested in vehicles and mechanical things. They are independent and honest. They don't have problems looking you straight in the eye. Not everyone fits this characterization, but many do. How does this compare with the reader's mental image?

General Comparisons

There are profound differences between the social democracies of the Nordic countries and the free-enterprise, market economy of the U.S. Outward appearances may be similar but living in the countries reveals cultural, historical, and institutional differences that influence how the labor force developed over time. One aspect is worth noting: cooperation. The Nordic countries have a long history of cooperating with each other through associations to counter imbalances of power or to pool resources. Landowners formed associations to counter powerful timber merchants. Workers formed unions to negotiate with individual mills. Forestry employers formed associations to counter powerful unions. Research institutions formed associations to attack the ergonomic problems in logging. Cooperation rather than conflict are social goals. Government rather than the market solves disputes and controls and allocates some resources.

Missing are some common attributes of U.S. logging operations such as: productivity pushes, competition, unemployment, minimum wages, insurance costs, macho work, long hours, complaints against governments or employers, and widely different logging machines and systems. Readers are left to assign values as positive or negative for these missing attributes based on their own view.

Table 1. provides a general look at forestry in the Nordic countries and two states to help readers scale their thinking to the operations and forestry activities.

View of the Labor Force

The largest view of the labor forces are provided by census statistics and table 2. shows the U.S. and Norway compared on some dimensions for 1980 census data. Data for 1990 should show substantial changes for both countries. What is more significant is how the U.S. and the Nordic countries think about labor. While individual logging managers vary, many U.S. firms behave as though logging labor plays no significant role in affecting productivity, quality, environmental performance, or any other goal of the firm. Labor problems are vaguely identified, but few constructive improvement measures are undertaken. Safety and health statistics verify this approach by the U.S. industry. In contrast, labor in the Nordic countries is viewed more as human capital, and measures are taken to improve performance because it is good for the firm and the labor force. Quality labor is scarce and both society and the firm take a high interest in working conditions throughout all industries.

Contrary to what many believe, the Nordic countries do not have extensive regulations covering the working environment in detail. Oregon's logging safety code is far bulkier than Norway's. Most working inprovements are made through research, cooperative efforts, and moral persuasion. However, the few laws, e.g. safety and health, may have criminal as well as civil consequences, e.g. for knowingly causing damage to workers. Also, as seen later, working agreements reinforce the importance of labor.

Which Labor Force?

It is important to clarify which labor force the following observations apply. Table 3. shows a breakdown of estimated labor forces for Oregon and Norway under the classifications of professional versus part-time; motor manual versus machine operators; and by the type of employment circumstances. Remarks later showing working conditions in Table 5. refer to professional workers who are employes. All labor force categories are important and deserve consideration.

Nordic Contractors and Active Forest Owners

A few brief comments are needed about the differences between U.S. and Nordic contractors and active forest owners (those who do all or part of their own harvesting activity). First, many Nordic contractors are one person-one machine companies. Owning a $300,000 harvester or $200,000 forwarder, one person will contract for work under social and legal environments quite different from the U.S. Many of these would violate U.S. contracting regulations and make contractors employes of the companies. Contractors work 50-80 hours per week and do not receive the benefits in Table 5. Contractor numbers are high in Finland where they are organized into a bargaining association. Their numbers are increasing in Sweden and Norway.

Harvest by landowners themselves contributes a significant but declining portion of Nordic harvests. These "active forest owners" have special problems as part-time loggers. Extension efforts reach many but not all, and this group has safety, health and ergonomic problems with their harvest activities. Farm tractors with winches, small cable systems, and small tractor-mounted processors are common

Table 1. Nordic Forestry, Oregon and North Carolina

Millions	Oregon	Denmark	Norway	Sweden	Finland	North Carolina
Population	2.7	5.1	4.2	8.3	4.9	8.0
Forest Area hectares	12.0	0.5	6.7	23.6	20.1	7.4
Harvest cubic meters	45.0	2.2	10.0	70.2	45.7	10.0
Ownership (percent) Private Non-Industrial	16.0	45.0	77.0	49.6	64.0	67.0
Industry or Large Common	22.0	20.0	10.2	23.5	8.0	23.0
Government	62.0	35.0	12.8	26.9	24.0	10.0
Employment Years Work in 1000's	14.5	3.5	7.5	25.0	10.2	8.0

Table 2. Logging Labor Force Characteristics: Norway and U.S. (1980 Census Data)

	Total	White	Black	Native	Spanish	Male	Female
U.S. Logging work force	173,221	142,784	26,119	3,333	2,415	95.5%	4.5%
Norway	6,843						
Logging	5,247					92.5%	7.5%
Forestry	1,596					74.2%	25.8%

Percent Rural

U.S.	77.0%
Norway	78.0%

Age Distribution Relative to Country (Percent)

Age Group	16-24	25-34	35-44	45-54	55-64	65+
U.S. Logging	19.8	29.6	22.3	16.0	9.8	2.5
All U.S. Workers	19.6	27.9	19.9	16.7	12.4	3.4
Norway Logging	24.8	14.6	13.7	17.0	16.8	13.1
All Norway Workers	20.8	23.5	19.8	16.4	12.8	7.1

Table 3. Which Labor Force?
(figures estimated by Author)

	Professional		Part-Time	
	Oregon	Norway	Oregon	Norway
Motor-Manual	8800	3400	2800	900
A	5%	30%	5%	5%
B	5%	50%	15%	90%
C	90%	20%	80%	5%
Machine Operators	4200	800	200	100
A	6%	25%	---	---
B	2%	10%	50%	100%
C	92%	65%	50%	---
	13,000	4200	3000	1000

A = Employees of Firms
B = Forest Owners
C = Contractors or Contractor's Employees

Table 4. Scope of Ergonomic Research in the Nordic Countries
Research Topics 1969 - 2000

1969 - 1973

The input of manual work to harvesting over time.
Capacity of forest workers as measured by oxygen consumption.
Biological measures of workers: anthropometric data, muscle strength, coordination, ergometer capacity.
Measurement of stress and strain on forest workers.
Analysis of blood chemistry and relation to work.
Heart rate measures.
Work attitude measures through questionnaires.
Measurement of noise.
Motor saw vibration and white finger (Raynaud's Syndrome).
Measurement of lighting and sight measures.
Shift work measurement with mechanization.
Training of mechanized harvesting operators.
Measurement of whole body vibration.

1974 - 1976

Work tests and their relationships with variables of interest and certain indices.
Blood lactate and chatechlomans in relation to vibration.
Work environment in tractor transport versus manual cutting (questionnaires).
Workers' evaluation of the ergonomic properties of the tractor for transport.
Development of clothing for cold weather.
Learning of grapple loading (forwarders).
Ergonomics of the tractor mounted winch.
Injuries using the tractor mounted winch.
Injuries in timber cutting in Sweden.
Work on small forest properties -- issues of safety and work technique.

1977 - 1980

Motor saw vibration and chain maintenance.
Work organization studies.
Job satisfaction surveys (Finnish).
Accidents of forest owners.
Treatment of disabled forest workers.
Packing of snow to aid cutting.

1981 - 1983

Organization of work in forestry.
Progression of work studies from Taylorism to human relations work to socio-technical autonomous groups to efficiency measures (rationalization).
Attitude and social attributes studies.
Training of forest workers.
Progression to results-related salary - Swedish wage system.

1984 - 1986

Risk analysis of the cutting work of self-employed.
Working techniques of forest owners - video assessments compared to trained students.
Working postures and health effects.
Training course improvements by risk analysis.
Whole-body vibration - measures of swaying.
Conventional operating stations versus swivel seat concepts.
Physical strain with farm tractors - measures and research methods.

1987 - 1989

Cutters without back problems.
Motor saw exhaust gasses.
Ergonomics of the farm tractor.
Work organization and rationalization studies.
Studies of leader's (supervisors) roles and functions.
Operator overload syndrome.
Effects of shift rotations.
Contractor labor force studies.
Mental loads in machine operations and decisionmaking.
Ergonomics and small forest owners.
Blood analysis of chemicals for stress.

Future ergonomic research
1990 - 2000

Ergonomics of small machines, e.g. farm/forest tractor.
Ergonomics of the small farm/forest owner, e.g., work capacity measures.
Chainsaw gasses.
Health status of forest workers.
Leadership (supervisory) assessments of roles and functions.
Operator overload syndrome -- neck and shoulder muscle disorders.
Review of accidents among forest workers.
Man-computer-machine interface.
Decision analysis of forest work.
Interactions among crew members -- social significance.
Work and social problems of contractors.

logging systems to augment the traditional motor-manual cutting and hand-piling.

Workforce Reduction and Changing Roles

The Nordic countries are in the final stages of logging workforce reductions that will bring the numbers of workers down to a tenth of the numbers needed to harvest lesser amounts of timber after World War Two. Productivity improvements through several stages of machines and systems brought daily worker productivity from less than one cubic meter per day to over ten to fifteen cubic meters per day.

Finnish and Swedish "rationalization" during the 1970's began to change the way work in forestry was organized. In major cooperative efforts, the involved groups have defined a picture of the kind of work needed for the future and the numbers and kinds of workers needed to carry out the work. Norway has also recently made this assessment. Basically this future worker will be a capable machine operator with motor-manual skills who can perform all harvesting as well as silvicultural operations, such as planting, cleaning, etc. Workers will be largely self-supervised and responsible for many functions now performed by supervisors and forestry technicians. After two to four years of schooling, training will continue within the organization at a level of one to three weeks annually. The work year may be only 160-180 days long. Target wage levels are the average for all industry occupations.

After agreeing on the characteristics of the target forest worker "goal picture", institutions and organizations are adjusting to produce such workers. The Nordic countries vary slightly in their needs and the way organizations are structured but they are moving forward with positive actions to improve their labor force in logging. There has never been a comprehensive look at the U.S. forestry workforce, but a conference is planned for 1992 at Oregon State to bring about such a basic understanding.

Aging Labor Force

Forest workers in the Nordic countries are older than those in the U.S. Norway appears to have over 30% of its workforce (professional and part-time) over 60 years. See Figure 1. Workers may stay in the occupation longer than some U.S. loggers who can be injured, suffer health problems (e.g. back problems) or become dissatisfied with the heavy work by the age of 45 years. Special problems of older forest workers are addressed in part through working conditions, and efforts are underway to find recruits to replace the workers who must eventually retire. The U.S. has ignored problems of older loggers and thus, loses the knowledge and skills developed over many years as injuries and workloads compel these workers to leave the logging workforce.

Ergonomic Developments

Part of the success of the Nordic workforce is due to a long line of ergonomic research that began in the late 1920's. After the World War Two, the Nordic countries combined to share resources and ideas in the Nordic Research Council which funded much ergonomic research. Table 4. shows the titles of research projects carried out over the last 30 years. A review of these titles shows where progress has been made in the Nordic countries. Many of the projects have significance for current problems facing the U.S. logging labor force.

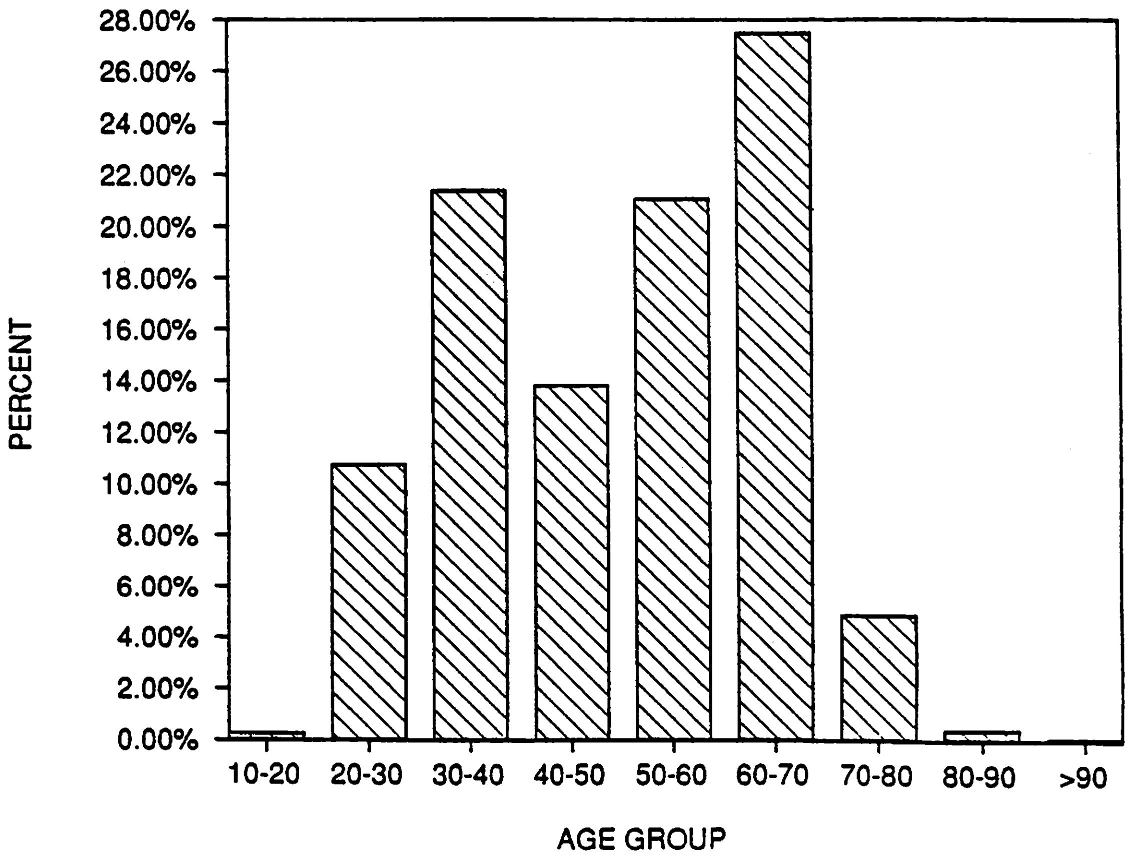
Early research efforts tied ergonomics to the improvement of techniques to enhance productivity. Later the research focused on the safety and health problems of forest workers. Interactions with machine manufacturers have lead to many improvements quickly coming into application in the field. For the U.S. logging industry, a strong effort to relate

Table 5. Working conditions: Norwegian and Oregon Comparisons

Criteria	Norwegian	Oregon
Money	Basics met Weekly wage $470 Machine operators $16 per hour Some guaranteed income levels e.g. 94% of hourly wage	Good pay Weekly wage $500+ Machine oper. $16 No guarantees of wages or levels
Wage Systems	Hourly wage Accord system = piece rate Incentive systems Machine rates	Hourly wage Piece rate sometimes Incentive/bonus system
Time	Hours per week 37.5 6 AM to 5 PM Break 30 minutes Does not include walk to mobile cabin	60 hours per week Daylight to dark 30 minute lunch
Work Status	Not as high as ave. wage earner 94% of average wage Less than construction & oil	High in local communities Low in cities and towns High level but seasonal work (6-11 months)
Medical	State covered 25 sick days per year Sick pay at 100% wage	May have employee insurance No pay if sick
Retirement Security	At 67 years retire State pays if no work avail. 2 wks Medical retirements well covered	Retire at 62 with Social Security No work-->No pay or unemployment insurance Med. Ret. thru. Work Comp. System
Age Changes and Income	Add 6% for 52-56 Add 10% for 57-61 Add 15% for 62-66	No difference
Education Status	Small % inc. for training schools and for courses Right to attend courses and be paid will attending	Negative to have education
Experience Status	Small % for experience	Experience counts but not for first hire or older workers
Work Control	Small % for self-controlled work or responsible work Work leaders facilitate work not supervise workers	Most self controlled but high pace Supervisors get more pay Workers supervised
Use of Own Vehicle	$0.47 per mile	Not covered

Job Change Over 50 Years of Age	$1300 to $3100 based on age One time pay	No benefits except unemployment insurance
Vacation	Weeks 5 to 6 weeks + extra for over 60 Extra pay to go (11.3%)	One week perhaps paid Shutdowns give unpaid vacation
Holidays	Paid for 8 or more	Employer decides
Safety Concern	High for both worker & mgt.	Low for both worker and mgt.
Safety Regulation	Little written down Depends on worker training Employer pays for protective equip. Must have safety committee Employer has criminal liability	Large book of regulations Safety inspectors check job & equip Employee supplies safety gear Must have safety meetings Employer has civil liability
Terminations	Not allowed after probation of 6 months.	Ready and quick for infractions Minority protections high

FIGURE 1. AGE DISTRIBUTION OF NORWEGIAN FOREST WORKERS



ergonomic improvements to enhancing productivity will make progress faster in the contractor dominated sector.

My best estimate is that the U.S. is about fifteen years behind the Nordic countries in application of ergonomic principles. For the Nordic countries, the issue of "operator overload" (shoulder and neck muscle complaints) is seen as a major problem of mechanization. Research is now trying to find ways to reduce these problems. As the U.S. moves to increasing mechanization, it would be senseless to ignore the current ergonomic problems of the Nordic countries. Only a determined industry- wide effort could bring the U.S. near the level of the Nordic countries over the next five years.

Future ergonomic research will be a combination of responses to emerging problems, a continuation of some research lines, and more emphasis on work organization from a social-psychological basis. Perhaps the U.S. will follow the activities of the Nordic countries and adapt the appropriate research results to solve industry problems, but I believe a major shift in managerial thinking is needed for the logging industry. Logging managers need to recognize that the source of productivity improvements lie with the labor force and that ergonomic improvements are not "pampering" the workers, but are in fact, a good investment in human capital development.

Safety and Health Relationships

Even with the reduction in labor force considered and the shift to mechanization accounted for, the Nordic countries have made improvements with the safety and health of the professional labor force. Figure 2. shows the trends in Norway and Oregon for the same periods. What is significant is not the absolute reductions but the form of the reductions. The shape of the curve for Norway is characterstic of a progress function, learning curve, or improvement curve. In contrast, Oregon's reductions are more a matter of evolutionary progress rather than the result of designed improvement efforts.

The Nordic countries have undertaken improvement efforts not only through the training schools, but through country-wide efforts in cutting and chainsaw use. To be sure, safety problems exist with contractors and part-time loggers, but mechanisms exist to address these issues. Similar programs have not even been tried in the U.S. so their potential success is not evident. In 1987 in Oregon, over 22 million dollars were spent on logging injuries through the Workers' Compensation Department. Improvement efforts cost a fraction of this amount.

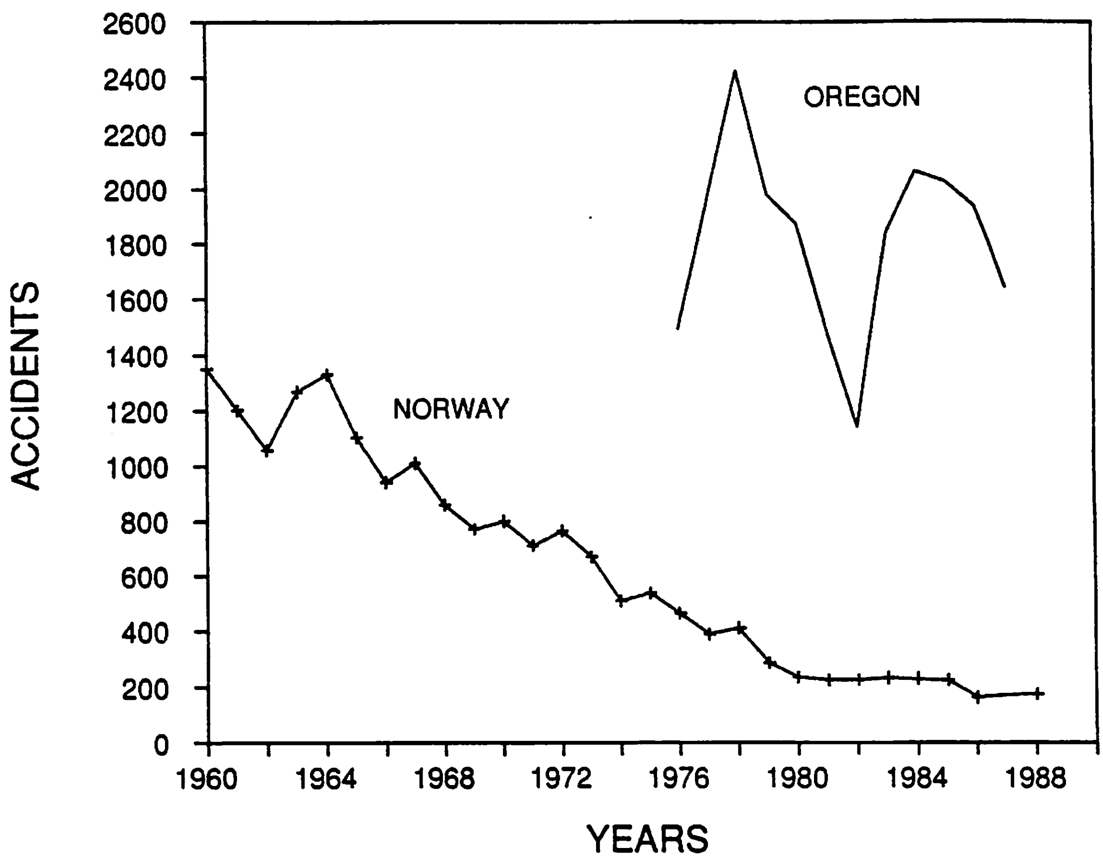
Selection and Training

The logging labor force in the Nordic countries comes from the rural communities (nearly 80% in Norway). Fathers, brothers and uncles taught their relatives the skills to cut and haul timber with horses and then with tractors. After the Second World War, the country formed forest worker schools to provide both specific logging skills to young workers and continue the secondary level schooling. However, it is not necessary to come from one of the schools to become a forest worker, and the Norwegian labor force today has a relatively small percentage who came from forest worker schools. In Sweden and Finland, the percentage is larger. Other training opportunities are provided by short courses and on-the-job training by cutting instructors. Within the Nordic countries the best equipped and functioning forest worker schools can be found and evaluations of graduates indicates their success as measured by comparative surveys.

The cost of training and the shift to mechanization is pressing to reduce the number of training schools. In Finland, there have not been enough to applicants to fill the available training slots. Also, these countries have not addressed the training needs of the contractor labor force. I could find no schemes that

FIGURE 2. ACCIDENTS IN LOGGING-NORWAY & OREGON

1960-1989



provided contractors with comparable training to that found for motor-manual work.

Selection in the logging labor force is rare in the Nordic countries even though scientists early established human performance differences among workers. The common view of logging is that it is a less skilled profession than construction, automobile manufacturing, etc. Status of loggers as measured by pay levels is less than the industry average-- 80% to 94% in Norway and Sweden. And in spite of the current supply of forest workers, signs of recruitment problems are evident. Because much of the pay is on a piece-rate (accord) basis, there is a natural selection that removes some of the lower skilled and less physically able workers from the workforce.

There are more women in the workforce but they are mostly in silvicultural operations as opposed to motor-manual harvesting. All Nordic countries are trying to attract women to forestry labor. Married teams of machine operators (harvester or forwarder) have been suggested for the more remote regions of the north. Recruitment of forest workers and image-building are under research and development at present.

There are a few myths about training in the Nordic countries that should be dispelled among forest operations professionals.

1. Workers must be trained in the Nordic countries--There are no legal rigid legal requirements only general ones. There has been little documentation of training gains but managers can't conceive of not training workers to do the job properly.

2. The equipment manufacturers provide the training when you buy the machine-- This type of training is of short duration and only of a "transfer of training" kind, e.g. from the manufacturer's prior model to the new one or to operators who have some training already.

3. Everyone is trained--In all the Nordic countries many forest workers are self-taught, and the forest owners who do their own logging don't always take advantage of training opportunities.

4. The State provides the training--State resources underwrite the schools but more than half of the training is developmental for youth. Languages, math, sciences, and physical education are taught as well as forestry and logging. Private companies and forest owners pay for at least a part of the training.

5. Training models and ideas can just be adopted in the U.S.--The historical, cultural and economic basis for development of training is quite different than conditions found in the U.S. Certain ideas have immediate applications, but many concepts need evaluation before trials and implementation.

Working Conditions

Table 5 lists a partial comparison of the labor forces of Norway and Oregon on some relevant criteria. The comparison is between the professional forest worker of Norway and the contractor empoye in Oregon. Data from Norway are the operating agreements between the Forestry Employer's Association and the Forest Workers' Union. Data from Oregon are the author's summary of observations.

Brief commments are offered for the criteria to clarify what the comments cover.

CRITERIA: EXPLANATION

*Money: refers to the wage level and differences plus guaranteed wage levels if any

*Wage System: refers to predominant and lesser wage systems used

*Time: refers to working hours, duration, breaks, etc

*Work Status: refers to a general comparison to industry averages in the community

*Medical: conditions governing sickness

*Retirement Security: retirement age and treatment for lack of work available to the firm

*Age Changes Add Income: do workers receive higher wages for increases in age?

*Education Status: benefit to worker from increased education or training

*Experience Status: benefit to worker from experience in the industry

*Work Control: who controls the work and the status of the supervisor

*Use of Own Vehicle: payment for driving to work

*Job Change for Workers Over 50 Years: refers to workers who change jobs after 50 years of age

*Vacation: time and pay levels

*Holidays: number per year

*Safety Concern: emphasis on safe work behaviors and health

*Safety Regulation: type of regulatory environment

*Terminations: ability to discharge workers

A complete comparison is not possible, but Table 5 shows significant differences between Norwegian and Oregon loggers. How does the reader's mental logger compare on the criteria listed?

SUMMARY

The observations presented show a limited comparison of the Nordic and U.S. logging labor forces. They are by no means comprehensive, but are meant to illustrate differences along selected dimensions. A more complete assessment will help determine which improvements of the Nordic labor force have application to U.S. circumstances. Also, it will show which concepts are not suitable.

For the author, a major conclusion is that the U.S. needs to conserve its logging labor force. From a safety and health view, major improvements are long past due. The U.S. logging industry does not offer a "career" in the industry as the Nordic countries are attempting to provide.

The productive behaviors and certain crew interactions found in U.S. logging operations could benefit Nordic loggers. As the unification of the European Community nears, the Nordic logging labor force will face competition from less expensive labor. Productivity will become much more important under these circumstances.

Both the U.S. and Nordic labor forces could benefit from the exchange of information on key issues. These observations hopefully begin that exchange.

REFERENCES

Arbemidsgiverforening, Skogbrukets. 1989. Ser Fremover Mot Ar 2000-Arbeidskraft i det Mekan. Skogbruk. Skogbrukets Arbeidsgiverforening, Oslo. 86 p.

Arbeidsgiverforening, Skogbrukets. 1988. Ser Framover Mot Ar 2000-Rekkrut., Lønnsnivå, Lønnssystem, MM. Skobrukets Arbeidsgiverforening, Oslo. 92 p.

Arbetsmiljoinstitutet, Skogsarbeten och SLU Skoghogskolan. 1989. Ergonomisk Checklista för skogsmaskiner. Skogsarbeten, Spånga, Sweden. 41 p.

Ergonomics Applied to Forest Engineering, Special Issue. 1990. International Journal of Industrial Ergonomics. Vol. 5, No. 3, Elsevier: Ambsterdam. 107 p.

Ericsson, Marten, Klas Norin and Peter Lindgren. 1989. Projekt Arbetsliv 2000. mimeo. 1989-02-28, Skogsarbeten, Spånga, Sweden. 11 p.

Freij, Johan and Anders Tosterud. 1989. Logging Trends 1987-92: Large Scale Systems and Methods. Results, Nr. 3, 1989. Skogsarbeten, Spånga, Sweden. 4 p.

Fryk, Jan, and M. Larson, D. Myrman, and I. Nordansjo. 1987. Forest Operations in Sweden. Skogsarbeten, Spånga, Sweden. 61 p.

Garland, John. 1990. Assessing Gains from Woodsworker Training. Int. Jour. of Ind. Ergonomics. 5(3). Elsevier, Amsterdam. 12 p.

Gustafson, Lennart, Erik Petre and Bo Pettersson. 1985. Vägar till Effectivare Arbetsorganisation i Skogbruket. Redogörelse, Nr. 10, 1985. Skogsarbeten. Spånga, Sweden. 32 p.

Harstela, Perttie. 1984. Ergonomics Applied to Logging. FTP Publications 1B. Kotka, Finland. Pp. 39-62.

Liss, Jan-Erik and Gothard Sennblad. 1989. Arbetsskador hos Självversamma Skogsägare. Uppsater ock Resultat, Nr. 146, 1989. Dept. of Op. Eff. Garpenberg, Sweden. 20 p.

Nordansjö, Ingemar. 1988. Training and Working Conditions in Swedish Forestry. Results. Skogsarbeten, Nr. 1, 1988. Spånga, Sweden. 4 p.

Norwegian Forest Research Institute. 1987. Norwegian Research on Forest Operations 40 years. Driftsteknisk Rapport Nr. 32. Ås, Norway. 208 p.

Samset, Ivar. 1988. Arbeidsliv. in Under Kroners Tak. Norges Skogeierforbund, Oslo. Pp. 161-212.

Stamm, Jørn. 1990. Rapport om Ulykker i Skogbruket på 80-Tallet. direktoratet for Arbeidstilsynet. Oslo. mimeo.

FOREST OPERATIONS AND SOILS
Properties at the interface machine-soil

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ABSTRACT

Nowadays forest mechanization faces soil conservation aspects. If some apparent effects of the machine operations are recognizable like soil ruttings other ones are induced in the depth of the soil profile and alter the characteristics of the soft medium. In the available litterature most publications imply case descriptions. The way the rubber tires of the machines load the soil is deeply involved in the compactions and related consequences. The report shows these relations after scientific experimentations. The results show how fundamental sciences are concerned for correct interpretation. Some interpretative models are described for further improvement either of the forestry tires either of the machines and proposals are suggested.

1.Characteristics of forest equipments

Mechanized forest equipments gather together several tools and devices. They are associated or integrated on a single body or on different frames. The forest machine presents different modes of assembling the bodies or frames. The various plans containing the axles of articulation between the frames define significant properties for the application of the wheels or tracks on the ground surface.
Single horizontal articulation, i.e. rotation around a vertical axle, offers turning possibilities for mechanical or hydraulic steering. When the axle of rotation is horizontal, following a parallel or a perpendicular to the longitudinal axis of the vehicle, it introduces rolling possibilities to the axles or to the bodies. Both possibilities are often in conjunction. They contribute more or less to the general stability and to the capability of transferring driving torques to the ground. Such relations must be taken into account especially when problems of soil damages occur.
Overall dimensions are involved too in locomotion and relations with the standing trees and with the soils. The external gauge of the vehicle introduces limitations to the accessibility to the stands. Clearcuttings and thinnings in forestry are two opposite conditions as well for steering definition as for overall dimensions and location of the masses of the moving bodies. Wheel base, total height and clearance range at the highest point of the loaded vehicle must stay within limits fixed by the distances between trees and top branches. Ground clearance, angles of clearance (front, central, rear), external turning radius are implied in mobility across all terrains.
Under static conditions the total mass of the vehicle is distributed upon the axles and on the wheels. Ballasting and payload will modify the location of the center of gravity when working with important consequences for the distribution of the loads upon tires or tracks following their own mounting under the tractor or machine frame. It has been studied that they are directly related with the effects in the soils.

The power systems driving the forest equipments define engine maximum gross power (kW at rpm), maximum net torque (daNm at rpm) at the driving wheels, speeds and/or rpm of the wheels are of course also in direct relation with the effects recorded in the soils. Forest machines operate mainly at low speeds and so at high even at very high torque transmitted to the soft soils. This is mainly the case when wheel dimensions are not appropriate.

Auxiliary devices mounted on the basic frame or frames alter in a more or less great proportion the distribution of the masses due to the load transfers in static and more effectively in dynamic conditions. Auxiliary devices like winches and their cables or like cranes with arms introduce highly variable reactions while hitching systems control in a better way the transfers to the frames and to the axles. Auxiliary devices have great effects upon wheels or tracks and through these to the soft soils.

2. Mobility characteristics

Mobility on soft soils implies directly the running devices. Most of the forest equipments are mounted on wheels equipped with rubber tires. Off road forest tires are derived from agricultural or from truck tires. Some reinforcements and local modifications have been applied to agricultural tires in order to insure sufficient resistance with respect to the particularities of the forest operation conditions like sticking, punching, rocky terrains, squeezing against remaining stumps, etc.

The tire structure is made of a compound material that mixes rubber and carcass matter. The moulding process creates various thickness all along the sidewall. If the rubber envelope is deformed under the load, the induced deformation causes sidewall deflections on both sides and bends the entire cross-section. It must be noticed that the greatest deflection happens at the point where the sidewall offers the least thickness

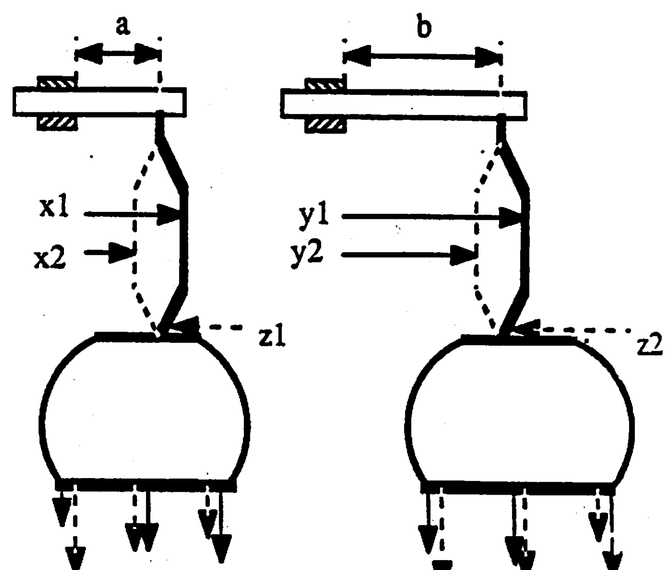
The inflation pressure supports the entire structure. Under high pressure the stiffness of the tire increases and a higher punching of the soil will happen. Lower inflation pressure will apply the tire on the support following various patterns derived from the deflection shapes at the equilibrium obtained between load distribution by the tire and soil reactions. This is of the higest importance because it modifies totally the conditions known for road tires. The distribution of the impacts on the contact area is distinctly influenced by the cleat foot-prints.

Due to the loading of the rim over the nave of the axle and the wheel-disk, both sidewalls of the tire are bended at a given height. It introduces sideways forces at that level and a moment with reference to the shoulders at the contact with the support medium.

That torque around the shoulder will deflect or stiffen the tread that moulds the soil underneath. Many experiences with different tires in various conditions have shown the relevance of the observations.

Measurements have leaded to calculation techniques that shown the necessity of stiff and wide treads supported by flexible sidewalls fixed on narrow rims (camel-shoe patent principle).

It must be noticed that the position of the wheels (distance a or b) on the machine and both form (defining distances x1, x2, y1, y2) and mounting of the disk (location z1, z2) play large roles in the load transfers by the tread to the soil following transverse sections to the equator direction.

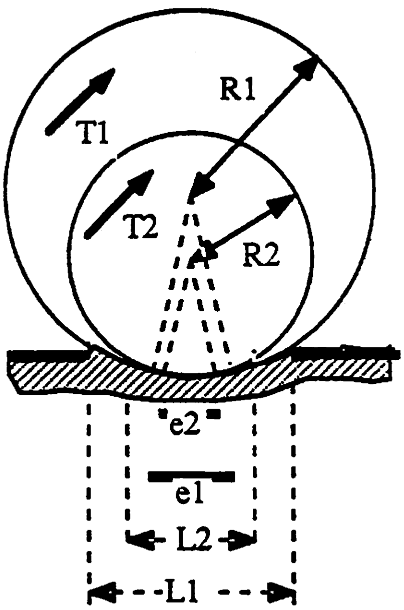


a,b : distance bearing-disk
x1,x2,y1,y2 : distance frame-disk
z1,z2 : fixation of rim on disk

Adaptation modes for the wheels

The longitudinal distribution of the effects of the loads in the soil, i.e. following the equator direction, shows that they are mainly applied under the axle and only on an area limited in the length, not at all on the total length of the tire foot-print.

The effectiveness of the tire for the torque transmission to the soil (T1, T2) must consider the real length of the contact area involved in the process.



Relativity of the lengths at the contact areas

From the figure here above the effective lengths of the contacts imply the ratios of e1/L1 and e2/L2 for wheel having radius R1 and R2 where R1>R2. The lengths e1 and e2 are the real ones for the zones of the soil underneath which are effectively prepared by compression. It has been measured that e1/L1 is smaller then e2/L2. The real contact zones will offer the highest resistance to the tangential shear forces applied by the cleats on the contact area because the highest portion of the load is applied there. Tests have shown that small wheels are more appropriate because they apply forces more acceptable by the resistance to shear obtained inside the soft soil underneath.

Haulage and pushing require high total weight if it is correctly transferred to the contact area between tire and soil also if the involved preparation of the soil underneath authorizes the application of corresponding forces to the material without creating shear too early. Effectively, direct hauling speed or that speed reached by a forest tractor with hitched logs remains rather low. The normal range of speed in most working circumstances stay within values of 0,3 to 3 or 5 km/h. The tractor empty will ride faster but within a range of speeds compatible with the stability and the safety, i.e. still low speeds in comparison with road speeds. Big wheels request more rpm reductions and apply rather high forces in front of the contact area where the soil is still weak. They involve important slip. Therefore also medium and small size tires are preferable for forest equipments.

Due to their specific functions three main types are distinguishable, i. e. :

- tractors for pulling or pushing,
- tool-carriers,
- transportation vehicles.

Load transfers are perhaps complex but it is highly adviseable to provide a maximum of instructions about the effects of loading unevenly the frames to the operators. For the operations in the forests it is advisable to have a vehicle with an articulated body preferably in three main plans and minimum two.
Front and rear bodies will insure the permanent contact of the wheels on the soil. If only the rear part of the body is motorized it will receive a maximum of the load transfers in order to maintain just a safety minimum on the steering wheels. Articulations between bodies may result from a combination of rotation around a longitudinal horizontal axle (tilting or wheel clearance) together with turning following a vertical axle (steering) and/or a transverse horizontal axle (angle of sight). In most of the cases, two angles must exist; they will offer tilting and steering possibilities. High ground clearance is not always necessary when snow height is not excessive and when stumps are cut close to the soil. When the ground clearance is limited, the operators will automatically avoid the rutting of the soil and so will limit the damages. In cross terrain locomotion obstacles like small rocks, remaining logs and small ditches may request some capabilities of negotiating such hindrances. This is obtained principally by articulations between front and rear bodies. Front, central and rear angles of clearance are then very important in order to avoid hang up conditions.

3. Tire contact with the ground

The analysis of the tire contact with the soil implies area and effects measurements. It is shown in previous reports that a main distinction must be done between the various

shapes of the contact areas obtained when loading the soil with a tire.
Main differences are recognized between theoretical, real and effective contact zones. Therefore a mean ground pressure calculated by dividing the wheel load by the area of contact has no significance.

When tires are build with lugs, the upper area of these cleats and dies introduces the main effect in the soil. It is called the impact of the tire. At the moment the tire comes in equilibrium with the reactions comming from the compressed soft medium lugs and spaces between them are in contact. Effectively, the inter-cleat zones maintain the soil during the punching by the lugs. The recording of the effects introduced inside the volume of soil underneeth the area of contact is rather difficult and means must still be conceived therefore. However the use of the penetrometer can provide very important data for the interpretation of the relations between wheel and soil.
Transverse profiles giving the load distribution across the contact area show peaks at some locations for all the tires. They correspond to higher compacted zones in the soil. In order to improve the quality of the contact the effects must be evenly distributed.

Tire squash ratio or :

$$t_H = \frac{H_0 - H_w}{H_0}$$

where : H : height; W : load; 0 : no load, is a first data about tire deformability.
The flattening ratio or :

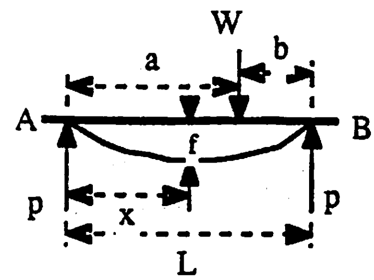
$$t_b = \frac{B_w - B_0}{B_0}$$

where : B : width, is the second parameter of deformation.
A variation of volume is recorded when the tires are loaded and it corresponds to :

$$\Delta v = - V \frac{\Delta p}{(p + \Delta p)}$$

where : p = pressure and v = volume

The application of the load by the tread upon the soil correspond to the general formula of the flexion of a beam. Effectively, the behaviour of the flexible tread is similirar to the shape of the different moments of flexion at each location along the beam :



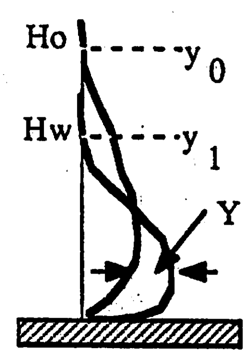
where f, for x<a is obtained from :

$$f = (Wbx / 6EIL).(L^2 - b^2 - x^2)$$

and for a < x < L, then :

$$f = (Wa (L - x) / 6 EIL) . (2xL - a^2 - x^2)$$

Sidewall deflection is calculated from :



$$Y = -M / EI = -W y(x) / EI$$

where : Y = sagitta after deflection
E = modulus of rigidity
I : moment of inertia
and e : thickness of a unit portion

The relations between the applied load and the deformations of the tires lying on hard or on soft soils are tested for various manufactures and inflation pressures. It is clear that the bahaviour on soft soil is totally opposite to what is observed on hard soil.
The conclusions from the comparisons between behaviours of different tires clarify tire-soil relationships and are able to manage

the choice of the tire aswell for orienting new concepts for manufacturing.

5. Soil and locomotion

Different theories are advanced for the representation or for the prevision of the effects of the tires on the soil. All the suggested models give more or less good results in case of cross-country if local tests with special measuring equipment are collecting specific factors or data. Some equations from BERNSTEIN and BEKKER are good examples. The first author says :

$$P = k Z^m$$

It needs values for :

k : modulus of deformation, kPa
m : spécific value for a soil
P : pressure due to the load, kPa
Z : ration of deformation

Bekker improves the expression and proposes

$$P = (\frac{K_c}{b} + K_\phi) Z^n$$

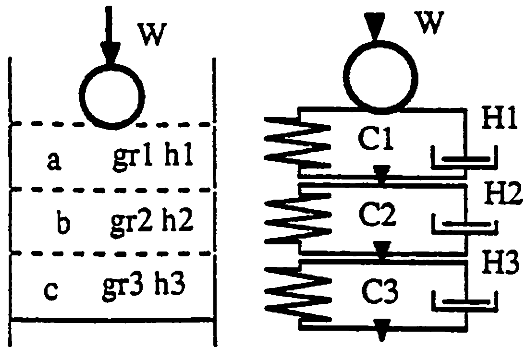
with :

K_c : cohesion modulus, kPa/mm^2
K_ϕ : fristion modulus, kPa
b : area implied, mm

Both expressions globalize the entire soil volume underneath the contact area of the tire. In reality the natural and the cultivated soil have a vertical profile with beds or layers. Each of them has a composition, a thickness and a state of its components. The distribution of the layers in a vertical plan are well known from the foresters and agronomists. The rheology has different general models for the modelization of the deformation. Some are analog models others are digital. The analog model proposed by Kelvin-Voigt is often recognized as one that fits to the soil deformation.

Data experimentally recorded from tests are applied and offer a rather good approach. A very carefull succession of trials with layers of soil having various thickness and state are able to provide data to the model that fits closely to the generality.

The multi-layer model is represented by :



In such a model :

a, b, c : soil layer
gr : granulometry
C1, C2, C3 : coeff. of granulometry
h or H (1,2,3) : soil moisture,

and between the layers the load transfers k are taken into account.

The equations are :

for the first soil layer :

$$\varepsilon_1 = \frac{P}{E_1} = \frac{P}{f(C1, H1)}$$

for the second soil layer, it is :

$$\varepsilon_2 = \frac{k_{1/2}P}{E_2} = \frac{k_{1/2}P}{f(C2, H2)}$$

and for the third soil layer of the example :

$$\varepsilon_3 = \frac{k_{2/3}P}{E_3} = \frac{k_{2/3}P}{f(C3, H3)}$$

and so on for the other layers.

The k factor corresponds to the amount of load transfered to the next layer of the soil. Solving these equations with the experimental data gives very good and confident results.

The fact the proposed expressions do not include other significant parameters than granulometry and soil moisture compromises the representativity. New developments are necessary and tets are already underway in order to get better interpretation possibilities.

The transmission of the driving torque to the soil and more especially to the upper portion of the soil profile is measured. When the wheel is applied on a hard plate following data are recorded for example with a commercial radial tire 14-30 inflated at 130 kPa:

load on the wheel daN	beginning of wheel slip,% (a)	total slip at % of a (b)	evolution between values of a and b, %
1000	ref or 100	220	ref, 100
1400	144	188	124
1700	209	189	178
2400	330	190	284

The effect of the loading of the wheel is recognizable from the records. Mainly the beginning of the wheel slip is noticed and influences the force available atthe moment when the total slip occures. Doing the same tests with the same tie on soft soil following results are obtained :

load on the wheel daN	anchoring at , %	slip at % (a)	slip evolution (b)
1000	ref,100	213	ref,100
1400	113	247	131
1700	127	266	158
2400	173	277	225

It is shown that large differences exist between both working conditions of the same wheel and tests done on hard soil have no real significance. A standardization of the testing conditions has been proposed several yaers ago. It is still not generalized. Foresters may introduce the need for such determinations related to the improvement of the soil quality. The tire prepares the soil for the transmission of the torque and for getting as much reaction as possible from the soil. It has been shown that the main zone prepared for the anchoring of the lugs in the soil remains at the perpendicular of the wheel nave and within a short length. Therefore wide tires for smalml or meedium radius of the wheel will offer the best conditions for the torque transmission moreover if the cross section of the tire has been correctly manufactured.

6. Conclusions :

Systematic experimentation about rubber tires fopr forestry and agriculture and verifications of the results recorded on test rigs in the laboratory by experiments in the field show that significant improvements are possible on both aspects, i.e. tire manufacture, tire mounting on machines and use of the mechanized equipments on soft soils. Some practical and commercial notions must be revised. New technologies in tire manufacturing will certainly reniew the possibilities and contribute to soil and environmental protection

7. References

1. ABEELS P.F.J.(1980), Ergonomy and farm mechanization, *International Symposium on Mechanization and Energy in Agriculture, Univ. of Ankara, Turkey, 6p.*
2. ABEELS P.F.J. (1980), Essais sur pneus, développement du type "Camel Shoe"., *Publ. Groupe de Mécanisation Agricole et Forestière, 24 p.*
3. ABEELS P.F.J. (1981), Agricultural and forestry tyres, choice in the context of energy savings., *Proceedings of the 7th International conference of the ISTVS, Calgary, Alberta, Canada,Vol.1, pp.1-10*
4. ABEELS P.F.J. (1981), Interactions between tyres and soils, relations for the design of flexible toric casings., *Proceedings of the 7th International Conference of the ISTVS, Calgary, Alberta, Canada, Vol.2, pp.472-486.*
5. ABEELS P.F.J. (1981), Contribution du système de relevage trois points du tracteur agricole à l'amélioration des performances de traction., *Proceedings of the 7th International Conference of the ISTVS, Calgary, Alberta, Canada, Vol.2, pp.487-497.*
6. ABEELS P.F.J. (1982),Stabilité des tracteurs agricoles et forestiers., *Proceedings IUFRO Seminar ONU-FAO-CEE-OIT, °As, Norway, pp.81-98.*
7. ABEELS P.F.J. (1982), Improvements in Harvesting Operations through Tire Development, *6th International Industrial Wood Energy Forum, Forest Products Society, Washington, USA*
8. ABEELS P.F.J. (1982), Performances of agricultural tractors and tire improvements, *ASAE Winter Meeting, Chicago, IL, USA, Paper 82-1570, 19p.*
9. ABEELS P.F.J. (1983), Uberlegungen zur Herstellung von Reifen fur Forstwirtschaftlich Fahrzeuge, *Forst-wissenschaftliches Centralblatt, 102, Heft 2, pp.80-86*
10. ABEELS P.F.J. (1986), Raisons du faisable en mécanisation agricole, *Revue M, Société Belge des Mécaniciens, Vol. 30, 1-2, pp.27-32.*
11. ABEELS P.F.J. (1983), Les formes de recherche et leurs résultats dans la promotion de la

mécanisation agricole. *Proceedings Landbouw RAI, Amsterdam, NL, pp.6*

13.ABEELS P.F.J. & BAUDEWIJNS J.M. (1983), Locomotion et propulsion en agriculture. Performances de pneumatiques agraires en traction et développement de profils appropriés de pneus. *Publication Groupe de Travail en Mécanisation agricole et forestière, Ministère de l'Agriculture, 23p., Journal Agriculteur, 43, 7p.*

14.ABEELS P.F.J. (1984), Progrès en locomotion de véhicules agricoles, *Actes 10e Congrès International de Génie Rural, CIGR, Session Technique 3, Budapest, Hungary, pp.484-491.*

15.ABEELS P.F.J.(1984), Modélisation des pneus hors routes et du sol en vue de l'amélioration de la traction. *Proceedings 8th International Conference, ISTVS Cambridge, UK, Vol.1, pp.3-15.*

16. ABEELS P.F.J. (1985), Contribution générale à la définition du pneumatique agraire. *Publication Groupe de Travail Techniques Avancées et Progrès en Agriculture, Ministère de l'Agriculture, 62p.*

17. ABEELS P.F.J. (1985), Rim, tire and soils, *Proceedings International Conference on Soil Dynamics, Nat. Tillage Machinery Lab., Auburn, AL, Vol.4, pp.630-642.*

18. ABEELS P.F.J. (1985), Computerization for the improvement of the tractive efficiency. *Paper 85-1053, ASAE, 14p.*

19. ABEELS P.F.J. & BATARDY J. (1985), Forest Harvesting Operations and Soil Damages., *Publ. International Energy Agency,Forest Energy Program,Cooperative Network on Rural Energy, Rungstedgaard,Denmark Vol.2, pp.334-338.*

20. ABEELS P.F.J. (1986), Testing off-road tires,*ISTVS-VDI Arbeitskreise Fahrzeug-technik, Battelle Inst.,Frankfurt, Fed. Rep. of Germany, 6p.*

21. ABEELS P.F.J. (1986), Damages to Forest Soils, *Proceedings Workshop "Energy Biomass from Harvesting to Storage", ITABIA, Milano, I, 10p.*

22. ABEELS P.F.J. (1987), Off Road Tires, Concepts and Applications, *Proceedings 9th International Conference ISTVS, Barcelona, Spain, Vol.1, pp.244-249.*

23.ABEELS P.F.J. (1987), Bodembeanspruchungen beim Einsatz von Forstmaschinen, *Kuratorium für Waldarbeit und Forsttechnik, Gross Umstadt, Fed. Rep. of Germany, 7p.*

24. ABEELS P.F.J. (1987), Mécanisation agricole en question, *Publ. Groupe de Travail Technologies Avancées et Progrès en Agriculture, Ministère de l'Agriculture, 8p.*

25. ABEELS P.F.J. (1987), L'évolution prospective du machinisme hors routes, *Publ. Groupe de Travail Technologies Avancées et Progrès en Agriculture, Ministère de l'Agriculture, 9p.*

26. ABEELS P.F.J. (1988), Une autre mécanisation pour l'agriculture de demain, *20 Conferencia Internacional de Mecanizacion Agraria, FIMA, Saragoza, Spain,16p.*

27. ABEELS P.F.J. (1988), Terres, cultures et travaux, *Musée Notre Passé Agricole, Beauvechain, Belgium, 4 p.*

28. ABEELS P.F.J. (1988), Improvements in traction and energy conservation (Amélioration des performances de traction des équipements), *3d Technical Consultation of the CNRE/FAO*, Energy Conservation, Helsinki, Finland, 13 p.

29. ABEELS P.F.J. (1988), Tire deformability, inner pressure and effects on hard and soft supports, *ASAE Paper n° 88-5011, 26p.*

30. ABEELS P.F.J. (1989), Mécanisation et conservation des sols, *Publication Union Belge des Sociétés de Génie Rural, Bruxelles, 20 p.*

31. BAUDEWYNS J.M. (1989), Essai de déformation sur support indéformable, *Rapport de recherches, Départ. de Génie Rural, UCL, 9p.*

32. ABEELS P.F.J. (1989) Mécanisation des opérations forestières, un dilemme contemporain, *Introduction au Séminaire sur les conséquences de la mécanisation des travaux forestiers sur le sol. Séminaire FAO/ECE/ILO, Louvain la Neuve, Belgique 11-15 septembre 1989, 25 p.*

33. ABEELS P.F.J. (1989) Forest machine design and soil damage reduction, *Séminaire FAO/ECE/ILO sur les conséquences de la mécanisation des travaux forestiers sur le sol, Louvain la Neuve, Belgique,11-15 septembre, 15 p.*

34.BAUDEWYNS J.M. (1989), Déformabilité d'un pneumatique agraire et variation de pression d'air interne, *Revue de l'Agriculture, vol. 42, n° 1*

35. ABEELS P.F.J. (1989) *Technologies appropriées défis de société et réponse en mécanisation agricole*, Séminaire Wallonie-Zaïre, Kinshasa, Min. Région Wallonne, 14 p.

36. ABEELS P.F.J. (1990) La conservation des sols et les opérations mécanisées, Commission Economique pour l'Europe, Comité du Bois, FAO Commission Européenne des Forêts,Organisation Internationale du Travail, Séminaire Munich, juin 1990, 14 p.

BENEFITS OF USING ROAD MATS MADE FROM RECYCLED TIRES ON LOGGING ROADS

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ABSTRACT

Road mats 9' X 20' made from recycled scrap truck tires have been used on logging roads to reduce rutting and erosion. Known as Terra Mats, they help stabilize earth roads, improve traction, and remove mud from trucks and trailers before they pull onto paved roads.

INTRODUCTION

Harvesting timber requires activities that cause non-point pollution of rivers, lakes, and streams. Road construction and maintenance, hauling logs out of the woods on earth roads, stream crossings, temporary drainage are some of the forestry activities that harm water quality. One way to limiting this damage is to build all weather roads with ditches and cross drainage. This may cost more than the value of the timber justifies. Most loggers wait for drier weather to harvest tracts that are difficult to access. Adding to the loggers access problems are the BMP's which are aimed at improving water quality by reducing erosion.

Most logging roads are not in continuous use; many are short haul roads used only one time. In their simplest form, they are cleared areas cut through the woods with scant attention paid to standard road building design criteria. Heavy rains wash silt from earth subgrades into ditches, creeks, and streams adding to the accumulation of sediments in the watershed that disrupt the environmental balance. It is in this area that the Terra Mat method can provide an alternative to the all-weather road at a much low cost. Terra Mats have been used in timberlands in most of the Southeastern States on all types of subgrades from ball bearing sand to placement directly on the forest floor. Terra Mats have been used to cross streams and swamps, on landings, broad-base dips, to stabilize travel surfaces, and to reduce mud tracked onto paved roads from logging roads. They reduce fuel consumption and maintenance costs, and help to increase payloads coming out of the landings. The U.S. Forest Service has incorporated Terra Mats in their specifications as an alternative method of road stabilization. The American Pulpwood Association has written two technical releases describing the use of Terra Mats in various applications.

Questions and Answers Describing The Terra Mat Method

1. Will the fastening wires puncture tires?

A. Of several hundred mats in use we have had only three reports of punctures which were due to poor workmanship on our part. This has been corrected with tougher product inspection.

2. How long will the mats last?

A. Tires are virtually indestructible. Fire and mechanical demolition are about the only way to destroy them. The galvanized steel connecting wires will last from four to eleven years depending upon the acid content (pH) of the soil on which the mats are placed.

3. Can the mats be re-used?

A. Yes. That is the major attraction of the method. Compared to twelve inches of stone hauled fifteen miles at a delivered price of six dollars and seventy cents per ton, the fourth time Terra Mats are used in place of stone, the Terra Mats are free.

4. Do the mats work on slopes?

A. The mats have been used on slopes as steep as 6%, however, they should be anchored with stone ballast or earth nails. (Staple shaped 1/2" diameter reinforcing rod with legs two feet long and a cross member wide enough to straddle the tire sidewall).

5. How are the mats unloaded?

A. Mats are generally hauled on flat bed trailers. They are loaded at the plant in a manner allowing them to be dragged off the trailer with equipment or pickup trucks at their destination. They can be dragged off the side of trailers with backhoes or lifted off with knuckle boom loaders several mats at a time.

6. How are mats moved on the job?

A. Mats are dragged with trucks, dozers, or skidders from one point to another. Skidders can drag one mat on top of another, unhook, grab both mats and repeat the process until seven or eight mats are grabbed and moved at one time.

7. How are the mats loaded and hauled from one tract to another?

A. The best way is to load them with a knuckle boom loader on a flat bed trailer and haul them to the next tract. A construction type track or wheel loader with a log chained to its bucket can pick up mats and load them from the sides of flat bed trailers. Mats can be draped over loaded log trailers with knuckle boom loaders.

8. Do the connecting wires ever break?

A. There have been very few reports of broken wires. The wire breaking strength is in the range of 2,000 lbs. Mats are loaded with chains hooked to the wires for handling. They are sometimes pulled off the trailers by hooking up to only one wire.

9. Can broken wires be replaced on the job?

A. Yes. We furnish a repair tool and replacement wires free with truck load shipments. Tools sell for forty dollars and wires for seventy five cents each. Repair instructions are furnished to customers.

10. After the mats have been in use and settled into mud can they be retrieved and re-used?

A. Yes. The best way to retrieve mats coated with mud and pushed into the subgrade is to roll them out. This is accomplished by driving a vehicle or piece of equipment onto the mat to be removed until it is in position to hook up to the end of the mat with chains at three points. The vehicle or equipment then reverses direction causing the mat to roll out of the ground.

11. Can skidders skid logs over the mats?

A. No. It has not been attempted and we do not recommend it unless the mats are covered with at least one foot of earth.

12. Will the mats work in soft ground?

A. The phrase "soft ground" covers a wide range of types from spongy, saturated material that resembles a water filled balloon to a sandy clayey moist material which can be penetrated to a depth of three feet with a half inch diameter steel rod. Terra Mats have been placed in both situations with limited success. The new type Tread Mat will solve many of the problems that were experienced with the standard mats. Treads beneath the sidewalls reduce the mud pumped up between the mat components and offer a higher degree of flotation. Mats have been placed in extremely soft conditions and filled over with a foot and a half of earth performing successfully. Tree length logs have been placed in wheel deep ruts with mats placed on top of them and enabled trucks to travel out of the woods loaded.

APPENDIX

1. APA releases
2. Product bulletin No. 9
3. Rubber and Plastics New article
4. Forests and People magazine article

CONCLUSIONS

Terra Mat is a revolutionary concept in logging road construction that is rapidly developing into a cost effective alternative method of road stabilization and erosion control. As more information is learned from the field, the method is being improved to meet the demands.

Terra Mats recycles waste tires into a product that helps protect the environment.

AMERICAN PULPWOOD ASSOCIATION INC.
1025 VERMONT AVENUE, NW, SUITE 1020, WASHINGTON, DC 20005

TECHNICAL RELEASE

90-R-38

TIRE SIDEWALLS USED AS MATS

Harvesting 4.013 July 1990

INTRODUCTION: Terra Mat (U.S. Patent #4801217) is a new product for protecting unpaved forest haul roads, log decks, and wood yards from truck and equipment traffic.

GENERAL FEATURES: Terra Mat Corporation uses sidewalls from scrap tires and links them together with corrosion-resistant fasteners to form durable mats. Assembly plants are in Youngstown, Ohio; Tarboro, North Carolina; and St. Mark, Florida. A New Jersey plant should open soon.

OPERATION: The mats are transported fully assembled. They can be handled with logging equipment and placed in position with the rim side of the tires facing up. Logging equipment or light trucks are used to re-position mats as needed. When used correctly, Terra Mats cause no damage to trucks and trailers.

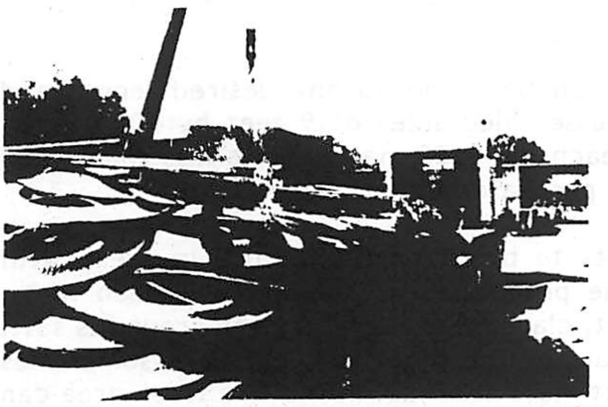

Fig. 1: Terra Mats are transported fully assembled.

Fig. 2: Properly placed mats.

APPLICATION: Terra Mats help protect sites by reducing rutting often caused by truck and trailer movement. They are useful in removing mud from tires of trucks and trailers before highway entry. Temporary or semi-permanent road surfaces requiring periodic maintenance can be constructed by filling in the annular spaces within the mats with stone ballast.

The product has some application in swamps, stream areas, and other wetland sites. A future Technical Release will discuss Terra Mat use in the Appalachians. In most wet areas, or where the ground is soft, multiple layers of mats are required, often supplemented with rock, sand, or brush.

Fig. 3: Mats can be positioned with a pickup truck.

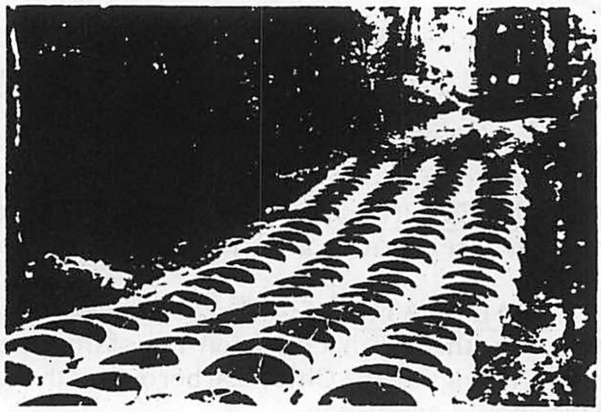

Fig. 4: Mats on haul road to protect site and control mud on tires.

Fig. 5: Terra Mat used at stream crossing.

Other potential sediment control uses include road bank protection, broad-based dips, water bars and turn-outs, subgrade stabilization over culverts, and stream bank sediment traps. The mats can also be used on log truck turn-outs, log decks, wood yards, and fire fighting equipment unloading areas.

SPECIFICATIONS AND COSTS:[1/] Terra Mats can be made to any desired length and width, although they are typically marketed in assembled sizes of 9 feet by 20 feet, at $170.00 each, or 9 feet by 16 feet, at $150.00 each. A 9x20 mat weights less than 1,000 pounds. The prices are $20.00 less per unit when purchased by the trailer load.

COMMENT: User comments reveal Terra Mats to be of particular use in areas with relatively firm ground or sandy soils, where the product is an option to wooden mats. Problems of mat instability have occurred in wet, clay soil areas where the ground is soft. The ground between tracks tends to hump up, causing the mats to buckle and sometimes catching the fasteners on the passing truck. Split mats used just in the tire track area can help alleviate this problem.

Paul Howe
Southeastern Division Forester

Information supplied by:
Jerry Goldberg
Terra Mat Corporation
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Youngstown, Ohio 44505
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[1/] All prices subject to change without notice.

AMERICAN PULPWOOD ASSOCIATION INC.
1025 VERMONT AVENUE, NW, SUITE 1020, WASHINGTON, DC 20005

TECHNICAL RELEASE
90-R-54

TERRA MATS--LOUISIANA REPORT

Harvesting 4.013 August 1990

INTRODUCTION: One of the most difficult problems facing a logger during wet weather is how to get the trucks out of the woods. Wide tires on skidders allow the timber to be brought to the loader, but often the road out of the woods is the limiting factor. Several options are available to address this difficulty: gravel, pulling the trucks out with a skidder or dozer, loading the trucks lighter than usual, or laying down a mat. Each solution has its advantages and disadvantages.

GENERAL FEATURES: Boise Cascade Corporation has been experimenting with a new type of logging mat made by the Terra Mat Corporation of Youngstown, Ohio. The mat (see Technical Release 90-R-38 for prices and availability) is made from the sidewalls of used tires and bound together with PVC-coated eight-gauge wire. Within a row, each sidewall is slightly overlapping the next and then tied with the wire. Initially, rows were joined together every four to five feet. As a result of field testing and product development, every sidewall joint is now bound securely with galvanized, coated wire.

Fig. 1: Mats installed at the intersection of the highway and haul road helped keep mud off the highway.

APPLICATION: Several mats were used this past winter with some good results. In one particular location, six mats (8 feet by 20 feet) were laid in the road ditch adjacent to a state highway. The mats were transported to the site by the logging contractor, unloaded with a knuckleboom loader, and dragged into place with a skidder. The six mats were tied together to make one large mat. The photographs show how the mats allowed access to the tract and at the same time helped reduce the amount of mud carried on to the highway by the trucks.

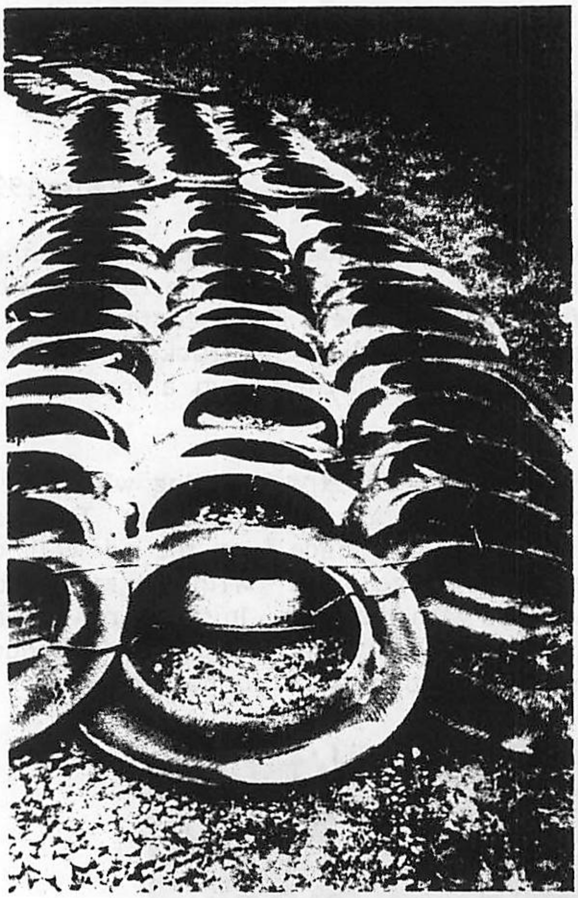


Fig. 2: Mats laid out prior to installation.

Fig. 3: Mats installed on logging job.

COMMENT: Particularly in areas with high visibility, such as this tract, everything a logging contractor can do to reduce rutting and eliminate debris on the road will improve the public's perception of logging and reduce the need for continually cleaning the highway entrance.

No one method is available to solve every access problem, but Terra Mats have proven to be an effective option under certain conditions.

Alan Wilson
Southern Forest Resources
Boise Cascade Corporation
P.O. Box 96
Elizabeth, Louisiana 70638

Reviewed by:
Bruce C. Alt
Southcentral Technical Division Forester

TERRA MAT™ CORPORATION

Reinforcing the earth with tires

The right time, the right idea

TERRA MAT® - U. S. PATENT NO. 4,801,217

FOREST PRODUCTS INDUSTRY

A new method of stabilizing logging roads uses recycled scrap truck tires manufactured into mats 9' X 20' weighing approximately 1,000 lbs. Known as **TERRA MATS** they are virtually indestructible. **TERRA MATS** are delivered fully assembled, unloaded and placed with conventional logging or construction equipment.

TERRA MATS are one way of helping the logging industry meet the intent of the BEST MANAGEMENT PRACTICES water quality standards by their use in *broad base dips; turn arounds; stream bank erosion control; energy absorbers; water turnouts; erosion protection; water bars; culvert fill stabilization and creek crossings.*

TERRA MATS reduce rutting of logging roads and help provide traction for loaded log trucks.

TERRA MATS can be moved from one location to another with logging equipment and even dragged with pick-up trucks.

TERRA MATS reduce or eliminate the stone and earth fill necessary to improve logging roads.

TERRA MATS help remove mud from the tires of trucks and trailers pulling on to paved roads.

TERRA MATS filled with stone ballast become a semi-permanent road surface requiring only periodic maintenance.

TERRA MATS can be used to cross swamps. They are dragged into place to provide a work platform for the construction of earth fills. Terra Mats will not float.

TERRA MATS work exceptionally well in sand. Trucks can drive over mats placed on "ball bearing" sand under their own power.

TERRA MATS reduce fuel consumption of logging trucks.

TERRA MATS recycle a solid waste that is a national health, safety and disposal problem of monumental proportions.

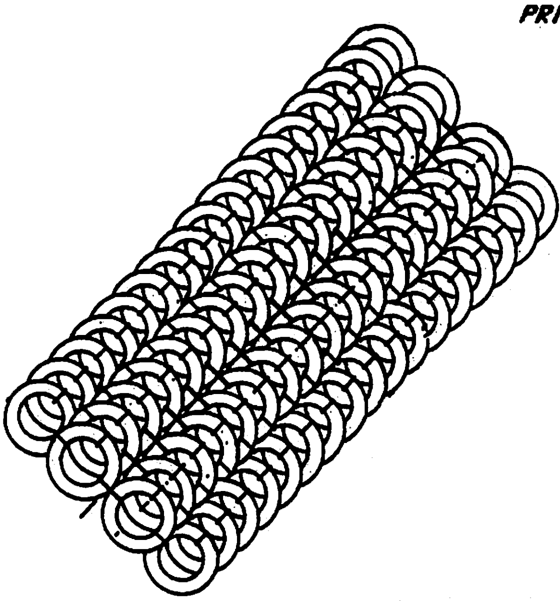
462 Arbor Circle, Youngstown, Ohio 44505, (216) 759-9412

TERRA MAT™ CORPORATION

Reinforcing the earth with tires

PRODUCT BULLETIN NO. 9 15 SEP 90

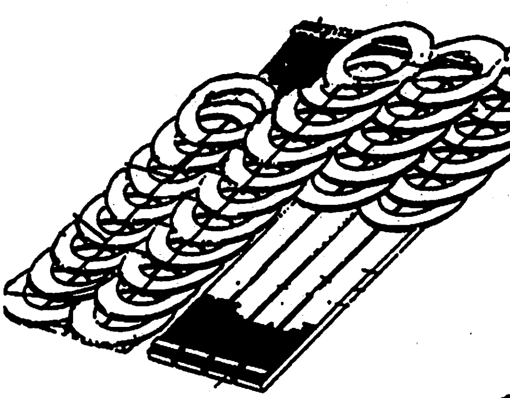
PRICES ARE VALID TO 15 OCT 90 ADD FREIGHT AND TAX



STANDARD MAT 9' minimum width X 20' long

Recommended for use on ball bearing sand; ahead of intersections of logging roads with paved roads; broad base dips on medium firm soils; creek crossings ; firm clay roads; pumping ground with fill; deep ruts with logs.

Price per mat: $190.00

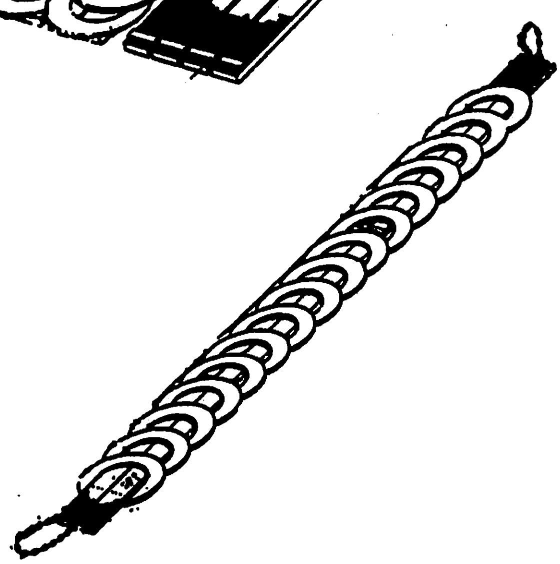


TREAD MAT 11'-6" wide X 10'-0' long

(NOT TO SCALE. THIS VIEW SHOWS THE GENERAL ARRANGEMENT ONLY. TREADS ARE COMPLETELY COVERED WITH TERRA MATS)

Truck tire treads beneath the Terra Mats provide additional floatation and support. Recommended for use on soft ground or directly on forest floor. Can be shipped in two sections or joined.

Price per mat: $210.00



RUT MAT 3'-0" wide X 20'-0" long

Truck tire treads woven within the Terra Mats provide a durable mat suitable for use in deep ruts. Recommended to have on hand when other style mats are used with unprotected sections of earth road in between areas improved with mats. If ruts start to form, RUT mats can be dragged into position for an emergency repair of road.

Price per mat: (one section 3 X 20') $75.00

462 Arbor Circle, Youngstown, Ohio 44505, (216) 759-9412

Rubber & Plastics News

A Crain Publication

Week of September 18, 1989 | The Rubber Industry's International Newspaper | $36 per year, $1.75 per copy

Blazing a trail

Inventor turns tires into roads

By Edd Pritchard
Rubber & Plastics News Staff

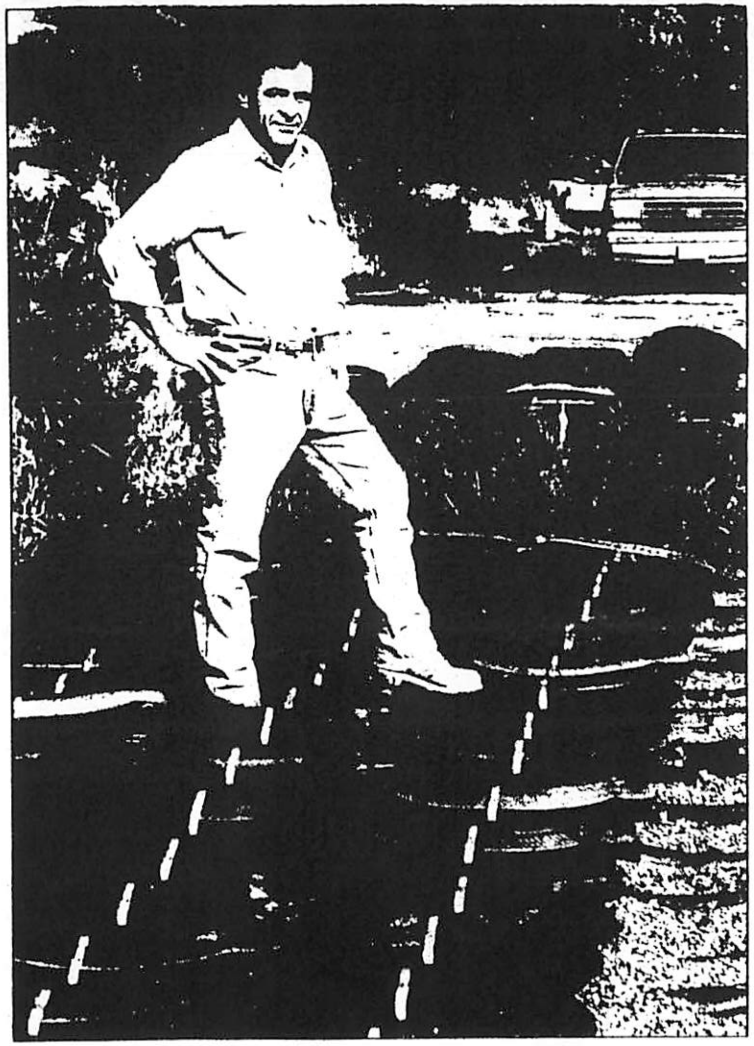
YOUNGSTOWN, Ohio—Jerry Goldberg is turning the rubber that met the road into the road—and a few other things.

A heavy construction public works contractor, Goldberg is using scrap tires in Terra Mats, a product made by binding together tire sidewalls with a metal band. The mats can be used to make temporary roads or as earth fills and levees in marshes, swamps and wet ground.

Goldberg believes Terra Mat is an inexpensive solution to the scrap tire problem. He has formed Terra Mat Corp. to make the mats and to license other companies to use the system.

Terra Mats are better than most of the multimillion-dollar scrap tire projects currently being proposed, Goldberg said, because the product doesn't send gases into the air and "you don't have to take tires 200 miles to some 'Wiz-

Continued on page 14



RPN photo by Edd Pritchard

Jerry Goldberg stands on a Terra Mat road that runs into a field behind his production site north of Youngstown, Ohio.

Inventor making roads from tires

Continued from page 1

ard of Oz' machine."

Scrap tires become a useful construction tool when used in Terra Mats, instead of being burned or buried in a landfill and becoming a pollution problem, Goldberg said.

Terra Mat Corp.'s first licensee is Location Consultants of Lafayette, La., Goldberg said. The engineering firm locates sites for oil and gas drilling rigs and landfills.

Terra Mats can be made at a construction site using a tire cutting machine. Goldberg also plans to produce the mats in 8-foot-wide by 40-foot-long segments that can be shipped to a site.

Goldberg said he's never run into a situation where tires were not available. Currently tire dealers are paying him to take scrap tires.

To make a temporary road, Terra Mat strips are put in place and ballast—usually stone—is poured through the mat to provide a hard surface. In addition to keeping heavy equipment out of a marsh or swamp, the Terra Mat keeps the stone in place by limiting lateral movement.

As a temporary road, Terra Mats can be installed quickly, at a lower cost and in any weather condition, Goldberg said. Without the mats, construction crews either slog through mud and muck or haul in an assortment of materials to build a temporary road.

Goldberg is concerned that buried Terra Mats could leach into ground water, causing a potential health hazard. He questioned Ohio's Environmental Protection Agency and, so far, indications are the product will not have a harmful effect on the environment.

Goldberg holds a patent for Terra Mat, which grew from another scrap tire product he developed out of neccesity at a job site in 1986.

Goldberg's company was involved in a large excavation project in Niles, Ohio, that required use of dynamite. He was working in a residential area and needed something to cover the blast site and contain flying rock.

Conventional wire mats were expensive and a crane was needed to put the mats in place. So Goldberg looked for an alternative and found a firm that recycled tire tread but not the sidewalls. Goldberg piled the sidewalls around the blast site and Dynamat was born.

After several successful uses of Dynamats at blast sites, Goldberg found the mats also supported heavy equipment that usually bogged down driving through swampy areas.

The techniques for making Terra Mats and Dynamats differ. While Terra Mats are tied together in orderly rows, Dynamats are made by placing the sidewalls in layers around a blast site. The Dynamat's top layer is bound together with strips of tire tread.

When a charge is set, the Dynamat lifts off the ground but there is little flying rock, Goldberg said.

Goldberg sees a future in Terra Mats, which he has used in various projects more than two dozen times in the last couple years.

Dynamats have been used successfully more than 50 times, Goldberg said, but liability problems have killed plans to market the product. Goldberg's insurance company anticipated lawsuits if anything ever went wrong at a blast site where Dynamats were used.

Goldberg operates Terra Mat Corp. at a site north of Youngstown. He currently employs four workers and has one cutting machine that can process 400 tires during an 8-hour shift. He has two more cutting machines ordered because he expects the market to grow quickly.

Because of their size and strong sidewalls, bias-ply truck tires are best for making Terra Mats, Goldberg said. He has used radial tires and may start using passneger sizes, but with both tire types more units are needed when using Terra Mats in projects.

In addition to the construction and oil industries, Goldberg is marketing Terra Mats for the logging industry for use in building access roads into timber areas.

Terra Mat: Loving Care for Logging Roads

By C. Richard Cotton

***Editor's note:** This space is usually reserved for profiles about Louisiana's outstanding or notable loggers. But when **Forests & People** heard that some Louisiana loggging operations were experimenting with something called Terra Mat, we thought it would be worth checking into.*

A 600-foot trail of Terra Mat protects a dirt road in Sladesville, N.C. The mats are made from old tires.

The rainy season in Louisiana, which sometimes seems to last about 12 months a year, has always posed a problem for the state's loggers. Rain turns usually decent forest access roads into virtually impassable quagmires. Delays caused by muddy conditions are well-known to logging contractors and foresters alike.

Remedies for the predicament, in the past, have included the use of wood mats or gravel. Now, from the midwestern expanses of Ohio, there is an available alternative. Called Terra Mat, it works well in most applications, according to foresters with one corporation that uses the system. Basically, the Terra Mat roadway is the sidewalls of discarded truck tires, lapped over each other and tied together with wire.

Bobby Aldy of Boise Cascade in DeRidder says his company is the first in Louisiana to use Terra Mat in logging. He explains the system is two-pronged in its benefits to the environment. "First, it uses old tires which are a disposal problem," says Aldy, "and second, it helps save the environment by making it easier to get in and out of sites. The forest industry is concerned about the environment."

Alan Wilson, Boise Cascade's area forester for the Elizabeth, La., district, has had practical hands-on experience with Terra Mat for several months now. "We have eight mats in the woods being used now and more made up, ready for future use," he said.

The reusability of the mats is what Wilson considers to be Terra Mat's strongest point. Gravel, he points out, has a one-time usage; once it's down, that's where it stays. Timber mats also have limitations, he says. "One of the primary ones is they are 11 feet wide and require a permit to haul. Also, they are not flexible and tend to be torn up by the trucks."

Terra Mat is comparable to timber mats in cost, but can be used more diversely in other applications. "Being flexible, we put the mat in a ditch and it worked fine, conforming to the ditch banks," Wilson said. "It also helped knock the mud off the truck tires before they entered the highway."

His final observation is becoming one of Terra Mat's biggest selling points because helping keep mud off the roadways is a big plus. It is also one the inventor, Jerry Goldberg of Youngstown, Ohio, did not foresee when he began development of his unique, patented product. Interestingly, the whole concept of using salvaged tire sidewalls began even earlier, and not for protecting roads.

It was for the containment of a dynamite blast Goldberg first utilized tire sidewalls. "We were doing some demolition work and needed something to keep the blast contained," he recalls.

The tire mat contained most of the flying debris and was dubbed DynaMat. Unfortunately, insurance liability came into the picture and DynaMat was discontinued. Undaunted, Goldberg pressed on with what he considered a product whose time had come. On a subsequent project in a marshy area, his trucks were getting bogged down so he "threw some (mats) down" for them. It worked. Terra Mat was born.

As mentioned before, Terra Mat is constructed of the sidewalls of discarded truck tires. Don Loup, Louisiana sales representative for the company, says the system fills many needs. "Tires are one of the toughest things manufactured," Loup says. "And they are a tremendous disposal problem."

He picks up a copy of Act 185, passed by the Louisiana Legislature in 1989, and points to the section banning the disposal of whole tires. "Tires 'float' back up out of the ground after they're buried," Loup explains. "They take a lot of space versus the disposal fees taken in." The salesman adds discarded tires hold water, allowing disease and mosquitoes to breed.

Loup concedes Terra Mat probably

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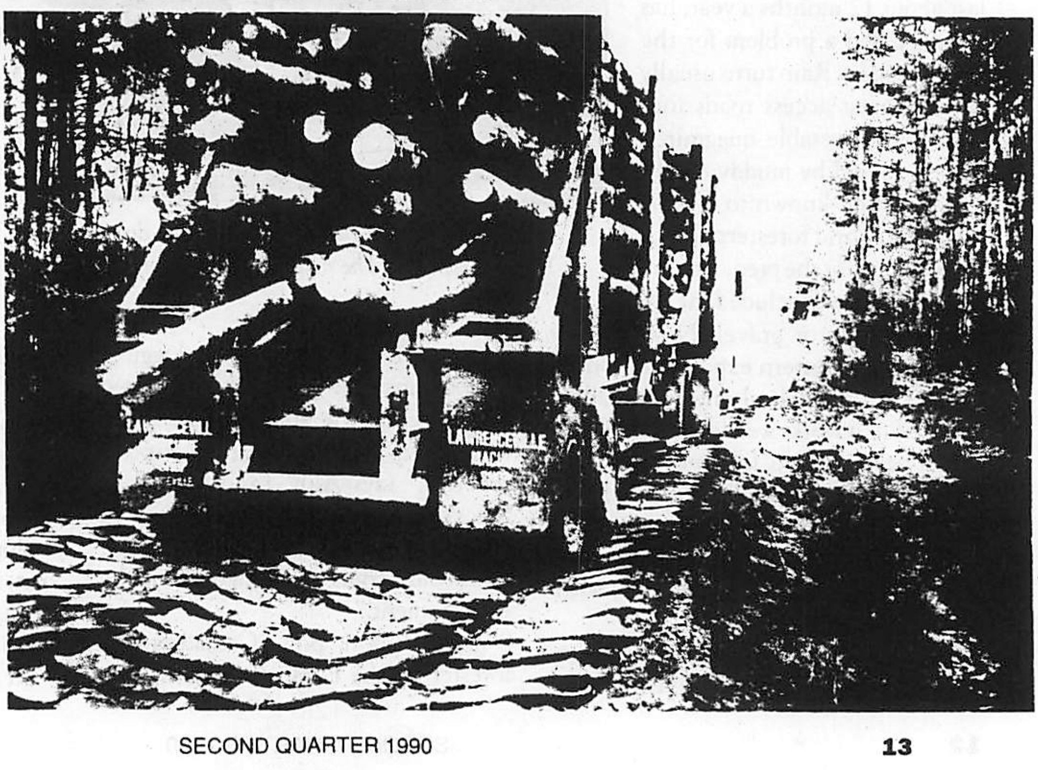

Terra Mat at work on soft dirt roads in Elizabeth, La., (above) and Virginia (left).

Terra Mat

Continued From Page 13

won't solve the nation's tire disposal problem but says it is a step in the right direction. "Terra Mat is innovative," he says. "It serves a purpose and solves a problem."

Twenty-inch sidewalls, or "beads," are cut from the whole tire at the Youngstown factory. They are shipped to the purchaser and assembled onsite. Loup reports roadway mats can be constructed virtually any width or length. Beads are tied together with PVC-coated eight- or 10-gauge wire.

Boise Cascade's initial order of 2300 beads and the necessary tying wire was placed after Wilson discovered the system in a trade journal advertisement. He estimates that number of beads would make about 40 mats measuring 10 feet by 20 feet. The forester says, "I wouldn't want to make mats much longer than that." If increased length is desired, Wilson merely lays mats end-to-end.

Loup points out that Terra Mat, when used on a problem spot early, can keep a road from deteriorating.

Wilson also recommends using Terra Mat early. The perfect time to use Terra Mat is when a rut has just begun to form, he said.

The system's debut at Boise Cascade was a 15-foot by 70-foot section used on a problem section of road where Wilson reports the mat performed "very well under several loads a day." One weakness the forester notes is Terra Mat's possible need for some sort of anchoring on hills or in curves.

Advantages, however, seem to outweigh Terra Mat's few disadvantages. Wilson says a mat of 20 feet or less can easily be dragged by a pickup truck or lifted with a knuckle-boom loader or small crane; an eight-foot wide mat, 20 feet long, weighs less than 1,600 pounds. He adds the mats' weak point, the tying wires, are easily replaced in the field.

The forester is pleased with the system's overall performance but cautions, "Terra Mat is not going to solve every problem, but many times it beats the alternative."

C. Richard Cotton is a freelance writer from Brittany, La.

PRELIMINARY EVALUATION OF LOG-LENGTH FORWARDER APPLICATIONS IN NATURAL STANDS

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ABSTRACT

Small landowners have limited timber harvesting options available from which to choose. In this preliminary report, a log-length forwarder approach was studied for time and production estimates. Compared to an earlier forwarder study of a Gafner Ironmule, the Tree Farmer forwarder travelled at similar speeds but loaded slower. As a first look at this forwarder approach, costs and silvicultural results appear very promising.

Key Words: Forwarder, NIPF landowner, Harvesting.

INTRODUCTION

Non-industrial private forest (NIPF) landowners have a limited selection of harvesting systems to meet their unique silvicultural needs. With small tracts, uneven-aged stands and management objectives beyond simple timber production, many NIPF owners would prefer a selective logging system that is cost-effective and produces minimal site impact. Unfortunately, conventional logging systems do not operate effectively under such constraints. Animal logging is viewed as an "ideal" logging system by many landowners, but productivity and availability limit this system's practical application. New harvesting systems are needed to meet the requirements of the NIPF landowner.

Harvesting systems which meet the requirements of NIPF landowners must have some very unique attributes. The equipment must be low cost both in initial capital and operating expenses. To fit the ownership pattern, contractors must be small as compared to current mechanized systems. Small tract sizes require frequent moves with conventional systems. Smaller systems which operate efficiently with lower production rates can harvest small tracts with fewer moves.

The ideal system should have minimal impact on the site, i.e., low soil compaction and disturbance. NIPF landowners object strongly to rutted trails. Often small tracts have had a variety of past management activities leaving the full range of products, pine plylogs to hardwood pulpwood. An appropriate system must be able to merchandise each tree to its highest and best use. Log-length (or cut-to-length) logs best give this high level of utilization. Short pulpwood while very salable to markets is very costly to handle; 20-foot length is much more efficient and cost effective.

Small landowners often object to clearcutting and prefer small patch cuts or selection cuts. They often have bug damaged wood for salvage. The system needs to be reasonably insensitive to cutting these small patches and skidding longer distances.

The system which appeared to best meet the needs of small landowners is one using medium size forwarders. It was estimated from past productivity studies of small forwarders (2) that a 4- to 5-cord capacity forwarder combined with 2 chainsaw operators would give a balanced combination. The owner/operator would run the forwarder which would give him supervisory control of both the stump area felling and processing as well as the roadside area where he loaded the trailers with the forwarder.

Using set-out trailers, a forwarder contractor could eliminate the hauling headache and concentrate on managing his woods operation. Truckers prefer a forwarder approach because the forwarder transports the wood to the trailer rather than trying to get the trailer to the wood which is common to skidder operations. Fewer woods roads and landings would be needed; the necessity for a crawler tractor would be eliminated. Since tractor/trailers aren't pushed or pulled out to an all-weather road, a lighter more cost efficient tractor can be used. Lighter tractors also give better payloads and run more efficiently on the highway. Set-out trailers loaded and waiting adjacent to a good road is a very attractive package to a trucking contractor. With strong enforcement of trucking laws, truckers are reluctant to have their rigs damaged while being pulled or pushed out of the woods.

Initial equipment cost for a forwarder operation was estimated to be around $100,000 which is about the same cost as just a feller-buncher or a single grapple skidder. Total cost per scheduled machine hour(SMH) was estimated at $54.00. To confirm the positive impacts of forwarding on small forest lands and to better understand the cost and productivity relationships, field studies were needed. Fortunately, a local contractor had recently established a forwarder operation and agreed to have it studied.

The Forwarder Crew

Logging equipment used in the study consisted of 3 Stihl 038 chainsaws, SwedePro safety apparel, a Tree Farmer C6D Forwarder with a Cranab boom and grapple, and 2 frame-style set-out trailers with 4 sets of standards. The owner/operator was a forestry graduate who had had many years of woods experience working with his father who was a logger. As an experienced equipment operator, the owner was a quick learner on the equipment. At the time of the first productivity studies, he had been running the forwarder for 2 months and therefore was still early on his learning curve. As a business owner, he was highly motivated to develop a successful logging operation.

The contractor secured most of his own timber to be harvested from local landowners who knew him and his father. Initially, his past reputation helped him procure his wood, but after 6-months of operation, his forwarder system is attracting new cutting opportunities.

Tracts to be cut have mostly been clearcuts, but forwarder clearcuts don't look like skidder clearcuts. Absent are the numerous push out roads and landings. Usually, only one landing is required and it is relatively small and located next to an all-weather road. No large piles of limbs and tops from gate delimbing are evident at the landing because trees are limbed in the woods.

Landowners also notice the lack of rutted skid trails. Even main forwarder roads which carry most of the wood are not deeply rutted. Where tops and limbs can be thrown into the forwarder trail, very little visual compaction results. Since the forwarder drives over the terrain rather than skids through it, much of the surface litter is undisturbed. Young regeneration trees are not destroyed as with skidding.

One tract which was cut consisted mostly of small patches of blown down trees scattered throughout a tract of 60 acres. The landowner had a forester mark trees to be removed. The stand was thick and in need of thinning so extra trees were marked around the downed ones to get access. Still the patches were held to small areas. The forwarder crew had no difficulties removing this wood. Chainsaw operators processed the downed trees into log-lengths and the forwarder transported all wood out to a single small landing next to a county road. More wood was recovered than the forester had estimated. The landowner was so impressed with the lack of damage by the forwarder crew that he allowed them to thin the entire remaining stand after the wind damaged wood had been removed. This time, the forwarder crew did their own tree selection.

Objectives

Since forwarder operations of this type are relatively new to the South and are still being developed and refined, it was important to document the descriptive components and identify areas for improvement. Some of the objectives of this study were as follows:

1. Determine the productivity of a log-length forwarder operating in natural stands.
2. Evaluate the interaction between felling and forwarder productivity.
3. Compare results with previous studies.

METHODS

Standard time and production study methods were used to evaluate productivity. Plots in the felling area were identified and the forwarder was timed picking up the wood from these plots. Plot size was variable and sized to the capacity of the forwarder. Chainsaw felled trees which had been limbed and bucked into log-lengths were measured. For each log, species/product category, length, end diameters, and location was recorded. A system of X/Y coordinates located each log butt. Also to define how the logs were arranged, an azimuth from each butt was recorded. The azimuth of the Y-axis was also noted.

The forwarder was timed during the loading and travelling phases by video camera recordings of its movements. Markers were put out at each place where the machine stopped to determine distances between loading positions. Log identification numbers were recorded as the logs were placed on the machine.

Office analysis involved taking times from the video. Time elements included: swing out, grip, swing in, travel preparation, and travel time and are defined as follows:

Swing Out - Time began when boom/ grapple began to swing out, away from the forwarder bed, to pick up a stem. If a stem had just been dropped into the bed the swing out element began at the moment the stem was released, unless the operator paused to look around for other stems or for some other delay after dropping the stem.

Grip - Time began when the grapple began to move in order to grasp the stem. Time ended when the boom swings in with the stem. If the operator dragged the stem toward the forwarder bed, then this time counted as swing in time. If, after dragging the stem around, the operator puts one end of the stem on the ground and slides the grapple toward the center of the stem then this counted as grip time. It was not uncommon to alternate back and forth between swing in time and grip time once or twice during a cycle.

Swing In - Time began when the stem was dragged toward or carried to the forwarder bed. Time ended when the stem was laid in the bed and was released by the grapple. Usually swing out time began just after swing

Table 1. Plot Summaries.

Plot No.	Pieces	Volume/piece (cubic feet)	Volume/plot (cubic feet)	Dispersion (feet)	Orientation (degrees)
1	21	10.8	227.3	15.0	50
2	27	7.4	199.8	10.3	24
3	5	13.1	65.7	?	?
4	12	10.1	121.2	9.9	19
5	36	9.7	349.2	19.8	99
6	56	6.3	352.8	29.9	96
7	72	5.3	381.6	29.7	73
8	30	10.1	303.0	5.8	19

in time.

Travel preparation - Time was taken to prepare for traveling. This included time taken to position boom/grapple so that it was secure during travelling and time taken by the operator to turn from boom controls to steering controls. Other actions may have been necessary for different machines in order to prepare to move.

Travel - Time taken to move machine from one place to another and began when the machine began to move and ended when another time element began.

Time elements were summarized by swing cycle, stop group, and loading cycle. A swing cycle went from swing out time to the next swing out. A stop group included all times from the end of one travel to the beginning of the next travel. A loading cycle began with the end of travelling empty and included all times up to the next travel loaded. Each travel time was treated separately.

Along with each swing cycle, stop group, and loading cycle, the corresponding number of pieces and cubic feet (CF) of wood (outside bark) was determined. For travelling, a distance was determined from X/Y coordinates of loading locations or by taping the distance moved.

For each plot an overall measurement of dispersion and orientation was calculated. Dispersion was defined as the standard error of the estimate for a straight line regressed through the mid-points of each log. The "Y" axis was a straight line distance from the origin along the path of the forwarder and "X" was the perpendicular distance from Y. Orientation was defined as the standard deviation of azimuths recorded from the logs.

RESULTS

Eight plots have been measured to date. Their sizes were variable depending on the way the wood was felled. Table 1 summarizes some plot statistics. A total of 259 pieces and 2000 cubic feet (22 cords) were timed. These plots created 6 forwarder loads and over 2 tractor/trailer loads. Average piece size was 7.7 CF (outside bark). The forwarder made 49 stops to pick up wood and 223 loading swings. Dispersion of wood reached a maximum of 29.9 feet. Orientation on the plots ranged from 19 to 99 degrees in variation.

Loading

Loading of the forwarder involved the operator turning around in his seat to address the loader controls, swinging out to the wood on the ground, griping the piece(s), and swinging in to the forwarder bunk and release the piece(s). This loading cycle would be repeated until all wood within reach had been loaded. Some operational delays might occur during the loading cycle when pieces on the load needed to be straightened. Then the operator would turn around in his cab and drive the machine to the next loading point to repeat the loading cycle(s).

Since the data for this study is only a starting point, it was felt that a comparison to past studies might give a bench mark for improvement. One of the most recent studies involved Gafner Ironmule forwarders working with short pulpwood (5- to 7-foot).(2) The Ironmules were working with hand piled wood and the operators had considerable experience in this type of work. Table 2 shows some comparisons of the Ironmule study to comparable measures with the current Tree Farmer study.

Because the Tree Farmer forwarder was transporting long pieces (20-foot pulpwood and sawlog lengths) and the Gafner was in short pulpwood, the volume per loading stop was greater for the Tree Farmer (40.7 CF versus 15.7). Even though there were more pieces at the Gafner loading stops (14.3 versus 5.3) the piece size for the Tree Farmer was much larger (7.7 CF versus 1.1).

The Tree Farmer loaded less volume per swing because of the lower number of pieces loaded. In the Gafner study the wood had been hand piled with ends aligned. The Tree Farmer's wood was scattered. The Gafner picked up 9.2 pieces for 10.1 CF as compared to 1.2 pieces and 8.9 CF for the Tree Farmer.

Swing cycles for the Gafner were significantly faster than those of the Tree Farmer. A Student's t-test for differences between loading time per swing for the Gafner to that of the Tree Farmer gave a t-statistic of 8.02 with 222 degrees of freedom, a highly significant difference. Loading cycle time per swing for the Gafner study was .52 productive minutes as compared to .70 productive minutes for the Tree

Table 2. Loading Summary.

Measurements	Tree Farmer C6D		Gafner Ironmule
	Mean	Range	Mean
Volume/stop (CFob)	40.7	4.3-109.8	15.7
Pieces/stop	5.3	1-12	14.3
Pieces/swing	1.2	1-4	9.2
Volume/swing (CFob)	8.9	.8-33.0	10.1
Productive Minutes per swing	.7	.2-2.4	.5
Productive Minutes per 100 CFob	11.2	1.8-85.8	5.2

CFob = cubic feet ouside bark

Table 3. Travelling Summary.

Measurements	Tree Farmer C6D		Gafner Ironmule
	Mean	Range	Mean
Travel empty distance (feet)	400	N/A	392
Travel empty speed (feet per minute)	323	N/A	221
Travel loaded distance (feet)	575	470-680	438
Travel loaded speed (feet per minute)	219	200-238	166
Travel distance between stops (feet)	37	12-104	23
Travel speed between stops (feet per minute)	92	20-196	34
Total travel minutes per 100 CFob @ 400 feet empty and loaded and 30 feet between stops	2.1	N/A	4.4

CFob = cubic feet outside bark

Farmer. A portion of this difference can be attributed to the longer reach of the Tree Farmer, but the major difference is in the extra time the Tree Farmer spends gripping and adjusting the wood while loading.

Time per 100 cubic feet shows the Gafner more productive. Even though the Tree Farmer had more wood to load at each stop, the wood's lack of order kept down production. By only putting on 1.2 pieces per swing, the Tree Farmer required 11.24 minutes per 100 cubic feet as compared to 5.15 minutes for the Gafner. Clearly, getting more wood in each swing cycle would improve the Tree Farmer's productivity.

Travelling

The forwarder experienced three types of travelling: travelling empty from roadside to the woods area, travelling while loading in the woods, and travelling loaded back to the roadside area for unloading. In the Gafner study there was no significant difference in speed of these three types of travelling if the distance travelled was accounted for in the estimation model. (2) The longer the distanced travelled the faster the forwarder moved.

For the 37 travels observed for the Tree Farmer and after accounting for distance travelled, there were no significant differences in travel speeds from the average speed measured on the Gafner (t-statistic = .46 with 36 degrees of freedom). Travelling empty was observed only once at 400 feet (Table 3). Travelling loaded was recorded twice at 470 and 680 feet for an average of 575 feet. Travelling between loading stops was observed 34 times for an average of 37 feet and ranged from 12 to 104 feet.

Table 4. Forwarder Load Summary.

Measurements	Tree Farmer C6D		Gafner Ironmule
	Mean	Range	Mean
Load size (CFob)	332	227-386	185
Pieces/load	43	21-72	169
Unload Minutes/100 CFob	3.3	N/A	3.3

CFob = cubic feet outside bark

Load Size

The Tree Farmer is a much larger machine than the Gafner. Table 4 gives some comparisons. The Tree Farmer carried almost twice as much wood as the Gafner (332 cubic feet versus 185 cubic feet; 3.7 cords compared to 2.1 cords). In piece count, the Gafner carried almost 4 times as many pieces.

Unloading was not measured for the Tree Farmer but was estimated to be the same as the Gafner or 3.3 minutes per 100 cubic feet.

Total Cycle

Putting loading with travelling and unloading, a total cycle time was determined. Table 5 shows that the Gafner has slightly higher productivity than the Tree Farmer (5.2 versus 5.1 cords per productive machine hour (PMH). Most of the Tree

Table 5. Total Cycle Estimates.

Times	Tree Farmer C6D			Gafner Ironmule		
	Productive min./load	% of Total	Minutes/ 100 CFob	Productive min./load	% of Total	Minutes/ 100 CFob
Travel empty (@ 400 ft)	2.1	4.8	.6	2.1	8.8	1.1
Loading	25.8	59.1	7.8	9.6	40.1	5.2
Travel during loading (@ 30 ft)	2.8	6.4	.8	4.0	16.8	2.2
Travel loaded (@ 400 ft)	2.1	4.8	.6	2.1	8.8	1.1
Unloading	10.9	25.0	3.3	6.1	25.5	3.3
Total	43.7	100.0	13.2	23.9	100.0	12.9
Cords/PMH			5.1			5.2

CFob = cubic feet outside bark

PMH = productive machine hour

Farmer's time is spent loading and unloading (25.8 minutes or 59%). If the loading for the Tree Farmer was proportional to that of the Gafner, it would require 17.2 minutes to load which would bring the total productivity up to 6.3 cords/PMH. Because the Gafner has a smaller payload, it proportionally spends more time in travelling than the Tree Farmer.

Assuming the cost of $35.81 per PMH (1) for the Tree Farmer C6D, its cost per cord is $7.02 compared to $20.06 per PMH for the Gafner 4510 and $3.93 per cord. If the loading time for the Tree Farmer could be reduced to 17.2 minutes giving production at 6.3 cords per PMH, total cost would drop to $5.68 per cord. Overall, the Tree Farmer crew appears to be producing wood on board trailer at $18 to 19 per cord.

CONCLUSIONS

With this current preliminary study the forwarder approach to harvesting small timber tracts looks very promising. The overall costs are reasonable and silvicultural results seem to be meeting landowner objectives. As with any start-up condition, improvements need to be made. Particularly, the wood placement during felling offers promise as an area for gains. Additional studies and training are being conducted with this crew to improve its efficiency and to further document its applicability to small landowner tracts.

LITERATURE CITED

1. Brinker, R.W., D. Miller, B.J. Stokes, and B.L. Lanford. 1989. Machine rates for selected forest harvesting machines. Ala. Agric. Expt. Sta., Cir. 296. 24 pp.

2. Lanford, B. L. 1982. Application of a small forwarder in plantation thinning. South. J. of Appl. Forestry 6(4):183-188.

1990 Council on Forest Engineering
Kill Devil Hills, North Carolina
U.S.A.

Forest Equipment Maintenance Productivity - concentrate on the small jobs!

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ABSTRACT

Time-to-completion of work orders in maintenance operations for forest harvesting equipment is shown to be gamma-distributed with a mean time of 3.5 hours. Since the majority of work orders have a completion time of less than 3.0 hours, improved productivity will require work studies to be concentrated on these short-duration jobs. Some techniques are suggested to achieve this goal.

INTRODUCTION

The forest industry has generally lagged behind others, such as mining, manufacturing and transportation for example, in efforts to improvemaintenance productivity. However, rapid mechanisation and accelerating costs have forced both companies and contractors to re-evaluate their machine maintenance costs.

Twenty years ago, a conventional harvesting operation would have generally consisted of units of chain saws, skidders and forwarders, mechanically simple machines with a relatively low capital cost. Today, multi-function tree processors, delimbers, flail-debarker/chippers, for example, may cost from $250,000 to $600,000 per unit, with a total system investment in excess of $1.0 million. Studies have shown that maintenance costs over a total production period of 12,000 hours can exceed 100% of the original capital cost [1].

Maintenance work is labour-intensive, the sum of wages and benefits usually exceeding 50% of total costs, rising to 70% under certain conditions of machine type and geographic location of harvesting operations [6] [7]. It is well documented that labour productivity, that is the direct work activity of a skilled mechanic, seldom exceeds 40% [4] [5]. The characteristics of maintenance work which contribute to this low figure include lack of repetitive functions, such as may be experienced in a manufacturing situation, lack of consistent work methods due to variable levels of training, and the wide variety of machines, machine components, configurations and year of manufacture within forest operational units.

PROBLEM DEFINITION

It is known that the greatest non-productive element in maintenance work is tool and part procurement (see Figure 1). It also the only element which is significantly job-variable [4].

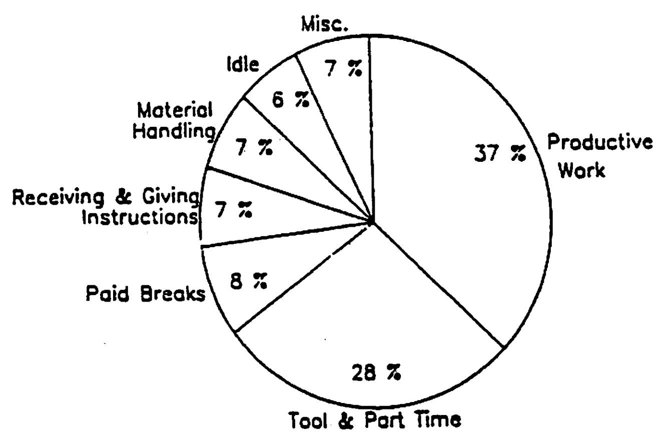

Figure 1. Distribution of Productive and Non-productive Work in Forestry Equipment Maintenance

Long-duration work orders (those > 8.0 hours) are usually well-planned in advance, with the required parts, special tools and replacement components being sourced and made available to the mechanic before commencement of the work order. Hence, the job proceeds smoothly, with infrequent delays for tool or part procurement, with set-up, material handling and clean-up time absorbing only a small proportion of total time.

However, it is postulated that short-duration work orders (those < 3.0 hours) have the lowest labour productivity, since they normally involve several trips for tools and parts, together with greater material handling, more involvement with supervision, and therefore relatively more non-productive time. Further study is require to confirm this hypothesis, but current estimates place labour productivity for this work in the 10%-20% range.

As a prerequisite to determining productivity levels in short-duration work orders, it was first considered essential to identify and classify the time duration of all work orders, particularly as they applied to the maintenance of heavy equipment in harvesting operations.

METHODOLOGY

Four maintenance operations were selected, two in the Eastern provinces and two in the Central provinces of Canada. All four are within the Boreal Forest region, where similar geographical, geological and meteorological conditions exist. All operations are owned by major forest companies, who purchase and maintain their own equipment either at central facilities or field garages.

Seven thousand work orders were obtained for the data set. In total, they represented just over 51,000 hours of maintenance work, equivalent to approximately 28 mechanic-years. Work order times were classified at one hour intervals, except for the first slot which, due to the significance of the frequency, was made a half-hour interval. It was noted that work order times were always rounded to the nearest half-hour up to approximately 20.0 hours, after which the rounding was one hour. No reason could be established for this policy, which varied between companies.

RESULTS

The mean of this data set was 7.4 hours. However, 5% of the work orders exceeded 40.0 hours duration. Since these were randomly and singularly occurring up to 230.0 hours, with many time slots having no entries, then for the purposes of this study, they were removed from the data set.

Therefore, with these work orders removed, the resultant data-set, representing 95% of the original 7,000 work orders, had a mean of 5.3 hours. The median point was 2.5 hours, but more significant to this study however was the mode point, which occurred at the 2.0 hour time slot, representing 21% of all work orders. Further, 19% of work orders occurred at the 1.0 hour time slot and 12% at the 3.0 hour slot. Also significant was that 80% of all work orders had a completion time of 8.00 hours or less.

A number of researchers in the field of maintenance operations have demonstrated that the characteristic shape of the Gamma Distribution could provide an accurate representation of work order times [2] [3]. Applying this finding to the data set used in this study produced a shape parameter (α), of 1.76 and a scale parameter (β) of 1.98 (see Figure 2), confirming that this data-set met that criteria. It should be noted, however, that the mean of the model curve ($\alpha.\beta$ = 3.48 hours) is less than the calculated mean of the actual data (5.3 hours), and results from a faster decay of the model curve in the 10.0 - 20.0 hour time slots, but a slower decay in the 4.0 -8.0 hour time slots.

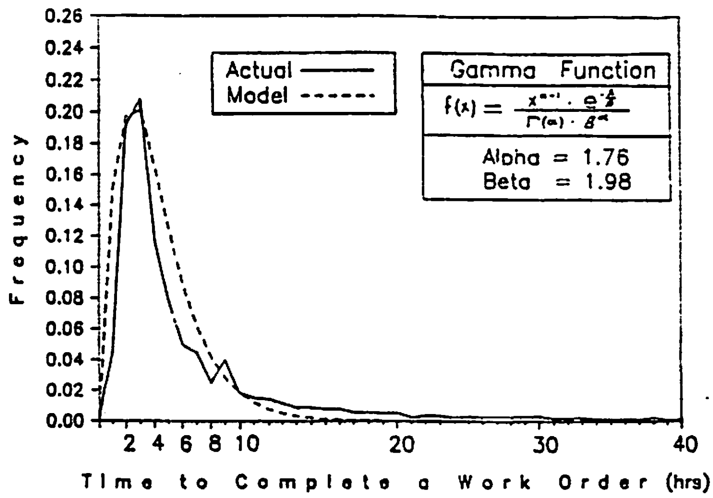

Figure 2. Gamma distribution curves for Forestry equipment maintenance operations.

CONCLUSIONS

It has been demonstrated that 52% of all work orders occur in the 1.0 - 3.0 hour time slot. While this grouping absorbs only 19% of total maintenance hours, it nevertheless represents a considerable impediment to the ability of a maintenance operation to enhance its labour productivity level. Therefore, if productivity is to be effectively addressed, work study resources, engineering services and maintenance management will have to concentrate on work methods and non-productive elements for work orders in this time slot group.

RECOMMENDATIONS

Some maintenance operations have already made considerable progress toward improved labour productivity for short-duration work orders. In larger shops containing more than ten mechanics, for example, planners have been able to schedule several similar short-duration work orders together, enabling one mechanic to move quickly from one job to the next using the same tools and parts. This is particularly effective if a non-mechanic can be assigned to the material handling function.

Another highly effective technique is the kiting of parts by the parts clerk prior to job commencement. Short-duration work orders such as oil changes, filter changes, brake repairs, etc. lend themselves easily to this approach. For some of these jobs, replacement of all parts regardless of their condition has also proven economically viable and very labour productive under certain conditions.

If work practices allow, one mechanic dedicated to similar high-frequency, short-duration work orders is also very productive. For example, a mechanic assigned to a special work bay where all parts and supplies are at hand for light truck maintenance, or for tire, brake, or hydraulic hose work, has been shown to enhance labour productivity.

Despite protests from parts clerks, the placing of small, frequently used parts in open bins and close to each mechanic work station, can save hours of non-productive part procurement time. Those operations which have adopted this technique have not recorded significant parts loss, as a result.

A careful analysis of the physical layout of the maintenance shop to determine optimal locations for special tools, parts and supplies, welding equipment, machine tools and cleaning equipment can also result in a significant productivity improvement for all mechanics. Layout software for can be adapted for maintenance operations.

ACKNOWLEDGEMENTS

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Some of the data used in this paper was included in a presentation made to the 1989 Institute of Industrial Engineers Conference, Toronto, Canada, and is reproduced with their permission.

REFERENCES

[1] Franklin, G. and J. Rickards. "Information - key to improved maintenance management decisions." Proceedings of the 68th Annual Meeting, Canadian Pulp and Paper Association, Montreal, Canada, March 1988.

[2] Maze, T.H. and S.K. Mallya. "A method for automotive equipment maintenance work measurement." Maintenance Management International, Vol. 6, No. 4, 1987, pp. 273-283.

[3] Niebel, B.W. "Establishing standards in the service area." Proceedings of the AIIE Fall Conference, 1983, p. 607.

[4] Rickards, J., and W. Williams. "Maintenance labour productivity in woodlands garages of the Canadian forest industry." Canadian Pulp and Paper Association, Publication No. W.S.E. 2922 (B-2-d), Feb., 1984.

[5] Rickards, J. and W. Williams. "The productivity of maintenance mechanics." Proceedings of the IIE International Conference, Chicago, USA, May 1984.

[6] Rickards, J. "Labour costs and productivity in forest equipment maintenance." Proceedings of IUFRO International Symposium on Work Study in Forestry, Thessaloniki, Greece, June 1988.

[7] Logging Operations Report, Woodlands Section, Canadian Pulp and Paper Association, Montreal, Canada, 1986.

OPERATION BIGFOOT:
The Development and Application of Variable Tire Pressure/Central Tire Inflation Technology for the National Forests of the United States

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ABSTRACT
Tests conducted to-date demonstrate that benefits (reductions in road maintenance, a decrease in the thickness of roadway aggregate and asphalt surfacing, improved driver comfort, reduced vehicle maintenance, etc.) accrue when vehicles hauling forest products use central tire inflation/variable tire pressure (CTI/VTP) technology. Truck drivers, using CTI, can control the pressure of groups of tires to ensure appropriate tire deflection for the various operating conditions they encounter. Exposing the CTI/VTP concept so that it gains acceptance continues to be a worthwhile goal.

BACKGROUND
To minimize road construction/reconstruction costs, reduce road and vehicle maintenance costs, improve mobility and accessibility, and increase driver comfort, the U.S. Department of Agriculture Forest Service suggests the use of central tire inflation/ variable tire pressure (CTI/VTP) technology. VTP/ CTI allows the control of tire pressures (or, more correctly, tire deflections) to match varying conditions of speed, load, and road. Tire deflection is defined as the ratio of the difference in tire height between the loaded and unloaded conditions to the unloaded height, expressed as a percent (Fig. 1).

For high-speed highway operations, we often find pressures of 90 to 110 psi, or 8 to 10 percent deflections under load. For low-speed hauling—typically 35 miles per hour or less—there are distinct advantages to running tires with 20 percent deflection—or 25 psi unloaded, 45 psi loaded.

Much of the hauling of forest products takes place on a combination of roads under a variety of conditions (Fig. 2). A driver could stop a truck and deflate or inflate tires to the desired deflection manually, but these adjustments are most efficiently made using CTI. CTI equipment permits the driver to make pressure and deflection adjustments from inside the cab while the truck is in motion.

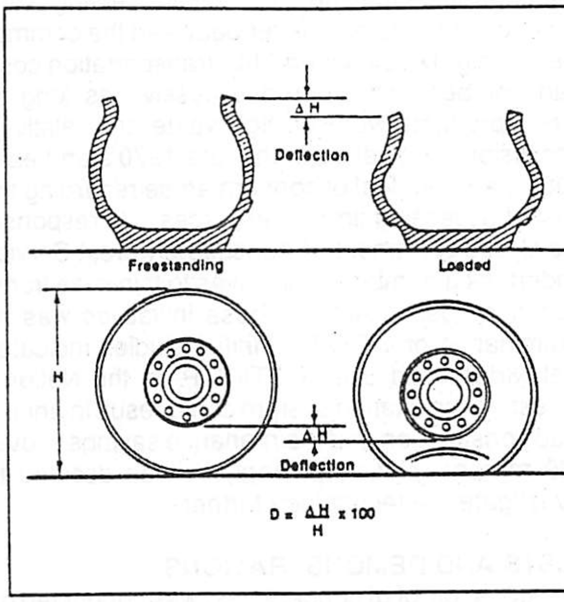

Figure 1. Tire deflection diagram.

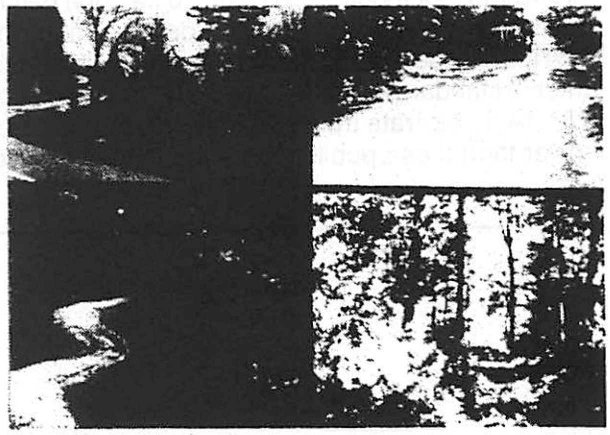

Figure 2. Hauling of forest products occurs on a variety of roads.

CTI/VTP technology is not new. Allied forces in World War II used CTI on some large amphibian vehicles to improve mobility. After the War, the technology languished in the Western World due to relatively highly developed transportation systems. VTP/CTI technology did not die out, mainly due to the efforts of eastern bloc nations and the interest of some European manufacturers servicing the Third World transportation market. VTP/CTI had, and continues to have, application in areas with lesser developed transportation systems. Interest in VTP/ CTI was revived in the United States due to increasing concern for mobility on the part of the military. CTI-equipped wheeled vehicles offered a cost-effective alternative to tracked vehicles. Domestic and foreign manufacturers developed and now produce CTI hardware for a variety of military vehicles.

Although the transportation system serving North American forests had never been—in the common view—"highly developed," the transportation costs had not been considered excessive as long as forest products were of high value and relatively accessible. However, in the late 1970's and early 1980's a great deal of concern arose regarding the cost of accessing timber resources. In response, the U.S. Department of Agriculture Forest Service undertook a number of initiatives to minimize transportation costs. Among these initiatives was an examination of CTI/VTP. Initial studies indicated that widespread use of CTI/VTP on the National Forest transportation system could result in annual road construction and maintenance savings of over $20 million. Not surprisingly, it was decided to investigate the technology further.

TESTS AND DEMONSTRATIONS

In 1983, a "proof of concept" test was conducted on the Klamath National Forest, California, to determine the feasibility of VTP/CTI use. The results were promising, but much would have to be done before further application could be considered. Among the first tasks to be accomplished was obtaining at least interim standards from the Tire and Rim Association (T&RA) to operate trucks with tire pressures much lower than those published by the industry. Also, additional tests were needed to determine the effects of operating with reduced pressures (and increased deflections) on hauling vehicles.

In the mid-1980's, the Forest Service, in cooperation with the Rubber Manufacturers Association (RMA), tested and evaluated the effects of VTP/CTI on commercial hauling vehicles and their tires at the Nevada Automotive Test Center (NATC), Carson City, Nevada. Each of two essentially identical 18-wheel logging trucks, equipped with commercially available tires, were run more than 5,100 miles over an AASHTO-type, closed-loop test track. One truck was run with tires at the RMA recommended pressure and deflection of 90 psi and 10 to 12 percent deflection, the other at 20 to 22 percent deflection—53 psi front axle, loaded and unloaded; 53 psi loaded for drive and trailer axles; 25 psi unloaded for drive and trailer axles. As a result of NATC tests, the RMA established interim standards (Appendix I) for tire pressures and deflections—standards that were needed before further testing, demonstrations, and application could proceed.

In the late 1980's, the Forest Service constructed and operated a test track in cooperation with the U.S. Army Corps of Engineers and the Federal Highway Administration (FHWA) at the Waterways

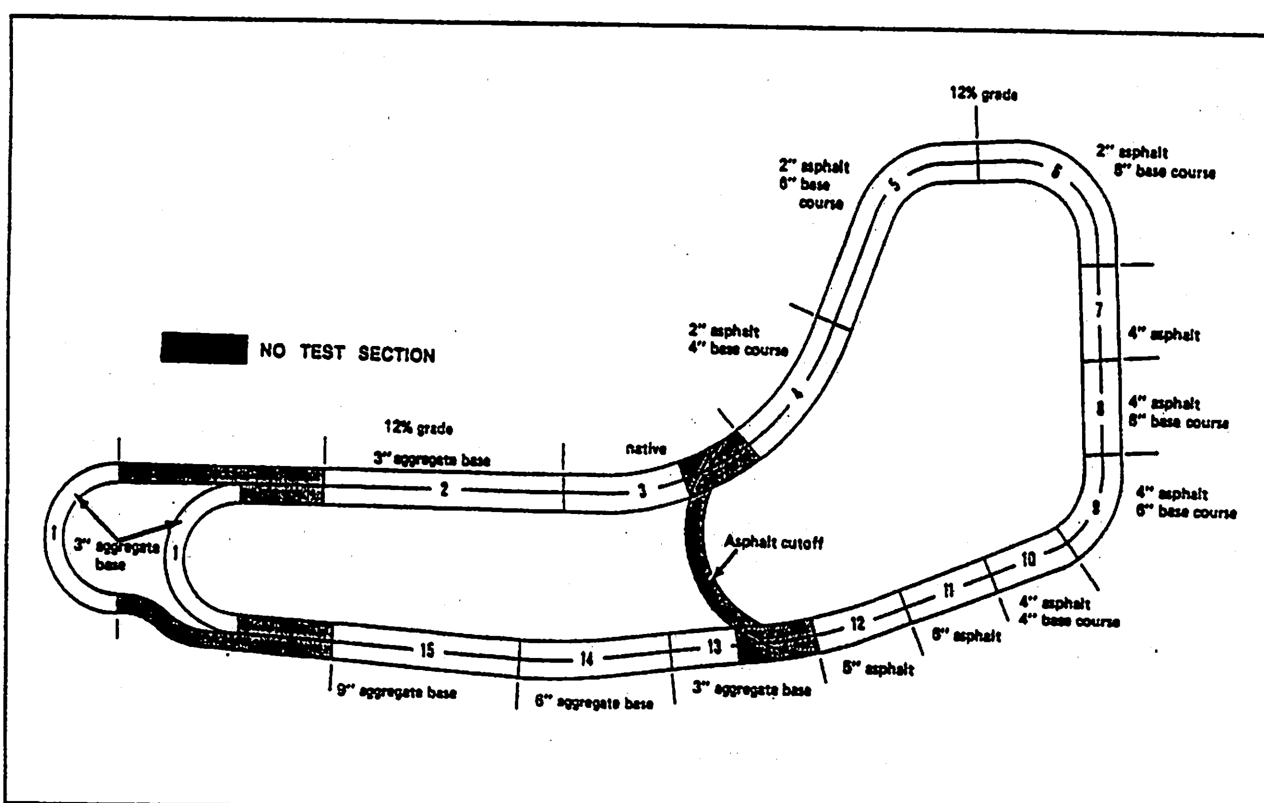

Figure 3. Diagram of WES Test Track.

Experiment Station (WES), Vicksburg, Mississippi. The primary purpose of these tests was to evaluate the effects of VTP on road surfacing design procedures and maintenance frequency. Tests on factors affecting trucks, tires, and drivers continued. The same trucks used at NATC ran over a closed-loop track consisting of 15 instrumented sections of a variety of surfacing designs—including native, aggregate, and asphalt sections (Fig. 3).

Concurrent with the structured tests at NATC and WES, field demonstrations were conducted in a variety of locations in Alabama, Oklahoma, Idaho, Washington, Oregon, California, Montana, Alaska, Michigan, and Wisconsin. Goodyear and Michelin Tire Companies and many purchasers and trucking companies were major cooperators in many of these projects. The demonstrations included typical log hauling operations and road construction and maintenance projects. The demonstrations were run to introduce the technology to potential users, to gain field experience, and to get user reactions and recommendations regarding further use of CTI/VTP.

RESULTS

The overall results of the various tests and demonstrations are very encouraging and generally point to significant benefits associated with the use of CTI/VTP technology. It should be noted that not all benefits are realized to the same degree under all conditions or in all locations. The following is a sampling of the results obtained over the past 6 years.

Tire Wear and Damage

All CTI/VTP tests and demonstrations have been run using steel-belted radial tires. Since CTI/VTP technology requires running tires at pressures significantly different than have been commonly used, the first question and concern often relates to tire wear and durability. Results have varied from test to test, some showing less wear with VTP, some more. The most significant test so far has been run independently by Goodyear Tire Company. During 1989, they compared tire wear on over 400 tires on trucks hauling under a variety of conditions on locations in Oregon. CTI-equipped and standard trucks were paired throughout the test period, each pair operating together throughout the test period. The Goodyear tests showed no significant variations in tire wear between trucks running with VTP and those running with standard pressures and deflections. Factors such as season of the year and haul location had a greater effect on wear than tire pressures.

There have been no reports of increased tire damage (protector ply punctures, sidewall cuts, etc.) with VTP tires. In fact, under the severe test conditions at the NATC, the VTP truck experienced significantly less tire damage than the high-pressure truck. There have been no problems with tire bead unseating, even at 25 psi.

While no tires run under VTP conditions have been run to full "life cycle," to date there seem to be no problems associated with recapping these tires. Bandag Corporation has been a major cooperator in the CTI/VTP program, and has not detected any problems associated with recapping tires run under VTP. Some of these tires have been through two to three recapping cycles.

Future demonstrations will continue to monitor tire wear, recapability, and durability since this is an item of major concern.

Vehicle Maintenance

The softer ride resulting from running on softer tires significantly reduces the vibration and shock loading imparted to truck components. This is particularly true when trucks are operated under rough field conditions. For example, at the NATC site, the low-pressure truck experienced one-fourth of the part failures of the high-pressure truck. Parts and labor cost due to shock and vibration damage after 5,173 test miles came to $0.47/mile for the low-pressure truck; $4.15/mile for the high-pressure truck. The low-pressure tires transmitted one-sixth the vertical energy transmitted by the high-pressure tires (Figs. 4 and 5).

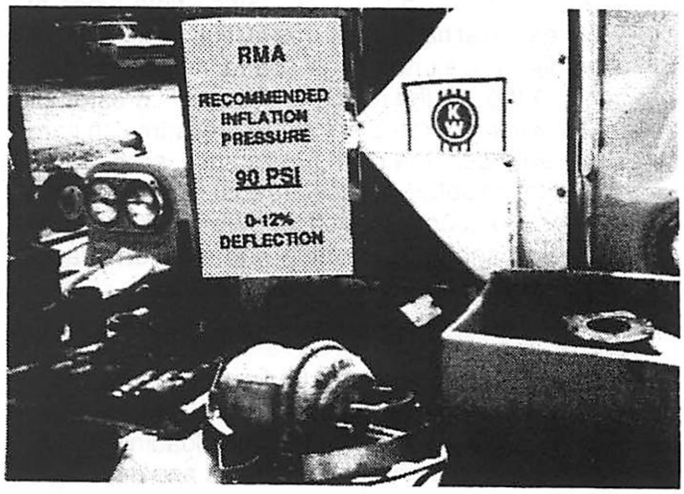

Figure 4. Parts replaced on truck with high-pressure tires.

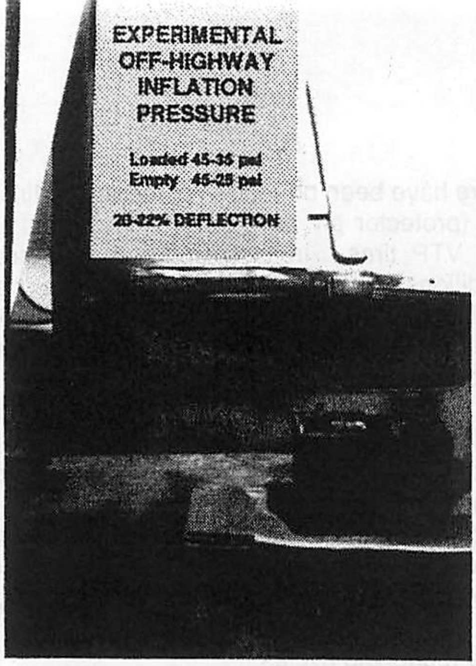

Figure 5. Parts replaced on truck with low-pressure tires.

It is recognized that most hauling is not done on such severe conditions as were built into the NATC site. Hauling under normal conditions is less destructive than on the test track, but maintenance costs for parts impacted by shock and vibration should be less over a period of time if VTP is used on a vehicle. Future work will be done to quantify the relative costs of VTP and standard operations and to quantify maintenance costs associated with CTI systems. It should be noted that there has been very little damage experienced by CTI components, even to the external hoses and valves associated with the external CTI systems used in several of the demonstrations.

Fuel Economy

Fuel economy appears to be about the same for VTP and standard vehicles. Since both types of vehicles run at high pressures at high speeds, there is no difference under high-speed, highway operations. Although the rolling resistance is greater for trucks when operated at low tire pressures on hard surfaced roads, the rolling resistance is less when operating on softer surfaced roads. Any increase in fuel consumption is also offset by improved traction (less slip) and reduced "hop and skip" on "washboard" and potholed sections of road.

Driver Impacts

U.S. Army tests over the years have shown that exposure to energy imposed to a driver's body through truck vibrations and shock loading significantly reduces driver attentiveness and increases fatigue and potential for injury to internal organs. The threshold value measured in standard Army tests is 6 watts (4.4 foot-pounds/second) of energy as detected by in-cab accelerometers.

The instrumentation installed in the trucks used on both the NATC and WES test facilities indicates a significant difference in the energy levels imparted to drivers between VTP and standard vehicles. The exposure to damaging and fatiguing energy levels is significantly less for trucks operated at lower tire pressures (Fig. 6). There could be considerable, long-term benefits associated with VTP use that will require longer term studies than have been conducted to date.

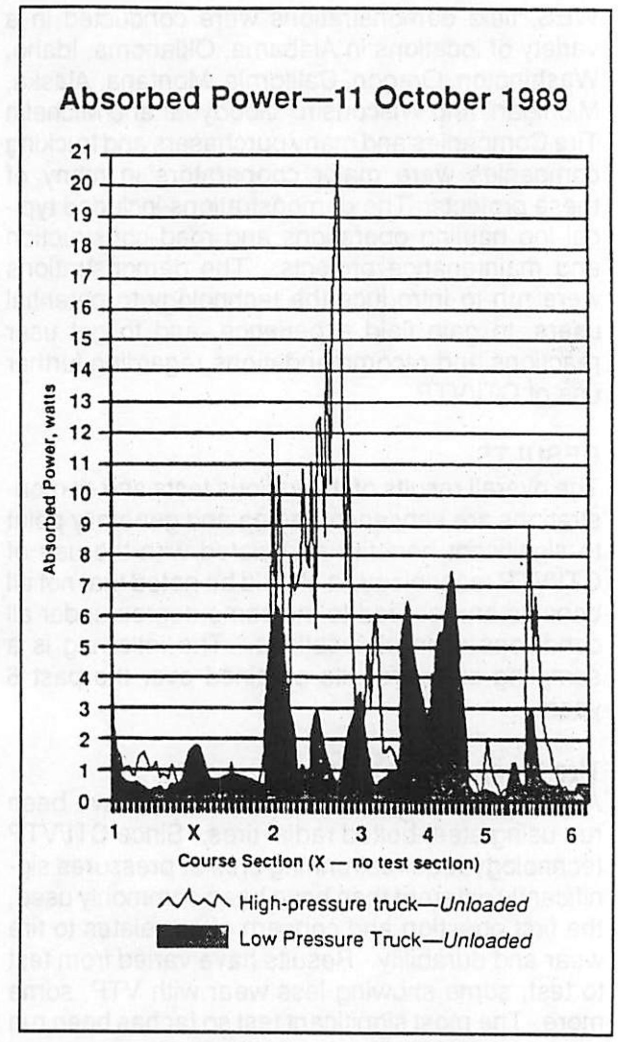

Figure 6. WES ridemeter graph comparison.

Drivers report that low-pressure trucks required some time to adjust to different steering conditions, somewhat similar to changing to radial from bias-ply tires. Reports indicated that high-pressure trucks drifted out on turns; low-pressure trucks held the road better and did not drift.

Drivers universally noted a softer, more comfortable ride—with benefits such as reduced "backslap" and less spilled coffee.

Road Construction and Maintenance Costs

The initial CTI/VTP studies indicated that substantial savings in road construction costs should be a major benefit associated with using the technology. The larger contact area or "footprint" associated with tire running at reduced pressures transmit loads over a larger area. The lower unit pressures transmitted to the road reduce surfacing requirements to support equal loads (Fig. 7).

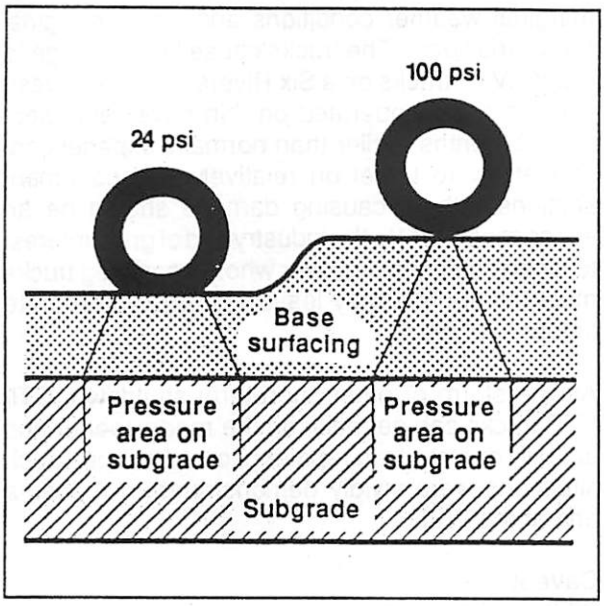

Figure 7. Pressure diagram.

The "theoretical" projections regarding surfacing have been substantiated by the tests at NATC and WES and several of the demonstration projects. The paved sections on the NATC track—2 inches of asphalt concrete—with a saturated subgrade rutted after 55 passes and failed at 81 passes in the high-pressure lane. One section in the low-pressure lane failed with a severe pothole at 121 passes; the other section continued in service through 169 passes when the test was terminated.

The road surfacing tests at WES terminated at the end of November 1989, and the results have not been completely tabulated or published yet. Preliminary results indicate substantial benefits accompanying VTP. In the thinner asphalt sections, the pavement failed twice in the high-pressure lane within 500 passes. In the low-pressure lane, the first failure occurred near 2,000 passes. (Fig. 8)

The aggregate sections yielded results that should be of particular interest for those who operate where it rains (and it rains on all of us sometime). While the aggregate sections for the high- and low-pressure lanes held up very well during dry periods, the effect of moisture and the response of the track sections to traffic under such conditions was dramatic in some areas. After 2.5 inches of rain over 6 hours, the high-pressure lane experienced failure in the 9 inch aggregate section. Some damage did occur in the low-pressure lane, but not as severe. Perhaps more significant were the conditions that developed after the rain stopped. The high-pressure lane continued to deteriorate and became essentially impassable. Low-pressure traffic imposed on the damaged traffic lane actually healed the surface and operating conditions improved.

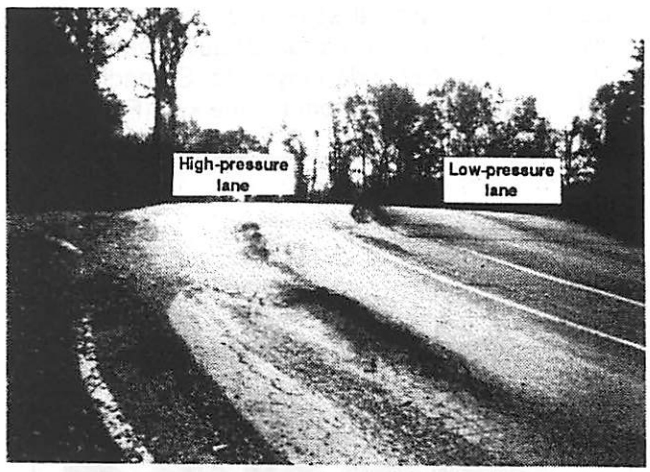

Figure 8. Asphalt surfacing comparison.

In Alaska, it was determined that a greater depth of shot rock fill over muskeg was required to support construction traffic than log haul traffic. A demonstration construction project, specifying haul vehicles with CTI, resulted in savings in excess of $100,000. A change order on another contract specified the use of VTP technology which permitted the use of lower quality rock at a savings of $400,000.

The tests and demonstration projects universally show that use of CTI/VTP results in reduced expenditures for road maintenance. Even in areas with highly developed road systems, such as the Prong Flight sale in Oregon and the gravel haul project on the Olympic National Forest in Washington, road maintenance savings were evident. CTI/VTP reduces requirements for surface blading and surface rock replacement. Running unloaded vehicles at the low pressures of 25 psi really reduces washboarding, a major mode of road deterioration.

Vehicles with CTI/VTP actually heal road damage. Washboarding, ruts, and potholes in aggregate surfaced roads are "ironed out" by the kneading action of the softer tires. In areas where standard pressure trucks and VTP trucks are mixed, the CTI/VTP trucks have healed/repaired the damage caused by other vehicles.

The WES tests indicate that surface blading can be reduced to one-fourth or less than normal. The high-pressure lane in the 12 percent gradient section had to be graded four times. The low-pressure lane was never graded. Similar reductions in maintenance effort have been noted on other projects.

Mobility

Use of CTI/VTP can yield substantial benefits where mobility over marginal soils and steep terrain is critical. Trafficability of standard hauling vehicles is enhanced in loose sands, clays, etc. Spreading the load over the longer footprint is the key (Fig. 9).

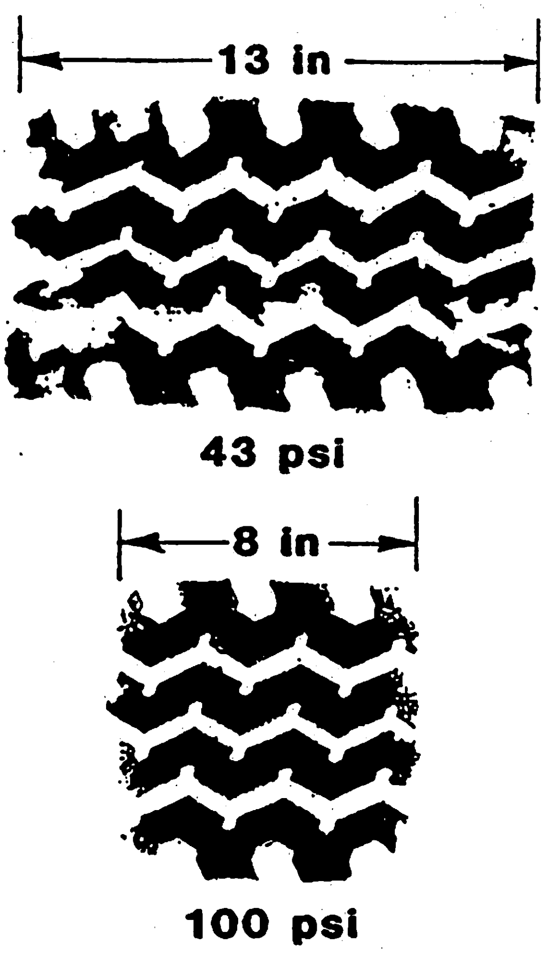

Figure 9. Comparative footprint diagram.

Enhanced gradability for vehicles using CTI/VTP has been demonstrated on a timber sale and a separate gradability study in Oregon. Unassisted loaded vehicles were able to pull grades in excess of 20 percent.

Due to lower tire-to-ground contact pressures and improved traction, the potential for extended haul seasons and fewer in-season shutdowns is very good. CTI/VTP-equipped trucks can operate under marginal weather conditions and under marginal road conditions. The trucks cause less damage to roads. VTP trucks on a Six Rivers National Forest, California, sale operated on thin pavements sections 2 months earlier than normally experienced. The ability to travel on relatively thin pavement sections without causing damage should be an economic benefit to the industry and of great interest to local road agencies over whose roads log trucks must travel once they leave agency or corporate timber haul roads.

After a storm or other short-term shutdown, CTI/VTP trucks can get back on the roads sooner and actually contribute to repairing road damage. Such situations were vividly demonstrated in Alabama and at the WES.

Caveat

While we have noted many successes and benefits associated with the use of CTI/VTP, it should be noted again that not all benefits accrue to all users in all locations. CTI/VTP should be applied after examining the local situation, identifying the potential costs and benefits of using CTI/VTP, and choosing to apply the technology where and in the manner that makes economic and environmental sense.

STATUS OF EQUIPMENT DEVELOPMENT

There are several methods available to achieve the benefits associated with variable tire pressure. VTP can be instituted on projects by using airing stations, or central tire inflation systems, either external or internal systems. Airing stations require setting up and operating air compressors with inflation manifolds to speed up tire inflation. Tires are deflated using quick-coupling release valves that attach to the truck valve stems. Airing stations are not particularly cost effective, but are a relatively inexpensive way to demonstrate VTP/CTI concepts on a one-time, short-term basis.

Central tire inflation systems, both external and internal, have similar components, such as:

-Air compressor: Normally the one on the vehicle used to supply air to the braking system.

-Air dryer: Essential item in cold, wet climates; needed to preclude formation of ice in the tires and CTI system.

-Priority valve: Ensures that braking system always has adequate air pressure.

-Controller: In-cab device used to control and monitor tire pressures, inflation, and deflation. May include an overspeed safety feature to automatically inflate tires if speeds exceed range specified for tires and pressures being used.

Air is supplied and exhausted to the tires in an **external** system through a series of hoses and rotating valves that are mounted on the outside of the truck. In **internal** systems, air is supplied to the tires through drilled axles and special hub assemblies. All system components are mounted inside the normal dimensional limits of the parent vehicle (Fig. 10).

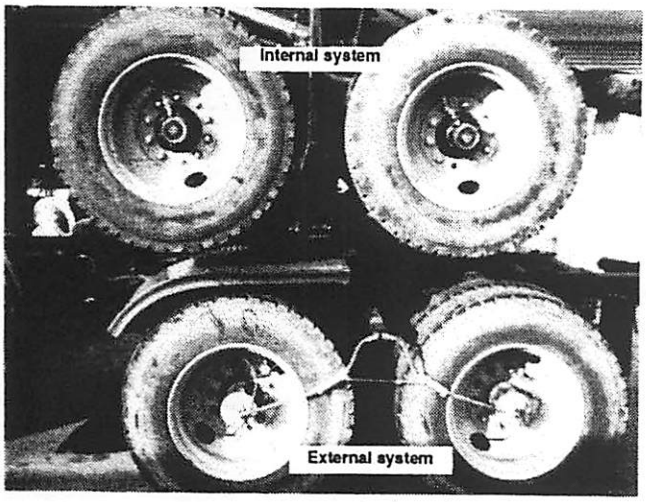

Figure 10. External and internal CTI systems.

Currently CTI systems are available on commercial vehicles through some European manufacturers. They are often used in Third World and developing nations. Internal systems are also available on domestically made military vehicles.

External systems and airing stations have been used on the majority of Forest Service demonstration projects to date. The components for such systems are available from a variety of manufacturers. Unfortunately, each system must be custom made and fabricated for each truck. There are no complete "kits" on the market. Costs for retrofitting an 18-wheeled log truck range from $7,000 to $15,000.

The Forest Service recently executed a development and procurement contract with Eaton Corporation for the delivery of 15 retrofit internal CTI system kits over in the next 20 months. The installed cost of these "preproduction" models will be $8,000 each for an 18-wheeler truck. It is anticipated that additional systems will be procured later. These initial systems will be installed on Forest Service 10-wheel dump trucks and on 18-wheel log trucks owned by cooperators participating in tests and demonstrations. The agency is also working with other manufacturers and examining the potential installation on large fire tankers as well as the smaller vehicle fleet.

DOCUMENTATION

The Forest Service has published a booklet, "Guide for the Application of Variable Tire Pressure Technology on National Forest Roads" explaining how to apply CTI/VTP technology to national forest timber sales. The agency has also produced a videotape, "Where the Rubber Meets the Road" which explains CTI/VTP concepts and illustrates many applications of CTI. Copies of both may be obtained free of charge from the San Dimas Technology and Development Center, 444 E. Bonita Avenue, San Dimas, California 91773 (*Attn:* Paul Greenfield). Phone (714) 599-1267.

FUTURE PLANS

The Forest Service will continue a program of demonstration projects to verify and modify the tests results obtained at NATC and WES, to establish local cost data bases, and to continue to expose potential users to the technology. Demonstrations for 1990 are planned in South Dakota, California, Oregon, and Washington. with the potential for others not yet identified.

The agency will continue to purchase and convert its own heavy vehicles to CTI where appropriate.

Our objective is to sell the VTP/CTI concept and gain more widespread exposure and acceptance of the technology as a means of minimizing the total cost of transporting forest products.

Measurements of Maximum Pressure at the Soil-Tire Interface of a Rubber-Tired Skidder

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Abstract

An electronic data acquisition system was developed to measure and record soil-tire interface pressure data during skidding operations. The computer based data system consists of a laptop portable computer, an analog to digital convertor system, a pressure transducer-Wheatstone bridge system, and a 2 Ampere-hour NiCad battery. The system was calibrated in the laboratory using an Instron Universal Testing machine and a lug section of a skidder tire. Field test were run to measure maximum soil-tire interface pressure under different conditions.

Key Words: Pressure, Soil, Skidders, Compaction

Review of Literature

The trend in the management of forest lands in the south-eastern United States is to use heavy machinery in all aspects of management. The use of heavy machinery in the areas of harvesting, site preparation, planting, and stand tending causes the concern of soil damage. The potential for soil damage is greater in forestry than in traditional agriculture because of the year round use of heavy equipment regardless of weather conditions. Soil compaction is a major threat to tree growth in the south due to the lack of freezing and thawing of the soil (Mitchell 1981). The projected natural recovery of some southern soils is about 50 years (Drissi 1975). The area affected by increased soil density, or compaction, is quite large because the majority of harvesting is done by rubber-tired vehicles (Burt 1984).

Several studies on compaction of forest soils support the need for further study of the compaction process. On one logging site, skidding increased the soil density in the ruts 20 percent and between the ruts 10 percent over undisturbed soil. This study estimated that twelve years in the ruts and eight between the ruts would be required for the infiltration and percolation rates to return to their original levels. The same study also estimated that even for five years, there would be a reduction in seedling survival and tree growth in the ruts due to high soil density (Dickerson 1976).

Some factors affecting the severity of compaction are: soil type; moisture content; ground cover (Miles 1978); vehicle parameters, such as tire type, size, shape, and inflation pressure (Porterfield and Carpenter 1986); the number of vehicle passes made on the soil (Vanden Berg and Gill 1959). Because of the infinite variability of the factors affecting soil compaction, understanding the compaction process is difficult at best.

All research on soil compaction was done under artificial conditions until Burcham and Matthes' (1985) work. A method was developed to take pressure readings in an undisturbed condition by mounting a pressure transducer in a lug of a rubber skidder tire (Burcham and Matthes 1985). Measuring soil-tire interface pressure can be difficult, since there is no standard for measuring soil-tire interface average or peak pressure. Soehne (1958) stated that for tractor tires without high lugs, the maximum pressure at the soil-tire interface equals 1.4 to 2 times the mean pressure. Vanden Berg and Gill (1959) stated that the soil-tire interface pressure should not be determined from vertical load on the tire and the total contact area between the tire and the soil.

VanDevender and Matthes (1987) developed and tested a Fluid Coupled Pressure Cell (FCPC), which consisted of a hydraulic cylinder, piston and sleeve arrangement. The FCPC was constructed so that the piston served as the sensing face, while the oil in the cylinder transferred the pressure from the sensing face to the opposite end of the cylinder where the transducer measured the pressure. The cylinder's sleeve was mounted in the center of the width of the tire by drilling a hole in a lug along the radius of the tire and inserting the sleeve. Then the cylinder was threaded into the sleeve so that the face of the piston was at the surface of the tire's lug and the transducer was inside the carcass of the tire. A hole was cut in the tire rim and an air tight plate was used to pass the electrical leads from the transducer inside the carcass of the tire to the data acquisition system mounted on the rim.

A reliable mobile soil-tire interface pressure sensing system could prove to be a valuable tool in developing a better understanding of the compaction process in forest soils. Such a system would make possible the study of such variables as inflation pressure, load size, tire size, and operating conditions, and their effects on soil compaction. These studies would aid in the design of harvesting equipment to maintain soil compaction within acceptable limits.

Objectives

The objectives of this study are:

1. To calibrate system in the laboratory.
2. To obtain reliable results in the field with the system subject to changes in load and tire inflation pressure.

Instrumentation

The soil-tire interface pressure measurement system consists of a sensing unit and a control unit. The sensing unit measures the soil-tire interface pressure, and the control unit supplies the system's power, controls the sensing element, and stores the pressure readings.

Because a sensing element was required to measure the soil-tire interface pressure, the element needed to be mounted either at the soil-tire interface or in such a way as to measure the pressure at the soil-tire interface. Since a pressure transducer was selected for use as the sensing element, mounting the element on the surface of the tire was infeasible due to the dissipation of the measured pressures by the surrounding tire rubber. These restrictions led to the design of a Fluid Coupled Pressure Cell (FCPC), which consists of a hydraulic cylinder, piston and sleeve arrangement (VanDevender et al 1987). The FCPC was constructed so that, while the piston served as the sensing face, the oil in the cylinder transferred the pressure to the other end of the cylinder, where the transducer measured the pressure. The cylinder's sleeve was mounted in the center of the width of the tire by drilling a hole in a lug along a radius of the tire and inserting the sleeve. Then the cylinder was threaded into the sleeve so that the face of the piston was flush with the lug's surface and the transducer was inside the carcass of the tire. A hole was cut in the tire rim and an air tight plate with an electrical connector was manufactured to pass the transducer's signals to the control unit via the rim plate's electrical connector (Figure 1).

The control unit consisted of the following components: a lap top portable microcomputer; an analog to digital converter system; a pressure transducer-Wheatstone bridge system; and a 2 Ampere-hour NiCad Battery. The components were mounted in a housing which was bolted to the right rear rim of the

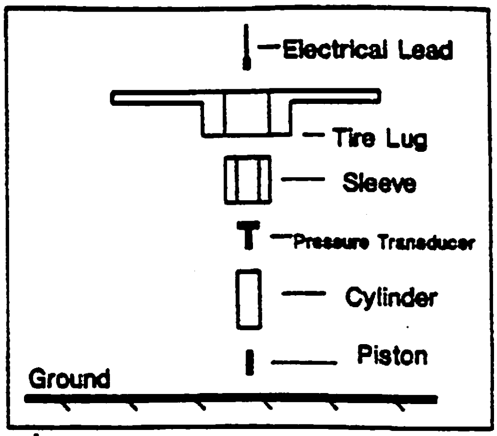

Figure 1.

skidder. The computer stores a pressure reading in RAM every 0.23 seconds. Data can be acquired for fifteen minutes before the memory is full; therefore, a Tandy portable diskdrive is used to download the data periodically.

<u>Methods</u>

The transducers used in this study were calibrated using a Model 1011 Instron Universal Testing Instrument with a 1000 lb (500 kg) force load cell. A section of a lug from a Firestone Forestry special tire was cut so that the length (8.03 cm) of the lug was equal to the width (8.03 cm) of the lug and the area of the test lug was 64.52 cm^2. A FCPC was mounted in the center of the lug in the same manner that it was mounted in the skidder tire. A frame was constructed of 1/4 inch steel plate which would attach to the load cell of the drive mechanism of the Instron and have the test lug and the FCPC attached to the lower portion.

An 8 inch diameter PVC pipe, 8 inches long with 1/4 inch wall thickness was used for holding soil to be used for calibrating the transducers. A calibration regression equation was developed to correlate the digital readings with soil-tire interface pressure.

The average interface pressure was calculated by dividing the weight of the unloaded skidder by the contact area. The pressure was 83 psi.

Tests were run using a cleared area between two plantations. The tests were run unloaded at 18 and 12 psi inflated tire pressures.

A graph of an example run is shown in Figure 2. The tests were repeated for each inflation three times. Figure 3 shows the results for the comparison between inflation pressures and runs. The pressure peaks were averaged to give average maximum soil-tire interface pressure. The average maximum pressure for 18 psi inflation pressure was 66 psi. The average maximum pressure for 12 psi inflation pressure was 61 psi .

Conclusions

The data acquisition system and the calibration technique have proved effective. The results showed that there are some intermediate peaks when the tire touches the surface. The average maximum soil-tire interface pressures for 18 and 12 psi inflation pressure were 66 psi and 61 psi respectively. This shows that there is not a significant difference with inflation pressures of an unloaded skidder.

Future plans include further tests of the system with different loads and with different soil types.

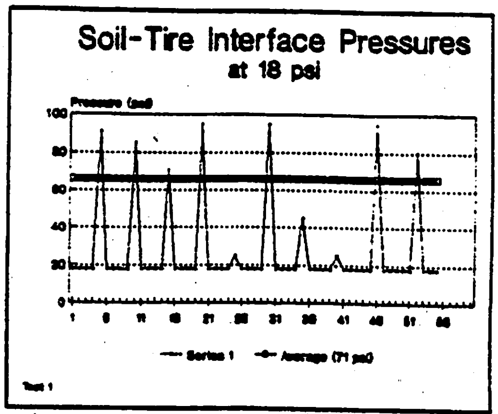

Figure 2.

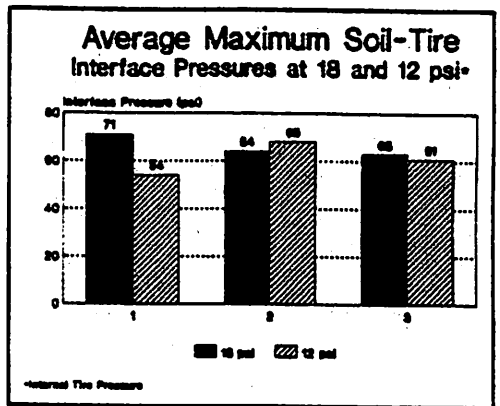

Figure 3.

References

Burcham, T.N., and R.K. Matthes. 1985. Mobile Soil-Tire Interface Pressure Sensing System. ASAE Paper #85-1586.

Burt, E.C., J.L. Koger, J.H. Taylor, and A.C. Bailey. 1984. Performance of Log-Skidder Tires. Transactions of the ASAE 27(3):670-673.

Dickerson, B.P. 1976. Soil Compaction After Tree-Length Skidding in Northern Mississippi. Soil Sci. Soc. Am. J. 40:965-966

Drissi, D.K., 1975 Recovery of abandoned logging road soil in North Carolina Piedmont. Unpublished Master Thesis. Department of Forestry, North Carolina State University, Raleigh, NC. p.59.

Matthes, R.K., 1989. Measurements of pressure at the Soil-Tire Interface of a Rubber-Tired Skidder. ASAE paper #89-7066.

Miles, J.A., 1978. Soil Compaction Produced by Logging and Residue Treatment. Transactions of the ASAE 21(1):60-62.

Mitchell, M.L., A.E. Hassan, C.B. Davey, and J.D. Gregory. 1981. Effects of Soil Compaction on Root Development and Seedling Establishment. ASAE Paper #81-1040.

Porterfield, J.W., and T.G. Carpenter. 1986. Soil Compaction: An Index of Potential Compaction of Agricultural Tires. Transactions of the ASAE 29(4):917-922.

Soehne,W. 1958. Fundamentals of Pressure Distribution and Soil Compaction under Tractor Tires. Agricultural Engineering 39:276-281.

Vanden Berg, G.E., and W.R. Gill. 1962. Pressure Distribution Between a Smooth Tire and the Soil. Transactions of the ASAE 5(2):105-107.

VanDevender, K.W., F.S. To, R.K. Matthes, and W.E. Ellis. 1987. Computer Based Soil-Tire Interface Data Acquisition System. ASAE Paper SER-87-106.

THE EFFECTS OF IN-WOODS FLAIL DEBARKING ON DEBARKING CHAIN WEAR

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ABSTRACT

The purpose of the study was to determine how and why flail debarking chains wear and if there were possible ways to extend the life of these chains, keeping in mind that chain costs are the largest single expense incurred by loggers currently using this technology.

Key Words: Machinery, Harvesting, Debarking

INTRODUCTION

In-woods debarking/chipping operations have proven themselves to be an effective method of producing quality pulpwood chips. Many contractors utilizing chain flail technology have been able to consistently produce pine pulpwood chips with .5 percent bark content or less. These bark contents are comparable to those found by Twaddle (1990) in pine pulpwood chips produced in stationary chipping facilities in the Southern United States.

Economically, in-woods debarking/chipping operations are feasible. This is not to say that there is not room for production cost reductions in harvesting operations that have made use of chain flail delimber-debarker technology. Stokes and Watson (1989) reported that chain cost constituted twenty percent of the total operating cost of chain flail delimber-debarkers. "The magnitude of this cost indicates that advances in chain management and technology afford a great opportunity for improving the acceptance of this technology" (Watson and Twaddle 1990).

There has been little or no effort on the part of the chain manufacturers to develop chain specifically for use in chain flail delimber-debarkers, forcing chip contractors to utilize chain that has been designed for applications other than debarking felled timber. This is due mainly because the chain being used in debarking/chipping operations represents such a small portion of their overall chain sales. By finding ways to reduce chain wear, and thus extending the life of the chains that are being used in flail debarking operations, overall operating costs can be reduced and profit margins can be increased. Increasing the profitability of this type of harvesting system will make in-woods debarking/chipping technology more attractive to the logging community.

To develop methods and material to extend chain life, it must be first understood how and why flail chains wear. In a cooperative study that has spanned two years, Mississippi State University, the U.S. Forest Service, and Weyerhaeuser Company have studied the factors that influence chain wear in an attempt to develop a chain maintenance program designed to minimize chain wear and extend the life of flail chains.

PROCEDURE

The chain wear of five brands of chain; Campbell Beacon 7, Super Campbell, Campbell Alloy, Trawlex, A8A

Alloy and Canadian Chain; was monitored in three bands of chain flail delimber-debarkers; Manitowoc 1642, Forest-Pro Model 23 and the Peterson-Pacific Model 4800. An outline of these trials can be found in Appendix A. Chain wear was determined by several chain measurements that were conducted daily. The measurements included total chain length, number of chain links, the diameter of individual links at both working ends and the total length of the individual chain links. The number of green tons of pulpwood chips produced was also recorded daily to later be used in determining the amount of chain wear that occured per green ton of pulpwood chips produced.

New chains were measured and mounted in the flail at the beginning of each trial and the prescribed measurements were performed after the completion of chip production for that day. Chain measurements continued to be taken daily until the completion of a trial. The flail's feed rate and flail drum RPM's were kept constant throughout the trials to insure that fluctuations in the wear data due to these two factors were minimized.

RESULTS

Chain wear increases in proportion to the number of green tons of pulpwood chips that are produced by flail chipper operation. However, the wear patterns of flail chains are greatly influenced by the type of flail that is in operation. There are two basic flail configurations; horizontal drum chain flails and vertical drum chain flails.

A horizontal drum chain flail is a flail in which the flail drum is mounted horizontally, causing the rotating chains to form individual vertical planes perpendicular to the flail drum. The Forest-Pro Model 23, Peterson-Pacific Model 4800, and the newly developed Chipharvestor, Inc. Model 23 are all of the horizontal variety.

The greatest chain wear in the horizontal drum chain flail occurred on those chains located on the flail drum's center. The chains located on either end of the drum received significantly less wear per green ton of pulpwood chips produced than did those located toward the flail drum's center. This is largely due to the increased contact that is made by the center chains with the stems that are being processed. By design, horizontal drum chain flails center the stems being processed, causing this increased contact by the center chains with the processed stems. Subsequently, this increases the amount of wear the center chains receive in comparison to those chains located at either end of the drum in a horizontal drum chain flail.

A vertical drum chain flail is a flail in which the flail drum is mounted vertically, causing the rotating chains to form individual horizontal planes perpendicular to the flail drum. The Manitowoc 1642 chain flail is of the vertical drum chain flail variety.

Chains located on the lower quarter of the flail drum wear substantially more than at any other location on the drum in a vertical drum chain flail. This is due, in part, to the lower chains striking the floor of the flail after being deflected downward by contact with a stem being processed. A circular wear pattern in the floor of the flail was observed in all of the vertical drum chain flails included in the study, further suggesting that the increased wear that the lower chains received in the vertical drum chain flails was partially due to the chains hitting the floor of the flail.

Chain wear is also influenced by the location of the link on the length of chain. Regardless of the chain's position within the flail, the outer three links (those farthest from the flail drum) of a length of chain received more wear than did those located closer in proximity to the flail drum. This is obviously due to the outer three links being exposed to more frequent contact with the stems being processed than those links nearer to the flail drum. In these trials, chains with 7, 8, and 9 links were tested, and regardless of the number of links a chain had the outer three chains wore significantly more than those that were nearer to the flail drum.

The practice of doubling flail chains (placing two chains in each slot on the flail drum) influences chain wear. The practice of doubling flail chains was first employed only in the winter months, when the stems are hardest to debark, by contractors who wished to improve the bark content of their pulpwood chips. Many loggers now double up their chains year round in an attempt to keep the bark content of the pulpwood chips they produce to a minimum.

The doubling of the flail chains actually decreases the wear on the individual flail chains. Although the wear of the flail chains that are doubled up is not cut exactly in half, there is significantly less wear in those chains that were installed two chains to a slot.

Chain wear causes chain link failure. It had been speculated that flail chain links failed due to the chain stretching and then finally snapping, causing the link to break. In this study, there was no significant increase in the overall length of the individual chain links found. Because there was no increase in chain link length found, the hypothesis that flail chain links stretch causing failure is shown to be invalid. Many of the failed links were recovered and the vast majority of them failed at either working end of the chain, where chain wear was occurring.

The diameter at which flail chain links fail varies with the brand of chain. In this study, a failed flail chain link is one that has broken and become completely detached from the remaining length of chain. The failure diameters of individual links were obtained from the last diameter measurement taken on that link prior to its failure. The diameter measurements used for the failure diameters were taken daily, after pulpwood chip production for that day had ceased. The mean average link failure diameters for five of the chains tested can be found below in Table 1.

Table 1. Mean average link failure diameters for selected flail chain brands.

Brand	Diameter in Inches
Campbell Beacon 7	.350
Super Campbell	.350
Trawlex	.450
A8A Alloy	.350
Canadian Chain	.440

These failure diameters were later used to help approximate the green tonnage of pulpwood chips produced at which a chain/link position would fail.

A regression model was developed that would predict the diameter of a link in any chain/link position. The model was fitted with a single common intercept which would be the average original link diameter combined with the data from all possible chain/link combinations simultaneously.

The final chain link diameter model was:

Chain Diameter = Mean Avg. Original Diameter - [(Chain Wear per Ton) * (# of Green Tons of Chips Produced)]

Note: Each chain/link position for each chain brand has its own chain wear/ton coefficent due to the variation in chain wear caused by the chain/link position on the flail drum.

By plugging the mean average link failure of each chain brand into the regression model, along with the mean average original chain link diameter and the chain wear per green ton of chips produced coefficient for a given chain/link combination, the green tonnage of pulpwood chips at which a given chain/link position would fail can be predicted for each chain brand. Tables of the expected lives of Campbell Beacon 7 chain mounted one chain per drum slot, Campbell Beacon 7 chain mounted two chains per drum slot and Super Campbell chain mounted one chain per drum slot can be found in Appendices B,C and D respectfully. Chain life in those tables is expressed as the number of green tons of pulpwood chips produced until a given chain/link combination fails. An example of how those tables were derived is as follows.

The expected life of Campbell Beacon 7 chain mounted one chain per front drum slot - chain 1, link 3 is as follows:

Chain Diameter = Mean Avg. Original Diameter - [(Chain Wear per Ton) * (# of Green Tons of Chips Produced)]

.350 inches = .590 inches - [(.00006130 inches/ton) * (# of Green Tons of Chips Produced)]

Solving for the number of green tons of pulpwood chips produced, it is found that at the point that the third link on chain one reaches the failure diameter for Campbell Beacon 7 chain, 3920 green tons of pulpwood chips will have been produced on that set of chains.

Being able to predict at what tonnage a brand of chain will start to fail is extremely useful from a chain management perspective. Many chip contractors have extended the life of their chains by switching the ends of their flail chains (re-attaching the end of the chain that has been debarking the stems to the flail drum) after a prescribed number of loads. The reasoning behind the switching of the working end of the flail chain is that the links closest to the flail drum receive little wear. Worn links that have been re-attached closest to the drum will receive very little increased wear and is therefore unlikely to fail due to excessive wear, while the links now located on the working end of the chain are essentially un-worn, substantially extending the life of the total flail chain.

Instead of a chip contractor using his "gut feel" to determine when to rotate or replace his chains, a contractor could use failure prediction data for the brand of chain he is using as a guide for when it would be an appropriate time to rotate the ends of his flail chain to maximize their life. Suppose a logger averaged 27 green tons of pulpwood chips per chip van load and was using Brand "X" chain that showed significant link failures at 900 green tons of pulpwood chips produced; At approximately 33 loads of chips, about three days production for the average chip contractor, the contractor would want to rotate the ends of Brand "X" chain to increase his chain life and minimize his operating cost due to chain usage.

SUMMARY

Chain costs make up a significant part of the operating cost of a chain flail delimber/debarker. There is ample room for improvement in the design and durability of flail chain. As it is better understood how chains wear, less expensive, longer wearing chains can be developed for use in the debarking of timber. Chip contractors have extended the life of their flail chains and lowered their chain costs by switching ends of the chain attached to the drum prior to chain failure at the working end of the chain. Although methods of extending chain life have been developed, more research and development is needed on the part of the chain manufacturers in order to significantly increase the durability and life of flail chains.

Appendix A. Outline of chain wear trials (Carte, Watson, and Stokes 1989).

Trial	Month/Year	Flail	Chain	Chain Configuration
1A	July 89	Manitowoc	Beacon 7	single/7 link
2A	July 89	Manitowoc	Beacon 7	single/7 link
3A	July 89	Manitowoc	Beacon 7	double/7 link
4A	July 89	Manitowoc	Super Campbell	single/9 link
5A	July 89	Manitowoc	Trawlex	double/7 link
6A	July 89	Manitowoc	Trawlex	single/7 link
7A	July 89	Manitowoc	A 8 A Alloy	single/9 link
8A	July 89	Manitowoc	Canadian Chain	single/8 link
9A	July 89	Peterson	Super Campbell	single/9 link
10A	July 89	Peterson	Campbell Alloy	single/9 link
11A	July 89	Forest-Pro	Beacon 7	double/7 link
12A	July 89	Manitowoc	Super Campbell	single/9 link

Appendix B. The expected life of Campbell Beacon 7 chain in a Manitowoc flail processing loblolly pine thinnings, one chain per slot (Watson and Twaddle, 1990).

Chain Number[@]	Front Drum Link Number*						
	1	2	3	4	5	6	7
	green tons						
1			3920	3857	2056	2075	5933
2	4299	2595	1857	1555	1108	1106	2197
3	2756	2030	1225	1239	1094	392	729
4	2694	1568	949	981	502	392	729
5	2899	1201	778	723	511	392	729
6		2101	1190	862	682	500	994

Chain Number[@]	Rear Drum Link Number*					
	2	3	4	5	6	7
	green tons					
1				4492	4005	
2			3226	2415	2340	5512
3			2567	1278	1272	2354
4	6193	2237	1398	974	614	1542
5	5512	4253	1120	899	559	1486
6	5340	3145	1564	1127	852	1864

*Link 1 is nearest the drum; link 7 is furtherest from the drum.

[@]Chain 1 is at the top of the drum; chain 6 is at the bottom location on the drum.

Appendix C. The expected life of Campbell Beacon 7 chain in a Manitowoc flail processing loblolly pine thinning, two chains per slot (Watson and Twaddle, 1990).

	Front Drum Link Number*					
Chain Number[@]	2	3	4	5	6	7
	green tons					
1	8407	4748	4147	3510	3399	5433
2	6893	3858	3390	2917	1874	3386
3	4320	3053	2513	1590	881	1289
4	3446	2496	2132	1151	648	1045
5	3053	2244	1850	1020	702	881
6	4154	2676	2149	1678	1225	2112

	Rear Drum Link Number*					
Chain Number[@]	2	3	4	5	6	7
	green tons					
1	5173		8322	7362	6497	1190
2		9720	6190	3427	2216	3367
3		1024	4210	2759	1227	1744
4	1068	4492	2938	1826	895	1671
5	9720	4731	2863	1830	1085	1553
6		9182	5911	4175	3336	4557

*Link 1 is nearest the drum; link 7 is furtherest from the drum.

[@]Chain 1 is at the top of the drum; chain 6 is at the bottom location on the drum.

Appendix D. The expected life of Super Campbell chain in a Manitowoc flail processing loblolly pine thinnings, one chain per slot.

	Front Drum Link Number*								
Chain Number@	1	2	3	4	5	6	7	8	9
	green tons								
1					3340	2424	1882	1090	3601
2				8974	2493	2029	1270	1046	2700
3			2988	2678	1953	1487	908	779	1652
4			3817	2216	1572	1467	850	407	1652
5			3874	2252	1428	1410	767	407	2070
6				2906	3007	1781	1216	1082	2169

	Rear Drum Link Number*								
Chain Number@	1	2	3	4	5	6	7	8	9
	green tons								
1							3156	3958	
2						3685	1889	2382	
3				3999	2899	2114	1450	1066	1979
4				4370	2130	1958	595	885	2417
5				3674	2235	1480	831	869	1506
6					2773	2256	1388	1462	3026

*Link 1 is nearest the drum; link 7 is furtherest from the drum.

@Chain 1 is at the top of the drum; chain 6 is located at the bottom of the drum.

LITERATURE CITED

Carte, I. Cameron, William F. Watson, and Bryce J. Stokes. 1989. Factors Impacting Chip Quality From Flail Debarked Stems. ASAE Presentation at the 1989 Winter Meeting. Paper No. 897593. New Orleans, LA. December 12-15, 1989. 10 pp.

Stokes, Bryce J., and William F. Watson. 1989. Field Evaluation of In-woods Flails in the Southern United States. Proceedings of the IEA/BA Task VI, Activity 2 Meeting. New Orleans, LA. May 29-June 1, 1989. pp. 99-111.

Twaddle, A. A. 1990. Roundwood Chipping Facilities in the Southern USA: A Survey of Equipment and Chip Quality. Unpublished Masters Thesis, Mississippi State University. 111 pp.

Watson, W. F., and A. A. Twaddle. 1990. Review-Chain Flail Delimbing-Debarking. Proceedings of the IEA/BA Task VI, Activity 2 Meeting. Copenhagen, Denmark. May 30, 1990. 40 pp.

MECHANIZED FELLING ON A CABLE YARDING OPERATION

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ABSTRACT

A swing-boom feller-buncher harvesting trees for a cable logging operation achieved a production rate of 32.1 cunits per productive machine hour at a cost of $3.87 per cunit. This paper describes several factors that affected felling productivity and discusses opportunities to enhance mechanical felling efficiency.

Key Words: Mechanized harvesting, Feller-buncher, productivity studies, machine evaluation.

INTRODUCTION

The forest products industry in the Pacific Northwest is in a period of transition. It's resource base is shifting from old-growth timber to second-growth timber. These second-growth stands have smaller piece sizes and lower volumes per acre. Harvesting costs, on a unit volume basis, increase exponentially with a decrease in piece size. Thus, the harvesting of second-growth timber with traditional methods will result in lower productivity and higher costs.

This reduction in productivity has stimulated interest in the use of mechanized harvesting equipment. Mechanized harvesting can potentially reduce costs by increasing productivity and reducing labor costs, however it usually requires an expensive initial investment and high operating costs. One application of mechanization is in the felling phase of a logging operation. Mechanical feller-bunchers can increase felling productivity and can also potentially increase skidding productivity. By accumulating trees in the form of a bunch, hooking time can be reduced and average turn size can be increased.

The feller-buncher/grapple-skidder system is a common felling/skidding system in use in many regions of North America. It has been found to be a highly productive and cost effective system on fairly level terrain. The feller-buncher greatly increases felling productivity. In addition, by building optimum sized payloads for the grapple skidder, skidding cycle times are reduced and skidding productivity is increased. Unfortunately, the use of ground-skidding equipment is often limited in the Pacific Northwest due to mountainous terrain and site disturbance concerns. The use of a feller-buncher/cable yarding system could potentially result in similar productivity gains in the rugged terrain of the Pacific Northwest. A feller-buncher could be used to build optimum sized cable yarding turns to help reduce hooking time and increase yarding productivity. Peterson (1986) conducted a study that compared grapple yarding mechanically felled timber to manually felled timber. Yarding bunched timber was found to increase productivity by 65% and reduce costs by $1.50 per piece.

The increased use of mechanized processing equipment in "hot processing" situations on cable landings provides additional incentive to improve the productivity of yarding systems. A study by Kellogg and Robe (1989) found the productive utilization rate of a stroke-boom delimber on a cable landing to be as low as 42 percent. Much of the delimbers nonproductive time was spent waiting for wood to process. Yarding bunched wood could increase wood flow and improve a delimbers utilization rate.

The use of feller-bunchers on rugged terrain has been studied (Gonsior and Mandzak, 1986; Kimoto, 1987). However, there has been little research conducted on the use of feller-buncher/ cable yarding systems in the Pacific Northwest. The purpose of this study was to evaluate a logging system that utilized a swing-boom feller-buncher, swing yarder and stroke-boom delimber. The objectives were to (1) determine the site and stand conditions that significantly effect the productivity of the feller-buncher, swing-yarder, stroke-boom delimber and the system as a whole, and (2) determine operational techniques or procedures that improve component and system productivity.

STUDY METHODS

This study consisted of three primary components. First, a detailed time study was conducted on the mechanized felling operation. Second, a detailed time study was conducted on the cable yarding operation. Third, a multi-moment time study was conducted on the stroke-boom delimber. As bunches were created, an identification number was attached to each bunch. Bunch volumes were than measured and various bunch characteristics were recorded. This enabled individual cycle elements to be related to actual bunch volumes and characteristics.

During the mechanical felling time study, 454 cycles were observed for a total of 82 bunches. A cycle was defined as the activities required to fell, accumulate and pile individual trees. Individual cycle times were then combined to determine the time required to create individual bunches. Total felling observation time was 511 minutes and occurred over a two day period in August 1989.

Due to changes made to the logging plan and miscommunication between loggers and researchers, only 22 yarding cycles were observed that contained bunched wood. A yarding cycle was defined as the activities required to yard one turn. The cycles were observed intermittently over a three day period.

During the multi-moment time study, the stroke-boom delimber was observed a total of 127 minutes in the study area and 290 minutes in adjacent areas. Delimber operation in the study area was defined as any time during which turns were being yarded from within the study area, even if turns were partially or completely nonbunched wood. Delimber operation in adjacent areas was defined as any time during which nonbunched turns were being yarded from areas immediately adjacent to the study area with similar timber and topography. The yarding and processing time studies took place during a three day period in October, 1989.

AREA AND STAND DESCRIPTION

The study area was located in a second-growth conifer stand on private industry land southeast of Eugene, Oregon. The silvicultural prescription was a clearcut. Approximately 95 percent of the merchantable timber was Douglas-fir with the other 5 percent being primarily western red cedar, western hemlock, Grand fir, and bigleaf maple.

Topography ranged from gentle, 5 to 20 percent slopes, at the northern end of the unit to broken ground with slopes up to 60 percent at the lower end of the unit. Stand area was 84.0 acres in timber and 5.2 acres in roads. Merchantable volume averaged 32 mbf/acre (net Scribner) and average diameter at breast height was 22 inches.

The production study took place on an area that consisted of two large benches approximately 3.7 acres in size. The ground surrounding the benches rose to the west with slopes of approximately 45 percent and dropped to the east with slopes of approximately 55 percent. Slopes on the benches ranged from 5 to 20 percent. The timber in the study area was slightly smaller than the stand average. Merchantable volume averaged 27 mbf/acre (net scribner) and the average diameter at breast height was 18 inches.

LOGGING PLAN

FELLING

The felling of the unit was a mixture of mechanical felling and manual felling. A total of 39 acres were mechanically felled. Areas which were too steep to operate upon or had too large of trees to productively cut were identified by the feller-buncher operators and left for manual falling. An attempt was made to keep the manual fallers working ahead of the feller-buncher. This was done to try and open up at least one edge of the mechanical cutting blocks in hopes of increasing mechanical felling productivity. Unfortunately, the manual fallers could not stay ahead and typically they worked behind the feller-buncher.

A modified Caterpillar 235 excavator was used for the mechanical felling. The cutting head was a Rotosaw 2800-T sawhead with a cutting capacity of up to 28 inches. The boom had been reinforced and had a reach of 26.5 feet. The estimated machine rate for the feller-buncher was $99.58 per scheduled hour and $124.48 per productive machine hour (Table 1).

TABLE 1.

FELLER-BUNCHER MACHINE RATE CALCULATIONS.

Caterpillar 235 excavator			
Delivered cost	$350,000		
Residual value	70,000		
Depreciation period	5 yrs		
Scheduled hours/year	2000		
Interest expense	12%		
Tax, lis., ins., storage	2%		
		Ownership cost	$ 44.66/SH
Utilization	80%		
Repairs & maintenance	$6.00/SH		
Fuel consumption	6.5 gal/PH		
Cost	$1.00/gal		
Oil & lube consumption	0.11 gal/PH		
Cost	$3.60/gal		
		Operating cost	$ 11.52/SH
Rotosaw 2800-T sawhead			
Delivered cost (installed)	$145,000		
Residual value	29,000		
Depreciation period	5 yrs		
Scheduled hours/year	2000		
Interest expense	12%		
Tax, lis., ins., storage	2%		
		Ownership cost	$ 18.50/SH
Repairs & maintenance	$7.50/SH		
		Operating cost	$ 7.50/SH
Labor costs			
Base Wage	$12.00/SH		
O.P.E. Rate	45%		
		Labor cost	$ 17.40/SH
		MACHINE RATE	$ 99.58/SH

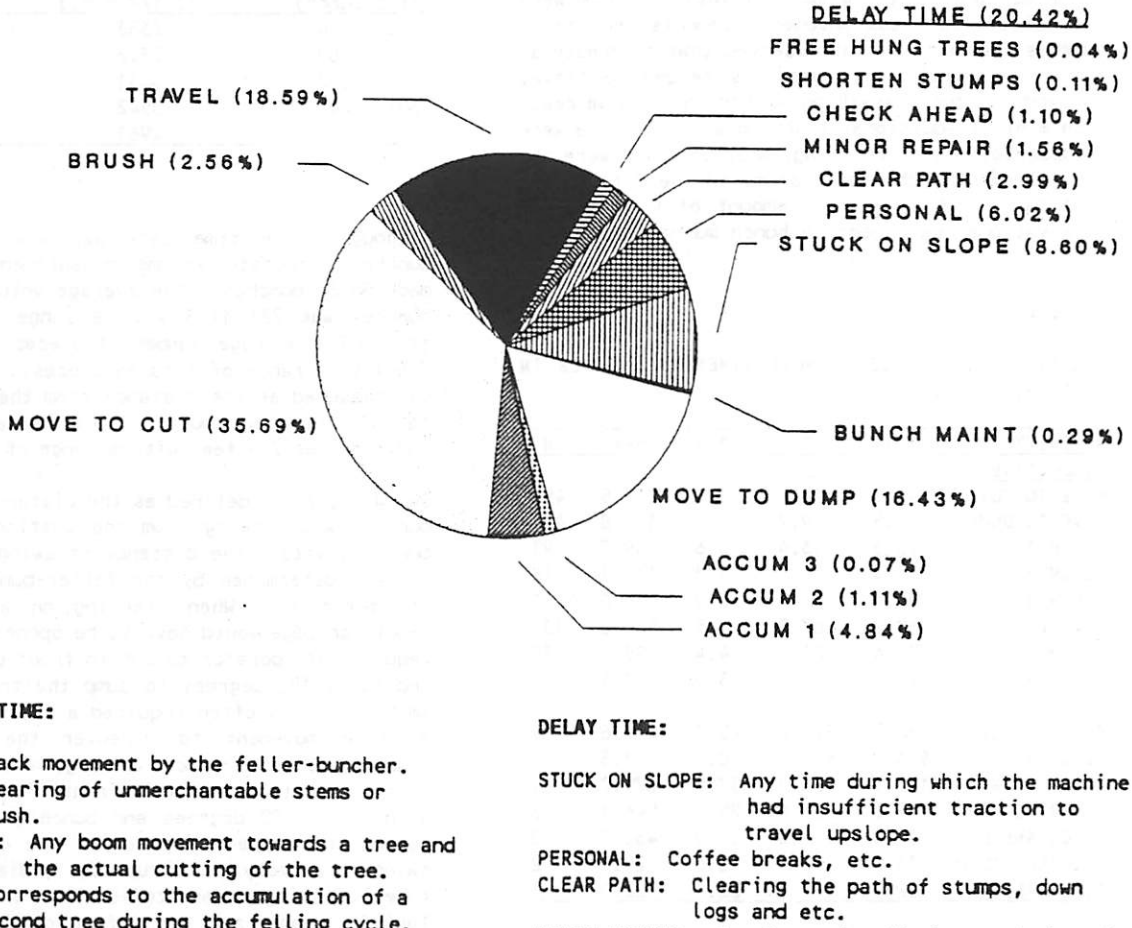
YARDING AND PROCESSING

Two yarding methods were used on the logging unit. The gentler sloping portions of the unit were yarded by a combination of tractor logging and snorkel logging. The timber was yarded in a whole tree form and decked along the roadsides where it was processed by a stroke boom delimber. The steeper portions of the unit, including the study area, were cable logged with an interlocking swing-yarder. A total of 36 acres were cabled logged.

Two cable yarding systems were utilized on the unit. When deflection was limiting, a modified high lead or "Grabinski" system was used. When deflection was not as limiting, a running skyline with a mechanical slack pulling carriage was used. The cable yarding time study data was collected only when the running skyline system was being used.

The yarder used was an S.Madill 122 interlocking swing yarder. While yarding the study area, a cat mounted mobile tailhold was used.

Processing was performed by a Denis stroke-boom delimber mounted on a tracked Caterpillar carrier. The delimber worked as a "hot processor", processing trees next to the yarder as active yarding was occurring. The delimber was capable of processing trees up to 30 inches in diameter.



PRODUCTIVE TIME:

TRAVEL: Track movement by the feller-buncher.
BRUSH: Clearing of unmerchantable stems or brush.
MOVE TO CUT: Any boom movement towards a tree and the actual cutting of the tree.
ACCUM 1: Corresponds to the accumulation of a second tree during the felling cycle. Includes boom movement towards the tree and the cutting of the tree.
ACCUM 2: Corresponds to the accumulation of a third tree during the felling cycle.
ACCUM 3: Corresponds to the accumulation of a fourth tree during the felling cycle.
MOVE TO DUMP: Any boom movement towards the bunch site and the release of the tree into the bunch.
BUNCH MAINT: Butt indexing or any other manipulation of the bunch.

DELAY TIME:

STUCK ON SLOPE: Any time during which the machine had insufficient traction to travel upslope.
PERSONAL: Coffee breaks, etc.
CLEAR PATH: Clearing the path of stumps, down logs and etc.
MINOR REPAIR: Repairs under 10 minutes in length.
CHECK AHEAD: Any time the operator would stop and inspect the ground in front of the machine.
SHORTEN STUMPS: Time spent recutting a stump to lower its height.
FREE HUNG TREES: Time spent freeing trees that were entangled in the canopies of standing trees.

FIGURE 1. Total time distribution for the swing-boom feller-buncher.

RESULTS

FELLING

A summary of the total time distribution for the feller-buncher is shown in Figure 1 and a summary of the felling time study statistics is shown in Table 2. The average production rate for the feller-buncher was 32.1 cunits per productive machine hour at a cost of $3.87 per cunit. A total of 621 trees were cut in 454 cycles. Approximately one in five cycles included the accumulation of at least one additional tree. Additional trees were accumulated whenever stem size permitted. There were 46 occurrences of multiple stems being cut with one activation of the sawhead, these usually occurred while cutting maple clumps. There were a total of 136 track movement elements for the 82 bunches created. It was observed that to create an individual bunch, the operators tended to travel forward and cut everything within their boom reach with minimal additional track movement. There were 38 observations of brushing, most of which were the removal of unmerchantable stems in the 2 to 5 inch size range. A very small amount of time, only 7 observations, was spent on bunch maintenance.

TABLE 2.

FELLER-BUNCHER CYCLE ELEMENT TIMES (ALL TIMES IN CENTI-MINUTES).

ACTIVITY	MEAN	SDEV	MIN	MAX	N
PRODUCTIVE					
MOVE TO CUT	40.2	23.4	0.3	213.5	454
MOVE TO DUMP	18.5	9.7	0.1	316.8	454
ACCUM 1	26.6	13.4	0.6	189.7	93
ACCUM 2	31.4	16.5	3.8	112.2	18
ACCUM 3	36.0	----	36.0	36.0	1
TRAVEL	69.9	67.9	.5	567.2	136
BRUSH	34.4	24.0	4.4	98.9	38
BUNCH MAINT	21.0	9.9	3.9	78.3	7
DELAY					
STUCK ON SLOPE	488.7	392.4	25.3	1645.6	9
PERSONAL	513.0	519.7	20.1	1412.3	6
CLEAR PATH	138.9	176.7	37.5	679.2	11
MINOR REPAIR	267.0	226.8	25.3	546.1	3
CHECK AHEAD	281.0	151.0	131.0	432.0	2
SHORTEN STUMPS	28.5	0.5	28.0	29.0	2
FREE TREES	22.0	-----	22.0	22.0	1

The most significant delay was "STUCK ON SLOPE", there were 9 observations for a total of 44.0 minutes. It had rained for several days prior to the felling of the study area and the ground was fairly saturated. Occasionally the operator would work the feller-buncher too far past the edge of the bench and not have enough traction to climb back onto the bench.

Table 3 shows the effect of bunch size on felling productivity. It was expected that to create bigger bunches, the feller-buncher would need to travel more and productivity would be reduced. However, the data shows that as bunch size was increased, productivity increased. One explanation for this is that the operators were not trying to make bunches of particular sizes, but would create a bunch by cutting all the trees they could easily reach from one setup position. Thus, the productivity would be heavily influenced by natural variations in stand density.

TABLE 3.

SUMMARY OF THE EFFECT OF BUNCH SIZE ON FELLER-BUNCHER PRODUCTIVITY.

BUNCH SIZE (ft^3/bunch)	PRODUCTIVITY (ft^3/P.M.H.)	NUMBER OF OBSERVATIONS
0 - 100	2383	22
101 - 200	2822	12
201 - 300	3451	12
301 - 400	3542	13
> 401	4961	5

Although cycle time data was available for 82 bunches, accurate volume measurements were only made on 64 bunches. The average volume for the 64 bunches was 221 ft^3 with a range of 25 to 986 ft^3. The average number of pieces per bunch was 7.6 with a range of 1 to 36 pieces. Butt indexing was measured as the distance from the closest butt to the farthest butt. The average level of indexing was 7.9 feet with a range of 1 to 20 feet.

Swing angle was defined as the distance the feller-buncher would swing from the cutting site to the bunching site. The distance of swing tended to be largely determined by the feller-buncher's method of operation. When starting on a new cutting block, an edge would have to be opened. This would require the operator to cut in front of the machine and swing 180 degrees to dump the tree behind the machine. This often required a substantial amount of boom movement to maneuver the tree around standing trees. Once an edge was opened, the operator could then cut in front of the machine and swing 45 to 90 degrees and bunch along his side. During this type of operation the operator could swing relatively unobstructed. A diagram of these types of swing movements is shown in Figure 2 and Table 4 summarizes the effect of swing angle on felling productivity.

TABLE 4.

SUMMARY OF THE EFFECT OF SWING ANGLE ON FELLER-BUNCHER PRODUCTIVITY.

SWING ANGLE (degrees)	180	90	45
PRODUCTIVITY (FT^3/P.M.H.)	2049	3319	3972
# OF BUNCHES	26	28	10
# OF TREES	175	182	34

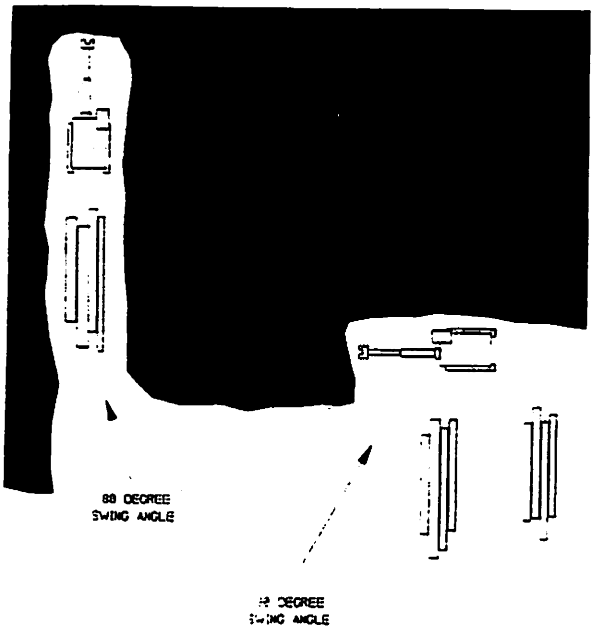


FIGURE 2. Diagram of 90 and 180 degree swing angles.

YARDING

A summary of the cable yarding time study statistics is shown in Table 5. The 22 turns came from four different cable roads. Move time was not included in the data summary since the study turns constituted such a small portion of the total number of turns from each cable road.

The average number of stems per turn was 4.4 with a range of 1 to 9 stems. The average number of chokers used per turn was 2.7 with a range of 1 to 4. Approximately 60 percent of the turns included wood for which the chokers had been preset. The average lateral yarding distance was 27 feet. The average yarding distance was 405 feet.

TABLE 5.

YARDING CYCLE ELEMENT TIMES (ALL TIMES IN CENTI-MINUTES).

ACTIVITY	MEAN	SDEV	MIN	MAX	N
PRODUCTIVE					
OUTHAUL	71.3	44.3	11.4	205.4	22
LATERAL OUT	39.5	21.8	7.1	137.6	22
HOOK	97.0	56.5	12.6	318.5	22
LATERAL IN	36.3	33.7	3.5	106.2	22
INHAUL	94.0	41.9	22.5	267.7	22
UNHOOK	86.4	47.2	14.4	505.8	22
TOTAL	424.5	95.5	207.6	798.2	22
DELAY					
WAIT DELIMBER	39.3	41.1	6.7	103.6	3
RIGGING DELAY	126.0	71.0	55.0	197.0	2
REPAIR	109.0	----	109.0	109.0	1
CONFERENCE	125.0	----	125.0	125.0	1

A description of the yarding cycle elements is given below.

PRODUCTIVE TIME

OUTHAUL: The travel of the carriage from the landing to the hooking site.

LATERAL OUT: The pulling of line from the carriage to the first tree/s to be hooked.

HOOKING: The hooking of trees and any line pulling after the first tree is hooked.

LATERAL IN: The lateral yarding of trees from their initial location to the cable road.

INHAUL: The yarding of trees from the hooking site to the landing.

UNHOOK: The unhooking of trees at the landing.

DELAY

WAIT DELIMBER: Any time yarding is delayed due to interference by delimbing activities, i.e. waiting for the delimber to get out of the way.

RIGGING DELAY: Cable road changes, cable repairs and other rigging delays.

REPAIR: Repairs and service under 10 minutes in length.

CONFERENCE: Discussions among the crew.

PROCESSING

A summary of the multi-moment time study data is shown in Table 6. The data indicates that delimber utilization improved when yarding bunched wood, however this is based on a small number of bunched wood turns and a scattered occurrence. Also, the lag and overlap between yarding and processing of turns in this type of situation makes it difficult to separate out the bunching effect on the delimber operation.

TABLE 6.

SUMMARY OF THE DELIMBER TIME STUDY STATISTICS.

ACTIVITY	% OF TOTAL TIME (STUDY AREA)	% OF TOTAL TIME (ADJACENT AREAS)
PROD. DELIMB.	69.4	50.9
OTHER PROD.	7.3	9.5
WAIT YARDER	11.8	14.5
WAIT LOADER	0.0	1.5
WAIT WOOD	9.8	19.0
REPAIR/SERVICE	1.4	0.7
OTHER	0.4	3.8
TOTAL TIME	127.25 minutes	289.75 minutes
LOGS/P.M.H.	52	45

A description of the delimbing activities is given below.

PROD. DELIMB.: Actual processing of trees.

OTHER PROD.: Landing and deck maintenance, sorting wood and setting top first trees aside for later processing.

WAIT YARDER: Any delays related to yarder interference.

WAIT LOADER: Any delays related to loader interference.
WAIT WOOD: Any idle time when there is no wood to process.
RIGGING DELAY: Cable road changes, cable repairs and other rigging delays.
REPAIR/SERVICE: Repairs and service under 10 minutes in length.
OTHER: Any other nonproductive delays.

DISCUSSION

The most likely factor to limit the use of mechanized felling equipment on a cable yarding operation is slope. Cable yarding ground is typically characterized as being steep and broken terrain. On gentle terrain, ground skidding systems are generally preferred due to their lower operating costs. There are however situations where cable yarding is the preferred alternative. Cable yarding is frequently selected when there is concern over the negative environmental impacts of ground skidding equipment. In the case of this study, areas of gentle terrain adjoined areas of steeper terrain that required cable yarding. These small adjoining areas could be yarded less expensively with the on site yarder than by moving in ground skidding equipment. If mechanical felling equipment is used in these areas, it is obviously desirable to maximize the amount of ground that is mechanically felled to help reduce the equipment mobilization costs.

The point at which a slope becomes too steep to effectively mechanically fell is difficult to ascertain. For this study, the feller-buncher appeared to operate easily on slopes up to 15%. It did operate on slopes up to 25%, but maneuverability was clearly reduced. All of the "STUCK ON SLOPE" delays occurred on slopes over 20%. The feller-buncher used was a relatively large converted excavator. It was chosen by the logger for two reasons. First, if his venture into mechanical felling was unsuccessful, he felt he could relatively inexpensively convert it into a log loader. Second, he felt it was the minimum size acceptable for handling the large capacity sawhead he chose. Feller-bunchers do exist that have self-leveling cabs and engine compartments. A self-leveling feller-buncher could allow operation on steeper slopes and increase the amount of ground available for mechanical felling.

The effect of bunch size on felling productivity is difficult to determine from the study data. The feller-buncher operators stated that they were attempting to create bunches of a uniform size that would make an ideal cable yarding turn. However, their operation was typically characterized by track movement forward, followed by cutting all of the stems within boom reach and placing them in one bunch, then moving forward again to start a new bunch. This method of operation could be easily slipped into by an operator trying to maximize his own felling productivity. Further research is warranted on the effect of bunch size on system performance. It may be advantageous to accept a reduction in felling productivity due to creating larger bunches if it increases yarding productivity enough to increase total system productivity.

The effect of swing angle on felling productivity has several implications in regard to logging planning. The data indicated a substantial difference in productivity between when the feller-buncher was opening up an edge and when it was working along an open edge. The cutting blocks in the study area were small, irregular shaped units, which meant that the amount of edge that had to be opened was large compared to the total area. On more level terrain, cutting blocks are generally larger and of more uniform shape, which results in the percent of area in edge being smaller. This suggests that mechanical felling areas should be laid out with large and uniform shaped cutting blocks. In the case of this study, the cutting block shapes and sizes were dictated by topography. Another solution to this problem could be to ensure that manual falling in adjacent areas is completed prior to the start of mechanical falling.

The small number of observations obtained during the yarding and processing studies make drawing any conclusions about these operations difficult. Discussions with the crew indicated their enthusiasm about this logging system was favorable. They felt that yarding bunched wood simplified their job and greatly reduced hooking time. They also felt that their turns did have a higher average volume when logging bunched wood.

CONCLUSIONS

This logging study demonstrates that mechanized felling can be safely and efficiently conducted on cable yarding operations within certain limits. Slope and cutting block size appeared to significantly effect felling productivity. The limited period of the yarding time study was a result of human error and not a result of equipment or system limitations. It should help demonstrate the importance of careful and complete logging planning for mechanized harvesting operations.

Additional opportunities exist to enhance mechanical felling efficiency that should be studied in Pacific Northwest conditions. First, a steep slope feller-buncher with self-leveling cab might improve felling efficiency and increase the amount of ground available for mechanized felling. Second, a grapple yarding system might be employed to more efficiently yard bunched wood.

ACKNOWLEDGEMENTS

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REFERENCES CITED

Gonsior, M.J. and J.M. Mandzak. 1986. Mechanized systems for harvesting small trees in mountainous terrain.

Kellogg, L. and S. Robe. 1989. Cable landing organization for mechanized delimbing. Report of a presentation made at the 1989 International Summer Meeting jointly sponsored by the ASAE and the CSAE. Paper No. 897074.

Kimoto, T.T. 1985. Felling, bunching, forwarding and processing coastal B.C. second growth. Proceedings, Joint Symposium of the IUFRO Mountain Logging Section and Sixth Pacific Northwest Skyline Logging Symposium, Vancouver, Canada; May 8-11. pp 73-74.

Peterson, J.T. 1986. Comparison of three harvesting systems in a British Columbia second-growth stand. FERIC Technical Report TR-73.

Applications of Harvesting System Simulation to Timber Management and Utilization Analyses

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ABSTRACT

Applications of timber harvesting system simulation to the economic analysis of forest management and wood utilization practices are presented. These applications include estimating thinning revenue by stand age, estimating impacts of minimum merchantable tree diameter on harvesting revenue, and evaluating wood utilization alternatives relative to pulpwood quotas and harvesting revenue.

Key Words: Timber harvesting, computer simulation, wood utilization, thinning.

INTRODUCTION

In the search for more efficient timber harvesting systems, several computer simulation programs have been developed in the last 20 years to model harvesting system performance (Goulet and others 1980). The interest in harvesting systems analysis resulted from increasing harvesting costs, the mechanization of timber harvesting, and the increase in "hot" logging that required a systems versus component analysis of the harvesting process (Goulet and others 1979, Corcoran 1973, Martin 1973). Further, reported stumpage prices and costs indicate that harvesting and hauling often constitute a large part of the total cost of delivered roundwood (Engalichev 1989). Accordingly, harvesting costs are a major concern to wood buyers and forest-land owners.

A simulation model essentially represents a set of assumptions regarding the mathematical and logical relationships that define how a system works (Law and Kelton 1982). The harvesting simulation models described and evaluated by Goulet and others (1980) generally model machine performance as a function of system configuration and harvest site attributes such as tree diameter distribution, volume harvested, tract dimensions, and truck haul routes. The system production rate reflects the productivity of system components and the interactions or bottlenecks that limit system output.

One primary advantage of computer simulation is that it allows experimentation with the computer model to gather data on system productivity that might otherwise be too costly or impossible to collect from real systems (Law 1986). The initial experiments with timber harvesting simulation focused on system configuration to identify the most efficient combinations of men and machines (Martin 1973). Subsequent applications have included estimating harvesting costs as a function of variables such as timber stand attributes, tract size, and input costs, as well as system configuration (Cubbage and Granskog 1982, McCollum and Hughes 1983, LeDoux 1985). Harvesting simulation also has been used to estimate harvesting costs and revenue for the economic analysis of forest management alternatives (Reisinger and others 1985, LeDoux 1986).

OBJECTIVE

The objective of this paper is to demonstrate potentially important applications of harvesting system simulation to the economic analysis of forest management and wood utilization alternatives. The applications demonstrated include the effects of:

1. Stand age at first thinning and pulpwood/fuelwood markets on thinning revenue.

2. Minimum merchantable tree diameter on revenues from thinning and regeneration cuts.

3. Pulpwood quotas and the wood utilization practices required to constrain pulpwood production on harvest revenue.

METHODS

The simulation model was developed initially to estimate harvesting costs and revenues from thinning and regeneration entries in Appalachian upland oak stands, and to evaluate the potential for increasing harvesting revenue via multiproduct harvesting (Baumgras 1990). Written in FORTRAN 77, this discrete-event model applies the next-event method of controlling simulation time. Simulation events represent changes in system state that occur at the beginning or end of a machine production cycle or scheduled production time.

The harvesting system simulated included manual chain saw felling, skidding with a rubber-tired cable skidder, and a hydraulic loader/slasher combination to buck, sort, and load hardwood roundwood products. Machine cycle times were estimated using cycle-time equations and delay-time distributions sampled from West Virginia harvesting operations (Biller and Baumgras 1988, Brock and others 1986, Sarles and others 1988). The simulated system production rate reflects component production and system interactions. Estimates of machine cycle time are sensitive to timber stand and tract attributes. The random X and Y coordinates of each cut tree were generated with the tree-location algorithm developed by Bradley and others (1982). The simulation model also tracks individual-tree attributes throughout the process from stump to deck, such that tree attributes that affect machine cycle time will affect all system components.

Inputs to the simulation include tract dimensions, road spacing, harvested stand attributes, minimum merchantable tree diameter at breast height (dbh), and minimum merchantable stem top diameter inside bark (dib). Tract dimensions were 1,400 by 1,600 feet (51.4 acres), with parallel skid roads on 200-foot spacing. Sawlog and pulpwood yields were estimated with tree taper equations (Martin 1981), hardwood log grade estimators (Yaussey and others 1988), and tree grade distribution estimators (Dale and Brisbin 1985). The use of taper functions provides a volume estimate to a variable top dib for evaluating selected wood utilization options. Although minimum merchantable tree dbh and top dib were treated as variables to evaluate utilization options, sawlog volumes were calculated only for trees 12 inches dbh and larger to a 10-inch top dib based on the International 1/4 inch log rule. Pulpwood/fuelwood volume represents bole sections less than 10 inches dib, and larger sections that would not make a grade 3 sawlog.

Harvested stand attributes were obtained from the stand tables summarized in Table 1. These tables were generated by OAKSIM, a growth and yield simulator for even-aged upland oak stands (Hilt 1985). The initial stand for the growth simulations represented a fully stocked upland oak stand at age 40 and site index 70. Percent of total basal area at age 40 by tree species groups include: white oaks: 38 percent; red oaks: 50 percent; red maple: 2 percent; and yellow-poplar: 10 percent. All simulated thinnings reduced stocking to 60 percent.

Case study results were not available to validate all simulations. However, simulation results compared favorably to the production rates sampled on two hardwood thinning operations (Miller and Sarles 1986, Brock and others 1986).

Table 1. Harvested stand diameter distributions for each thinning at 40 to 70 years (T-40, T-50, T-60, T-70) and regeneration cut at 90 years (R-90)

Entry	*Dbh class (inches)*									
	2	4	6	8	10	12	14	16	18	20+
	----No. trees/acre----									
T-40	4	64	71	36	11	1				
T-50		27	61	42	17	5	1			
T-60		8	42	41	22	10	2			
T-70		2	24	37	26	12	4	1		
R-90			3	21	39	36	19	10	3	1

Final harvest costs also were comparable to those reported by Bell (1989) for regeneration cuts in southern Appalachian sawtimber stands.

Timber harvesting revenue was calculated by deducting stump-to-truck harvesting costs and hauling costs from total revenue. Total revenue was the sum of the products of delivered product prices and estimated product volumes. Stump-to-truck harvesting costs were estimated from the harvesting simulation results. The harvesting simulations did not include trucking as a simulation event. Instead, haul costs were estimated as a function of haul distance. Road and landing costs were not included in the revenue analysis. These costs are highly variable and influence only revenue levels, not the revenue trends demonstrating differences between thinning ages or wood utilization options. All revenues were calculated on a dollar/acre basis and, therefore, represent derived stumpage values. To simplify the analysis, no effort was made to allocate net revenue between the logger and landowner.

To estimate total revenue, reported sawlog prices (Ohio Agric. Stat. Serv. 1989, Pa. State Univ. 1989) for the relevant tree species were averaged by USDA Forest Service log grades and applied to the sawlog volume estimated by log grade. Accordingly, sawlog prices reflect the species composition that includes high-value red and white oaks. Delivered prices by log grade are: grade 1: $300/Mbf; grade 2: $200/Mbf; grade 3: $100/Mbf. Sawlog hauling costs of $15/Mbf were based on a 30-mile haul.

Revenue estimates also included three pulpwood/fuelwood market scenarios for evaluating the effects of delivered prices and haul distance on harvest revenue. Pulpwood/fuelwood accounted for most of the wood removed in thinning, and most of the yield differences between wood utilization options. As a result, revenue trends were sensitive to pulpwood/fuelwood prices and haul costs. The three market scenarios as defined by delivered price, haul distance, and haul cost include; (1) $50/cord, 15 miles, and $4/cord; (2) $40/cord, 30 miles, and $6/cord; (3) $30/cord, 60 miles, and $10/cord. This range of delivered prices and haul costs effectively spans a wide array of potential market conditions for low-quality hardwood roundwood.

RESULTS

Thinning Cost and Revenue

The first application demonstrated shows the effect of stand age on thinning revenue. The attributes of the cut stands reveal important differences between the thinnings tested. Postponing thinning in 10-year increments increased total volume harvested, sawlog volume, numbers of merchantable trees cut per acre, and average tree volume (Table 2). Numbers of unmerchantable trees decreased with age at first thinning. In this analyses, only trees 8 inches dbh and larger were harvested. However, to satisfy silvicultural objectives, all trees 3.0 inches dbh and larger were felled.

Table 2. Hardwood timber stand attributes and yields by age at first thinning

Age (years)	*No. trees/acre* Merchantable[1]	Unmerchantable	Average vol./tree	*Volume harvested* Total[2]	Pulpwood	Sawlogs[3]
			ft³	--------*Cords/acre*--------		*Mbf/acre*
40	32	155	11.0	3.8	3.8	0.0
50	51	102	13.5	7.4	6.8	0.3
60	63	62	16.0	10.9	9.2	0.7
70	71	35	18.1	13.9	11.2	1.2

[1]dbh ≥ 8 inches
[2] ≥ 8 inches dbh to 4-inch top dib.
[3]USDA Forest Service factory grade 3 or better, scaling dib > 10 inches.

Table 3. Estimated harvesting costs and net harvest revenue by age at first thinning and pulpwood/fuelwood market

Age (years)	Stump-to-truck harvest cost Unit	Total	Net Revenue $50/cord and 15-mile haul	$40/cord and 30-mile haul	$30/cord and 60-mile haul
	Dollars/cord	*Dollars/acre*	*Dollars/acre*		
40	54	205	-30	-76	-129
50	38	280	58	-24	-119
60	31	340	153	43	-86
70	28	388	255	121	-36

As a result, postponing thinning results in more time available to fell merchantable trees because fewer unmerchantable trees must be felled.

The response of simulated thinning cost and estimated revenue to changes in harvest stand attributes demonstrates the importance of entry timing. Total harvesting cost increased with total volume per acre, from $205/acre at age 40 to $388/acre at age 70 (Table 3). However, unit costs declined from $54/cord at age 40 to $28/cord at age 70. Most important, revenue estimates show negative cash flows at age 40 for all price/distance levels (Table 3). Thinning at age 50 yielded a positive cash flow only with high pulpwood/ fuelwood prices and short hauls. With low pulpwood/fuelwood prices and a 60-mile haul, no thinning was economically feasible. Only thinnings at ages 60 and 70 yielded positive cash flows with a medium price and haul distance. Further, inclusion of road and landing costs would create additional negative cash flows. These results demonstrate the importance of estimating harvesting cost and revenue as a function of haul distance and the stand attributes associated with each thinning option. These costs and revenues are essential for effective planning of forest management activities.

Minimum Merchantable Dbh

The objective of the second type of simulation application was to show the effects of minimum merchantable tree dbh and pulpwood/fuelwood markets on net revenue. The harvesting entries evaluated included a first thinning at age 60 followed by an even-age regeneration cut at age 90. Since thinning at age 60 was not feasible with a low pulpwood/fuelwood price and a 60-mile haul distance (Table 3), that scenario was omitted. Although all trees in the cut stand tables were felled, only trees greater than or equal to the specified minimum merchantable dbh were harvested. However, costs reflect the effects of felling unmerchantable trees on simulated production rates.

The reductions in merchantable volume per acre and increases in average volume per tree that occur when the minimum merchantable dbh is increased are shown in Table 4. Due to differences in the diameter distributions between the thinning and regeneration entries, increasing the minimum dbh from 6 inches to 10 inches reduced thinning yields by 53 percent, but reduced final harvest yields only by 10 percent. Over the range of minimum diameters evaluated the average merchantable volume per tree increased by 18.1 and 25.4 ft^3, respectively, for the thinning and harvest entries.

With a price of $40/cord for pulpwood/fuelwood and a 30 mile haul, the simulation results indicate that net revenue from both entries was maximized with a minimum merchantable dbh of 9 inches (Table 5). Thinning revenue was sensitive to increases or decreases in minimum dbh harvested. Because there were relatively few small trees in the age 90 stand table, final harvest revenue was relatively stable at 6 to 9 inches dbh, decreasing sharply from $1,098/acre at 9 inches dbh to $565/acre at 14 inches. All changes in minimum dbh affected pulpwood/fuelwood volume harvested, but sawlog volume changed only when the minimum dbh exceeded 12 inches. It is important to note that reduced haul distance and increased pulpwood/fuelwood prices reduced the minimum

Table 4. Cut stand attributes for thinning at age 60 and final harvest at age 90, by minimum merchantable tree dbh[1]

Minimum merch. dbh (inches)	Thinning at age 60: Volume harvested	Thinning at age 60: Average vol./tree	Harvest at age 90: Volume harvested	Harvest at age 90: Average vol./tree
	Cords/acre	*ft³*	*Cords/acre*	*ft³*
6	13.6	11.5	40.6	28.6
7	12.6	13.4	40.4	28.8
8	10.8	16.0	40.0	29.4
9	8.6	19.2	38.8	31.4
10	6.4	22.7	36.4	33.9
11	4.5	26.2	32.1	37.8
12	2.9	29.6	26.8	42.3
13	--[2]	--[2]	20.7	48.2
14	--[2]	--[2]	15.7	54.0

[1]Trees smaller than minimum merchantable dbh felled but not harvested.
[2]Too few trees/acre to harvest.

merchantable dbh that maximized revenue, from 9 to 8 inches.

Information developed through simulation defines the harvest system cost and revenue functions and allow analyses of the marginal costs and revenues required to determine optimum harvesting practices. For the age 60 thinning entry, the marginal cost of harvesting to 8 inches dbh equals the difference in cost per acre between the 8- and 9-inch dbh limits, or approximately $80/acre based on the simulation results used to develop Table 5. The incremental volume was 2.2 cords/acre (Table 4). With a pulpwood/fuelwood price of $40/cord and a 30-mile haul, marginal revenue is $75/acre and less than marginal cost. With a high price and a short haul, marginal revenue is $101/acre, which exceeds the marginal cost.

Wood Utilization and Quotas

The third example of simulation applications evaluated wood utilization options and pulpwood quotas, which are important production constraints affecting loggers. Production quotas set by pulpwood mills limit the pulpwood volume a harvesting firm can market per unit time. The pulpwood production rate is determined by the system production rate (total volume/unit time) and the product mix (percent of total harvested volume in pulpwood). When operating with a quota, loggers can reduce scheduled operating hours to reduce the system production rate and/or alter wood utilization practices to change the production rate and product mix.

The effects of wood utilization levels on the pulpwood production rate and harvesting revenue were estimated by simulating harvesting operations with increasingly stringent utilization limits that defined both the minimum tree dbh and top dib harvested. Scheduled hours per day remained constant. These simulations were performed with the stand table projected for age 90, assuming an even-age regeneration cut preceded by thinning at age 60. Wood harvested was constrained by the dbh and dib limit evaluated for each iteration, yet all trees 3 inches dbh and larger were felled to model a silviculturally sound regeneration cut.

The simulation results show the reductions in total merchantable volume and percent of total volume in pulpwood/fuelwood that occurred with increased dbh and dib limits (Table 6). For example, harvesting to 6 inches dbh and 4-inches top dib yielded 40.6 cords, which was 57 percent pulpwood. Harvesting to 13 inches dbh and 10 inches dib yielded 16.4 cords, which was only 14 percent pulpwood. In the latter case, only wood large enough to make a sawlog was harvested.

Table 5. Estimated net revenue from first thinning at age 60 and final regeneration harvest at age 90, by minimum merchantable tree dbh[1] and pulpwood/fuelwood market

Minimum merch. dbh (inches)	*Thinning at age 60*		*Harvest at age 90*	
	$50/cord and 15-mile haul	$40/cord and 30-mile haul	$50/cord and 15-mile haul	$40/cord and 30-mile haul
	Dollars/acre			
6	98	-46	1363	1085
7	137	-6	1366	1088
8	153	43	1366	1092
9	132	48	1354	1098
10	75	18	1311	1081
11	10	-25	1205	1028
12	-53	-68	1048	934
13	--[2]	--[2]	833	754
14	--[2]	--[2]	620	565

[1]Trees smaller than minimum merchantable dbh felled but not harvested.
[2]Too few trees/acre to harvest.

The pulpwood/fuelwood came from below-grade bole sections 10 inches dib and larger.

Most important, the results in Table 6 show the estimated net revenue per acre and pulpwood/fuelwood production per day for each utilization option tested. These results demonstrate the potential effects of pulpwood quotas on maximum harvesting revenue. For example, with no quota, revenue is maximized at $1,098/acre by utilizing only trees 9 inches dbh and larger to a 4-inch top dib (Table 6). To maximize revenue with increasingly stringent pulpwood/fuelwood quotas of 20, 15, and 10 cords/day requires implementing tree- and stem-diameter limits of 9 inches dbh - 6 inches dib, 12 inches dbh - 6 inches dib, and 12 inches dbh - 10 inches dib, respectively. The resulting relative reductions in maximum net revenue by pulpwood/fuelwood quotas were: 20 cords/day, 6 percent; 15 cords/day, 18 percent; and 10 cords/day, 35 percent. Since trees 12 inches dbh and larger were harvested with all quotas, total sawlog volume and revenue were not affected. Adjusting merchantable dbh and top dib altered only the system production rate, product mix, pulpwood/fuelwood production rate, and net revenue.

DISCUSSION

The results demonstrate that timber harvesting simulation can be applied to develop information essential to planning forest management and timber harvesting operations. The examples presented also demonstrate the advantages of linking flexible product-volume estimators with harvesting simulation to evaluate forest management and wood utilization alternatives with respect to product yields, system production rates, and the resulting projected cash flows. Whereas the results presented are directly applicable only to the harvesting system, timber stand, and market conditions simulated, the procedures used have widespread applications.

The three applications presented use simulation to evaluate the relationships between cut stand attributes and the resulting system production rate and product yields. Cut stand attributes are a function of stand age and simulated wood utilization practices. Stand age determines the attributes of trees available for harvest. Utilization options determine the attributes of trees actually harvested.

Table 6. Estimated effects of minimum merchantable tree dbh and top dib[1] on volume harvested, pulpwood mix, pulpwood production rate, and net revenue per acre

Minimum merchantable: Dbh	Top dib	Total merch. volume	Product mix[2]	Pulpwood/ fuelwood production	Net revenue
----(inches)----		*Cords/acre*	*Percent*	*Cords/day*	*Dollars/acre*
6	4	40.6	57	21.1	1085
7	4	40.4	57	21.2	1088
8	4	40.0	57	21.4	1092
	6	38.0	54	19.5	1025
9	4	38.8	55	21.8	1098[3]
	6	36.9	53	19.9	1034[3]
10	4	36.4	52	21.6	1081
	6	34.8	50	19.9	1032
	8	30.9	44	15.6	907
11	4	32.1	46	20.0	1028
	6	30.9	44	18.4	989
	8	27.9	38	14.5	894
12	4	26.8	35	15.6	934
	6	25.9	33	14.1	905[3]
	8	23.8	27	10.6	836
	10	20.2	14	4.7	718[3]
13	4	20.7	32	11.7	754
	6	20.2	30	10.7	736
	8	18.7	24	8.2	690
	10	16.4	14	4.0	613

[1]Smaller trees and stem sections felled but not harvested.
[2]Pulpwood/fuelwood volume as percent of total volume harvested.
[3]Maximum revenue for no pulpwood/fuelwood quota and quotas of 20, 15, and 10 cords/day.

The results of these simulations indicate that thinning cash flows are dependent on the age of the stand when first thinned, that thinning is not economically feasible at ages 40 to 70 years with relatively low pulpwood prices and long hauls, and that commercial thinning at ages 60 and 70 years requires a pulpwood/fuelwood price of $40/cord combined with a haul of 30 miles or less. The results also indicate that cash flows from thinning and regeneration entries can be sensitive to the minimum tree dbh harvested, and that simulation results can define the marginal costs and revenues required to identify utilization options that maximize revenue. Finally, the estimation of pulpwood production rates and harvesting revenue indicates the extent to which altering merchantable tree dbh and top dib can reduce volume harvested and harvesting revenue to satisfy quotas on pulpwood/fuelwood production. Where the quotas imposed only on pulpwood production, a viable fuelwood market would allow increased utilization and harvesting revenue.

The analyses described are essentially experiments conducted with a computer simulation model and projected stand tables to evaluate harvesting and utilization options. It might not be feasible to conduct these experiments through numerous case studies of actual operations; nor is it practical to validate every simulation with case study data. Accordingly, computer simulation can be viewed as a method of developing cost and revenue estimates to identify the most promising options from a large number of possibilities. Field testing can then be focused on a limited number of options, with test results applied to validate and improve the simulation model. Although this can be a continuing process, the simulation results can provide information required to improve the planning of forest management and timber harvesting operations.

LITERATURE CITED

Baumgras, J.E. 1990. The effects of product markets and multiproduct harvesting on the economics of managing even-aged upland oak stands. Ph.D. dissertation. West Virginia University, Morgantown. 210 p.

Bell, R.D. 1989. Influences of various stand harvesting methods on timber harvesting costs in southwestern Virginia hardwoods. M.S. thesis. Virginia Polytechnic Inst. and State Univ., Blacksburg. 68 p.

Biller, C.J., and J.E. Baumgras. 1988. Analysis of rubber-tired skidder cycle times on steep slope hardwood sites. Trans. Am. Soc. Agric. Eng. 31(1):68-72.

Bradley, D.P., C.C. Hassler, and R.F. Green. 1982. Analytical procedures to locate trees for harvest simulators. For. Prod. J. 32(7):36-40.

Brock, S.M., K.D. Jones, and G.W. Miller. 1986. Felling and skidding costs associated with thinning a commercial Appalachian hardwood stand in northern West Virginia. North. J. Appl. For. 3(4):159-163.

Corcoran, T.J. 1973. Timber harvesting system design and equipment leveling through GPSS/360. Amer. Soc. Agric. Eng. Pap. No. 71-617. Trans. of the ASAE-1973:248-252.

Cubbage, F.W., and J.E. Granskog. 1982. Harvesting systems and costs for southern pine in the 1980's. For. Prod. J. 32(4):37-43.

Dale, M.E., and R.L. Brisbin. 1985. Butt log quality of trees in Pennsylvania oak stands. USDA For. Serv. Res. Pap. NE-568. 8 p.

Engalichev, N. 1989. New Hampshire forest market report--1989. Ext. Publ. 11. Univ. New Hampshire, Coop. Ext. Serv., Durham. 26 p.

Goulet, D.V., R.H. Iff, and D.L. Sirois. 1979. Tree-to-mill forest harvesting simulation models: where are we? For. Prod. J. 29(10):50-55.

Goulet, D.V., R.H. Iff, and D.L. Sirois. 1980. Analysis of five forest harvesting simulation models--Part II. For. Prod. J. 30(8):18-22.

Hilt, D.E. 1985. OAKSIM: an individual tree growth and yield simulator for managed even-aged upland oak stands. USDA For. Serv. Res. Pap. Ne-562. 21 p.

Law, A.M. 1986. Introduction to simulation: a powerful tool for analzing complex manufactoring systems. Ind. Eng. 18(5):46-63.

Law, A.M., and W.D. Kelton. 1982. Simulation modeling and analysis. McGraw-Hill, New York. 400 p.

LeDoux, C.B. 1986. MANAGE: a computer program to estimate costs and benefits associated with eastern hardwood management. USDA For. Serv. Gen. Tech. Rep. NE-112. 7 p.

LeDoux, C.B. 1985. When is cable logging economical? J. For. 83(5):295-298.

Martin, A.J. 1981. Taper and volume equations for selected Appalachian hardwood species. USDA For. Serv. Res. Pap. NE-490. 22 p.

Martin, A.J. 1973. Computer simulation as a low-cost approach to logging system balance. For. Ind. (August). p. 53-54.

McCollum, M.P., and C.M. Hughes. 1983. An equation for predicting harvesting costs on second-growth southern yellow pine sites in the midsouth. South. J. Appl. For. 7(2):89-92.

Miller, G.W., and R.L. Sarles. 1986. Costs, yields, and revenues associated with thinning and clearcutting 60-year old cherry-maple stands. USDA For. Serv. Res. Pap. NE-582. 18 p.

Ohio Agriculture Statistics Service. 1989. Ohio timber prices, Feb. 1, 1989. Ohio Agric. Stat. Serv., Columbus. 2 p.

Pennsylvania State University. 1989. Pennsylvania timber market report. the Pennsylvania State Univ. School of For. Resour., Coop Ext. Serv., University Park. 5 p.

Reisinger, T.W., W.B. Stuart, and T.A. Walbridge. 1985. Simulation of the impact of future market prices on the management of loblolly pine plantations. For. Prod. J. 35(3):26-30.

Sarles, R.L., J.L. Wartluft, and K.R. Whitenack. 1984. Chainsaw felling in hardwood thinnings. In: Harvesting the South's small trees. April 18-20, 1983, Biloxi, MS. For. Prod. Res. Soc., Madison, WI. p 58-65.

Yaussey, D.A., R.L. Brisbin, and M.J. Humphreys. 1988. Predicting volumes and numbers of logs by grade from hardwood cruise data. USDA For. Serv. Res. Pap. NE-613. 15 p.

Harvest Machine System Balancing with Queuing Simulation

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ABSTRACT

Single server queuing simulation evaluation of skidding systems: CAT508, CATD5H and CAT518. Timber harvesting cycle processing rate probability distributions were estimated through intensive harvest machine observation in August 1987 and January 1988. Machines activities were simulated under identical conditions to measure production rate and make an estimate of unit cost. CAT518 was best at shorter skidding distances and the CAT508 was best at long skidding distances.

INTRODUCTION

Harvest simulation using computer models is a practical method of comparing alternative harvesting systems (Bradley and Winsauer, 1976; O'Hearn, and others. 1976;Biller and Johnson, 1973; Johnson, 1984; Martin, 1975; and Corcoran, 1971). Due to an increasing demand for wood, especially within bottomland hardwoods, harvesting operations have become more mechanized. In mechanized harvesting systems, productivity and cost of operations depend on the appropriate selection of machine components, operation planning and scheduling, soil and weather conditions, and availability of machines among other factors. Components of a typical harvesting system include methods for severing standing trees (felling), inwood transportation (skidding), processing at the landing (limbing, bucking, chipping), loading and transporting to secondary processing destinations.

TABLE 1: Empirically measured machine costs and productivity rate distributions. Productivity of each cycle is measured as cycle time in seconds divided by cycle volume.

PROCESSING TIME, SECONDS/m^3

	August 1987			January 1988		
	CAT508	CATD5H	CAT518	CAT508	CATD5H	CAT518
Distance 122 meters						
Mean	179.84	196.92	143.92	132.94	145.29	108.50
Min.	24.94	46.27	11.60	34.92	46.02	43.90
Max.	459.82	740.17	658.36	940.58	474.91	228.72
STD	108.00	149.28	138.31	92.41	113.99	43.65
Distance 213 meters						
Mean	231.72	221.99	235.71	176.97	135.06	151.03
Min.	60.10	72.83	77.07	43.65	48.39	63.35
Max.	536.89	582.03	794.67	533.52	451.46	315.27
STD	127.46	152.15	126.71	94.28	78.32	60.11
Distance 335 meters						
Mean	274.87	271.87	261.90	214.63	169.36	173.72
Min.	75.70	87.30	66.60	99.52	57.24	50.51
Max.	838.69	465.30	640.77	1392.91	660.10	635.66
STD	163.37	148.91	128.45	128.45	109.62	69.84
Distance 457 meters						
Mean	385.11	300.06	271.37	212.01	176.34	234.71
Min.	115.73	99.02	94.41	98.02	95.41	29.06
Max.	1489.19	1017.16	693.28	609.97	503.34	1129.15
STD	283.22	184.20	180.46	184.33	82.81	186.69

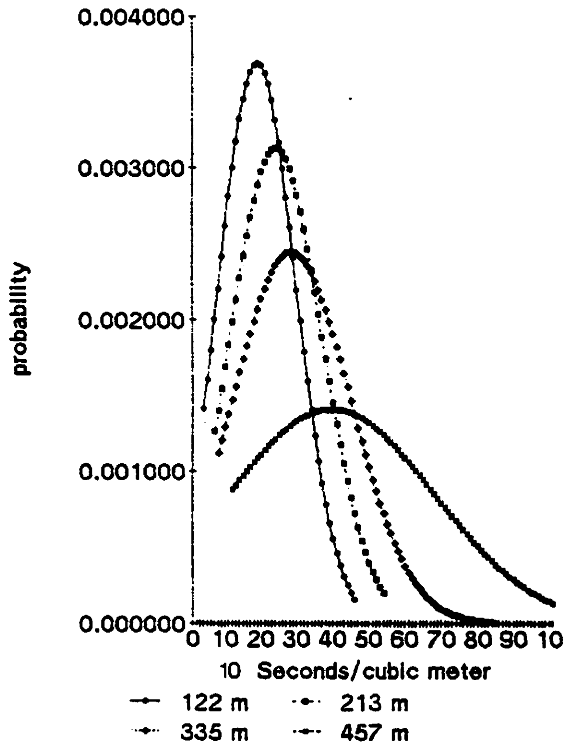


FIGURE 1. Probability density functions for the CAT508 in August data collection period.

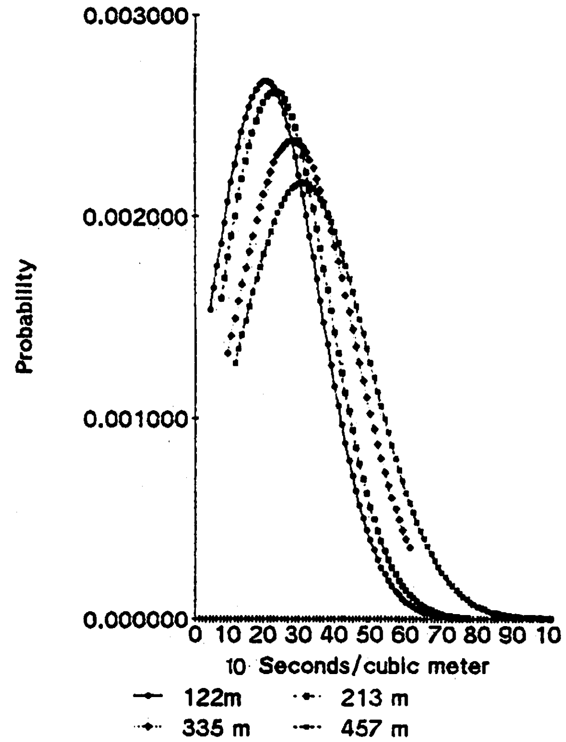


FIGURE 2. Probability density functions for the CAT05H in August data collection period.

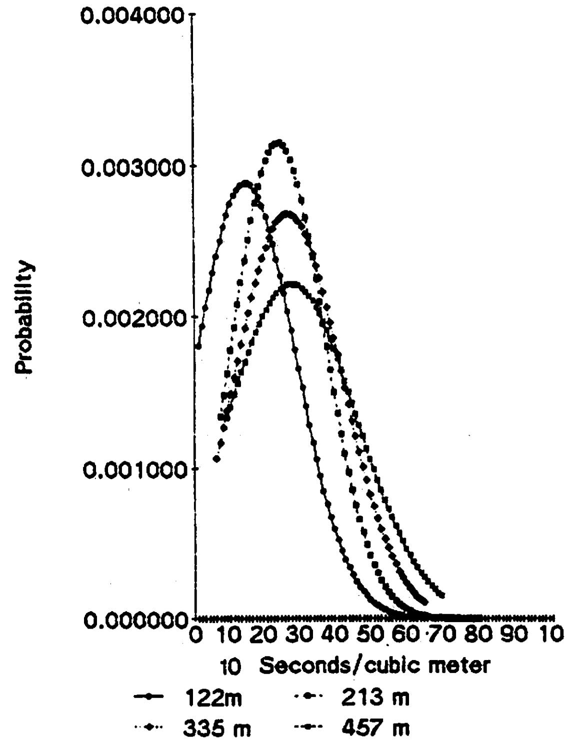


FIGURE 3. Probability density functions for the CAT518 in August data collection period.

The task of comparing the performance and profitability of harvesting systems has always been difficult because of the diversity of systems and variability of environmental conditions under which they are applied. All sources of variation result in uncertainty in evaluating the relative efficiency of a given system on a given stand. Computer simulation utilizing deterministic and stochastic variables is possibly the only feasible approach to incorporate all the variables influencing machine system productivity. The purpose of course is to enable managers to evaluate a wide range systems without the expense of operations testing in the field.

OBJECTIVE

The objective of this paper is to illustrate a method for comparing harvesting systems using empirically based stochastic simulation. Conducting harvesting studies in the field is expensive and time consuming, which usually results in few if any replications in the experimental design. Computer simulation can be used to at least partially substitute for replications. The assumption under which computer based simulation can serve as a surrogate for replications is if cycle time probability distribution is constant for a machine-site-operator-distance combination. One set of empirical observations can be used to estimate the production rate probability distribution. The production rate probability distribution can then be used to simulate production under controlled conditions. With this assumption machine system comparisons can be made under simulated identical conditions. This

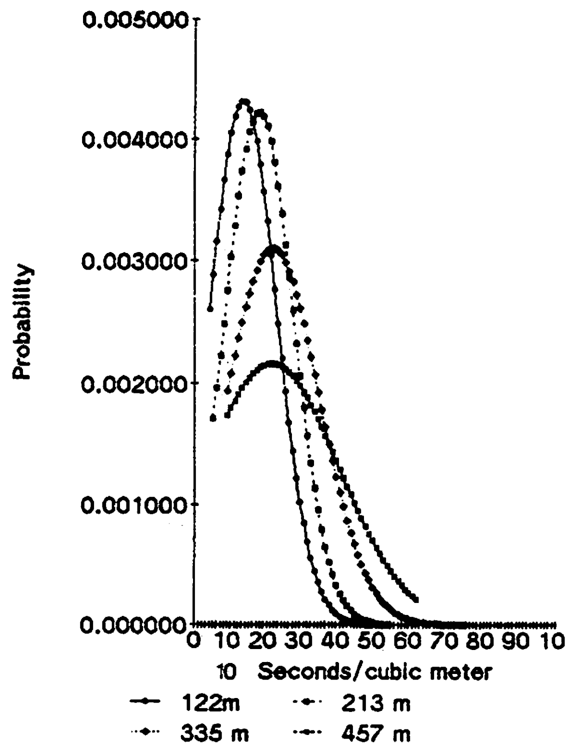


FIGURE 4. Probability density functions for the CAT508 in January data collection period.

does not substitute for true empirical replications. It merely extends the ability to extract information from existing data. The objective of this paper is to compare three skidder systems using empirically based stochastic simulation.

DISCUSSION OF SKIDDING SYSTEM MODEL

The example simulation model presented is a simple single server que. The server is the skidder. The que is the inventory waiting to be harvested. The rate at which the server processes wood volume is a random variable dependent on machine type and skidding distance. The probability distribution of the processing rate was measured by the experiment described by Roise and Hassan (1989). The relevant results are summarized in table 1. Processing rate is reported in units

TABLE 2. Simulation results based on empirical cycle time probability distribution. Each run number represents the cubic meters harvested after 10,000 seconds from each distance.

		Simulated Production in Cubic Meters							
Mach Sys	dist m	1	2	3	4	5	6	Mean	STD
508	122	55.04	55.01	57.34	55.38	55.47	55.72	55.66	0.79
Aug	213	43.29	45.01	43.09	43.03	43.09	42.23	43.29	0.84
	335	35.13	34.84	34.53	36.26	37.65	37.01	35.91	1.16
	457	26.18	26.35	27.14	26.60	25.44	25.55	26.21	0.59
05H	122	51.81	50.23	50.79	48.73	50.34	49.63	50.25	0.95
Aug	213	36.88	35.24	37.34	38.13	38.81	37.76	37.36	1.12
	335	44.73	44.53	45.24	45.01	44.56	44.19	44.71	0.34
	457	32.86	35.24	31.64	33.74	32.66	33.14	33.22	1.10
518	122	70.42	68.58	71.16	69.69	70.45	68.47	69.80	0.99
Aug	213	37.17	37.45	37.03	37.56	39.07	38.84	37.85	0.80
	335	42.97	42.24	41.50	41.16	41.36	43.60	42.14	0.89
	457	36.35	37.99	37.65	36.71	35.75	37.37	36.97	0.77
508	122	73.51	74.90	75.61	75.61	75.07	74.84	74.92	0.70
Jan	213	56.01	55.55	57.14	55.89	56.32	55.95	56.14	0.50
	335	47.73	48.16	45.72	46.12	46.23	45.64	46.60	0.98
	457	48.39	46.71	48.27	47.03	48.10	48.98	47.91	0.79
05H	122	68.24	68.75	70.00	69.21	68.81	68.61	68.94	0.55
Jan	213	73.03	74.65	73.77	74.25	72.44	73.09	73.54	0.76
	335	59.97	59.26	59.26	59.86	60.79	58.58	59.62	0.69
	457	57.08	56.46	57.11	55.69	57.17	57.59	56.85	0.61
518	122	91.78	91.90	90.91	93.48	90.88	91.33	91.71	0.88
Jan	213	66.06	64.90	67.51	65.84	67.79	65.81	66.32	1.01
	335	57.59	58.58	56.32	57.96	56.86	59.09	57.73	0.95
	457	42.66	42.83	43.20	41.39	43.34	42.80	42.71	0.63

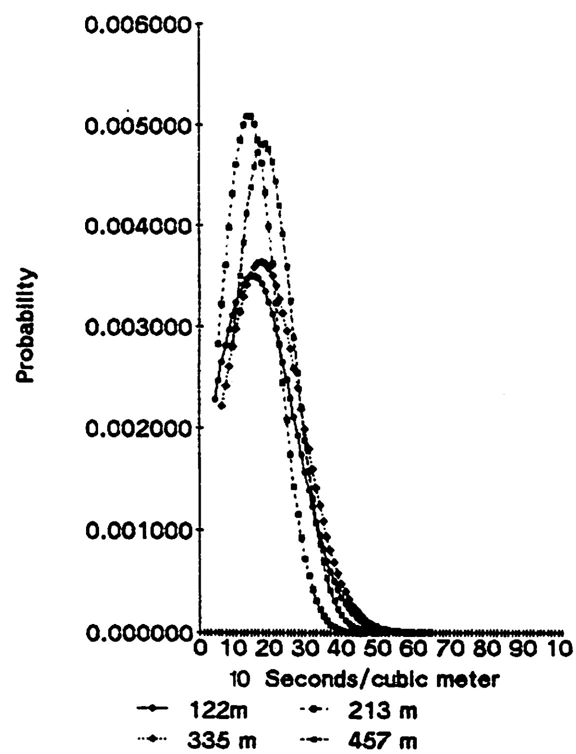


FIGURE 5. Probability density functions for the CAT05H in January data collection period.

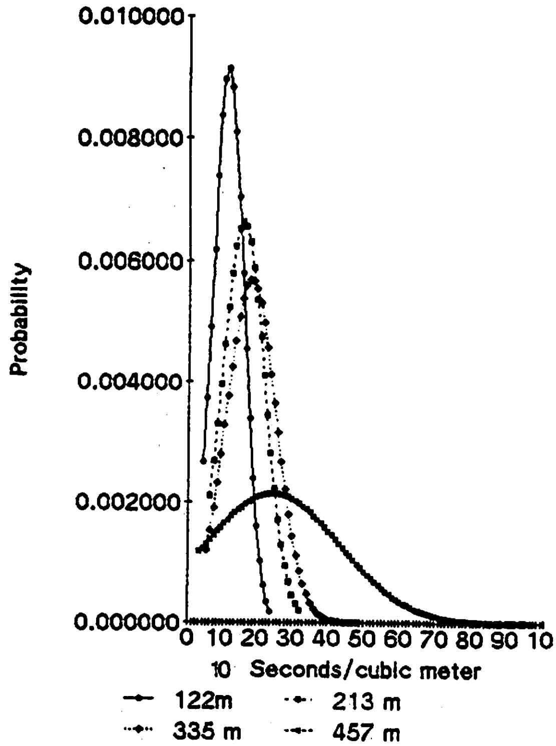


FIGURE 6. Probability density functions for the CAT518 in January data collection period.

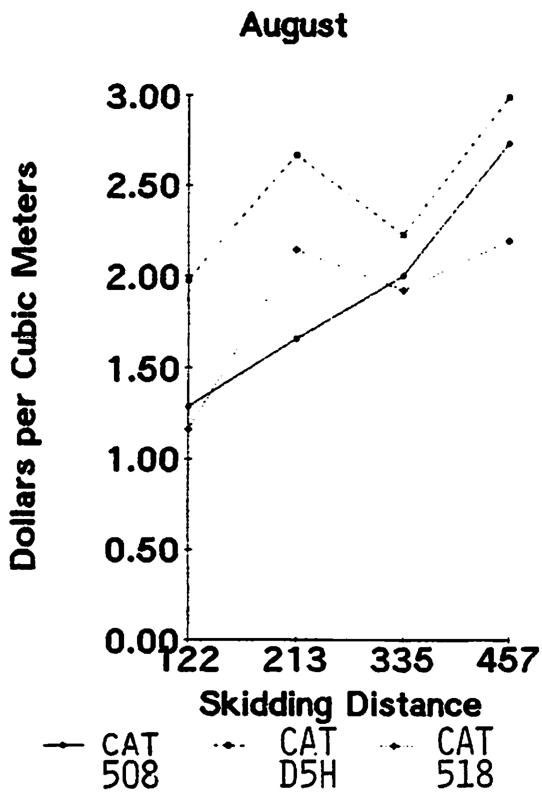
seconds needed to process a cubic meter of wood. Examination of histograms of the processing rate indicated that the probability distribution could be approximated by finite normal distributions. The empirical means, minimum and maximum values and standard deviation are listed in table 1. Figures 1 through 6 graph the probability density functions used in the simulation. Note that each figure includes a separate probability distribution for four average skidding distances (122, 213, 335 and 457 meters).

The finite normal single server que was used with the empirical mean values listed in table 1 in a simulation experiment designed to compare the productivity of the machines on identical sites over a fixed amount of time. Each machine was simulated for 10,000 seconds at each distance six times. Results of the simulation experiment are listed in table 2. Total cubic meter production was recorded. The average production of the six simulation runs was determined along with the standard deviation. It is implied by the Central Limit Theorem that the distribution of the simulated total production runs will have a normal distribution. Therefore statistical measures can be used to compare machine systems. The unit cost for each machine-distance combination of table 3 is the result fo using the following productive machine hour (PMH) cost estimates of $25.86, $35.85 and $29.23 per PMH for the CAT 508, CAT D5H and CAT 518 respectively and the total production listed in table 2. The estimated mean production costs for each machine in August and January are shown in figure 7.

TABLE 3. Estimated unit cost of the different machine systems. The machine cost from table 1 and cubic meter production from table 2 was used to estimate these values.

Simulated Production Cost in Dollars per Cubic Meters

Mach Sys	m	Run Numbers 1	2	3	4	5	6	Mean
508 Aug	122	$1.31	$1.31	$1.25	$1.30	$1.30	$1.29	$1.29
	213	$1.66	$1.60	$1.67	$1.67	$1.67	$1.70	$1.66
	335	$2.04	$2.06	$2.08	$1.98	$1.91	$1.94	$2.00
	457	$2.74	$2.73	$2.65	$2.70	$2.82	$2.81	$2.74
D5H Aug	122	$1.92	$1.98	$1.96	$2.04	$1.98	$2.01	$1.98
	213	$2.70	$2.83	$2.67	$2.61	$2.57	$2.64	$2.67
	335	$2.23	$2.24	$2.20	$2.21	$2.23	$2.25	$2.23
	457	$3.03	$2.83	$3.15	$2.95	$3.05	$3.00	$3.00
518 Aug	122	$1.15	$1.18	$1.14	$1.17	$1.15	$1.19	$1.16
	213	$2.18	$2.17	$2.19	$2.16	$2.08	$2.09	$2.15
	335	$1.89	$1.92	$1.96	$1.97	$1.96	$1.86	$1.93
	457	$2.23	$2.14	$2.16	$2.21	$2.27	$2.17	$2.20
508 Jan	122	$0.98	$0.96	$0.95	$0.95	$0.90	$0.96	$0.96
	213	$1.28	$1.29	$1.26	$1.29	$1.28	$1.28	$1.28
	335	$1.50	$1.49	$1.57	$1.56	$1.55	$1.57	$1.54
	457	$1.48	$1.54	$1.49	$1.53	$1.49	$1.47	$1.50
D5H Jan	122	$1.46	$1.45	$1.42	$1.44	$1.45	$1.45	$1.44
	213	$1.36	$1.33	$1.35	$1.34	$1.37	$1.36	$1.35
	335	$1.66	$1.68	$1.68	$1.66	$1.64	$1.70	$1.67
	457	$1.74	$1.76	$1.74	$1.79	$1.74	$1.73	$1.75
518 Jan	122	$0.88	$0.88	$0.89	$0.87	$0.89	$0.89	$0.89
	213	$1.23	$1.25	$1.20	$1.23	$1.20	$1.23	$1.22
	335	$1.41	$1.39	$1.44	$1.40	$1.43	$1.37	$1.41
	457	$1.90	$1.90	$1.88	$1.96	$1.87	$1.90	$1.90



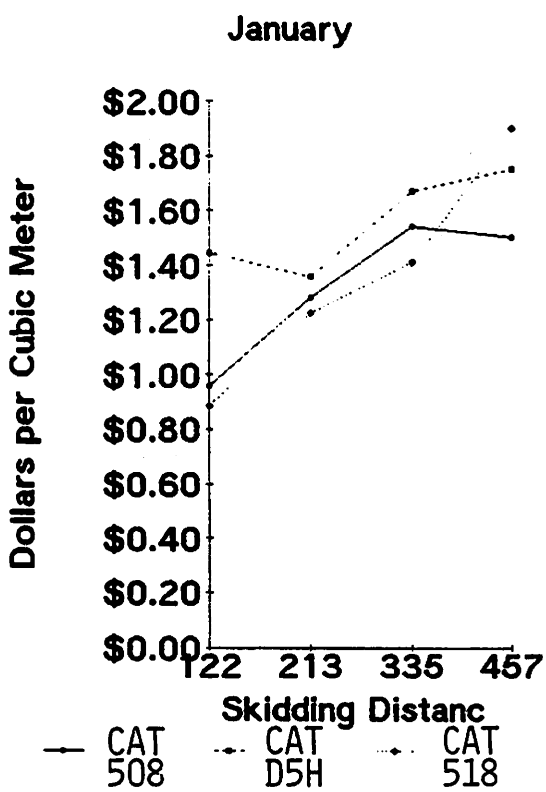


FIGURE 7. Simulated results relating skidding distance and cost for three skidding systems in August and January. Data from table 3.

To determine the difference between machine systems, at different times of year, the null hypothesis H_0: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$ was tested using analysis of variance with the six treatment levels, blocked by distance and six replications per treatment. μ_i is the true mean of each treatment population. H_0 was rejected in favor of the alternative hypothesis H_a; at least one of the six population means differs from the rest.

To determine which population means are different, the multiple range test developed by Duncan(1955) was used. The use of this test indicates that the unit cost all machine systems are significantly different. In other words the variance of measured production rate is small compared to the differences in average production rate.

CONCLUSION

The CAT518 is the least costly machine system in the majority of cases at skidding distances of 335 meters and under. Beyond 335 meter skidding distance the CAT508 is the least costly machine. The CAT D5H is inferior to both the CAT508 and the CAT518 for all distances and seasons.

Queuing simulation can be used to help evaluate harvesting machinery. It is not a substitute for experimental replications, but can be used as a surrogate for replications.

REFERENCES

Biller, C.J. and L.R. Johnson. 1973. Comparing logging systems through simulation. Transactions of the ASAE 16(6):1060-1063.

Bradley D.P. and S.A. Winsauser. 1976. Solving wood chip transport problems with computer simulation. USDA Forest Service Research Paper NC-138. North Central Forest Experiment Station, St. Paul, Mn. 8 p.

Corcoran, T.J. 1971. Timber harvesting system design and equipment leveling through GPSS/360. ASAE Paper No. 71-615. ASAE, St. Joseph, Mi. 15 p.

Duncan, D.B. 1955. Multiple range and multiple F tests. Biometrics 11, PP.1-42.

Johnson, L.R. 1984. Analysis of raw material extraction through simulation: a timber harvesting example. Unpublished Ph.D. Dissertation, West Virginia University, Morgantown, WV. 470 p.

Martin, A.J. 1975. Timber harvesting and transport simulators (THATS), with subroutines for Appalachian logging. USDA Forest Service Research Paper NE-316. N.E. Forest Research Station, Broomall, PA. 32 p.

O'Hearn, S.E., W.B. Stuart, and T.A. Walbridge. 1976. Using computer simulation for comparing performance criteria between harvesting systems. ASAE Paper No. 76-1567. ASAE, St. Joseph, MI. 17 p.

Roise, J.P, A. E. Hassan. 1988. Comparative simulation of forest Harvest Systems. ASAE St. Joseph, MI 49085-9659. Paper No. 88-7519. Dec. 13-16 Chicago, Illinois.

A MODULAR TIMBER BRIDGE FOR TEMPORARY STREAM CROSSINGS

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ABSTRACT

Maintaining water quality is a prime consideration when stream crossings are required on logging jobs. A longitudinally stress-laminated timber bridge was designed, constructed, installed, and evaluated at the West Virginia University forest on a commercial timber sale as a possible stream crossing alternative. Results indicate that this type of system is economical and environmentally acceptable for temporary stream crossings.

Key Words: Timber Harvesting, Longitudinally Stress-laminated, Hardwoods.

INTRODUCTION

The National Timber Bridge Initiative has generated a great deal of interest in designing timber bridges for rehabilitation of our nation's rural transportation network. Most of the modern timber bridge technology, to date, has focused on highway applications. However, the technology and designs are well suited and easily adapted for temporary bridging applications, including logging haul roads and for skidding over streams. This paper provides a brief background on longitudinally stress-laminated timber bridges and describes the design, construction, and installation of such a bridge for use on a commercial timber sale at the West Virginia University Forest.

LONGITUDINALLY STRESS-LAMINATED TIMBER BRIDGES

The bridge design receiving the greatest attention is the longitudinally stress-laminated timber bridge. In this system, the lumber is mechanically laminated on-edge using high strength, threaded steel rods. The lumber utilized in these systems is generally 4 to 16 feet long, 2 to 4 inches thick, and 5 inches and wider. The load bearing ability of this design is dependent on the compression and friction between laminae, as opposed to the more traditional glulam and nail laminated designs which rely on glue or mechanical fasteners.

The steel rods are spaced at regular intervals, through pre-bored holes on the wide face of each lamination. These rods are then stressed, in tension, up to 100,000 psi with a hydraulic jack. As the rods are stressed the laminae are compressed so that the fully compressed deck acts like a plate (i.e., where the deck members deflect together as a unit). In order to achieve and maintain desired stress levels, a deck is generally re-stressed at least twice during the first 1 to 2 months after being placed in service.

Lumber laminae within the bridge are discontinuous. Bending stress is transferred among these laminae via frictional forces between adjacent boards. This design aspect allows lumber of varying lengths to be incorporated into the deck; however, it is important to avoid butt joints in adjacent laminae. For highway bridges, butt joints across the width of the bridge are separated by four laminae and are spaced at least four feet apart along the length of the span. Decks are generally constructed with a positive or upward camber to compensate for the dead load deflection of the bridge.

To protect the bridge while in service, the lumber is treated with an oil-borne preservative (generally creosote). This provides protection against pest infestations, and reduces moisture content variation of the wood, which helps inhibit dimensional changes. This preservative will not react chemically with the wood, nor will it corrode the bridge hardware.

Some advantages of the longitudinally stress-laminated bridge design include:

1. A bridge can be designed and prefabricated into modules.

2. A bridge can be transported on a tractor-trailer to the installation site.

3. Locally available lumber can be utilized in bridge fabrication.

4. The bridge components will not delaminate over time. If compression between laminae decreases, the deck can be easily re-stressed.

5. A variety of lumber lengths can be utilized, allowing for utilization of shorter lumber.

6. The bridge can be assembled largely by unskilled labor.

THE WEST VIRGINIA UNIVERSITY LOGGING BRIDGE

In the Spring of 1990 a longitudinally stress-laminated timber bridge was designed, built, and installed at West Virginia University. Impetus for the project was the need to cross an environmentally sensitive stream as part of a commercial timber sale on the West Virginia University Forest. The bridge was installed on a haul road that provided access, over Lick Run, to the sale area. The project was conducted in cooperation with the Division of Forestry, Appalachian Hardwood Center, and Constructed Facilities Center, all at West Virginia University and Interstate Lumber Company in Kingwood, West Virginia. Interstate Lumber utilized the haul road and bridge to remove 160,000 board feet of tree-length material from the sale area using tractor-trailer units with a legal gross weight limit of 80,000 pounds.

Construction

The timber used in the bridge was rough, green 3-inch by 10-inch members ranging from 4 feet to 16 feet in length. All lumber was mill run (ungraded), mixed hardwoods (primarily white oak, yellow-poplar, and beech). Because of the nature of the application, the lumber was left untreated, which does limit life cycles to 5-10 years, depending on level of abuse during repeated installations and removals. The bridge was designed to be 16 feet wide, 40 feet long, 10 inches deep, and was fabricated in 2 modules, each measuring 8 feet by 40 feet. Approximately 6,400 board feet of 3 inch by 10 inch lumber was used.

All fabrication and construction was handled using unskilled labor at a laboratory on the West Virginia University campus. The lumber was crosscut to length, then 2-inch holes were marked and bored to accept the 1-inch diameter steel rods. Lumber lengths ranged from 4 feet to 16 feet. Two-inch holes were used to compensate for small misalignments between laminae. The highway bridge constraint for butt joints across the width of the bridge was relaxed to one butt joint in every 3 laminae and at least 4 feet apart along the length of the bridge.

Each of the two modules was fabricated separately. Boards were placed on edge and oriented parallel to the length axis of the bridge module. The high tensile strength steel rods (manufactured by Dywidag, Inc.[1]), extending transversely through the module were stressed to 50,000 psi using a hollow core hydraulic jack.

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1. The use of trade, firm, or corporation names is for the information and convenience of the reader and in no way constitute an official endorsement or approval by West Virginia University of any product or service to the exclusion of others that may be suitable.

A bearing plate and anchor plate were used with each rod. Within each 8-foot module the steel rods were spaced at regular 4-foot intervals (see Figure 1). An added advantage of this design is that the modules can be fabricated and permanently stressed in the shop prior to installation.

Additionally, holes were bored to accept 5 temporary stressing rods that would be used to stress the 2 modules together at the bridge site. Also, each module contained a 1/2-inch by 8-inch by 40 foot steel plate on each side, to improve overall stiffness of the bridge. Finally, 6-inch by 4-inch by 1/2-inch angles were installed on each end for protection and to prevent the ends of the bridge from flaring out.

Fabrication and construction of the modules was completed in approximately two, 12-hour workdays. About 13 percent of the man hours were spent in dimensioning the lumber, 42 percent in drilling holes, 30 percent in assembly, 9 percent in stressing, and 6 percent in miscellaneous activities such as welding, rigging, etc. Minimal equipment needs include one and preferably two drill presses, a cut-off saw and welding equipment.

Installation

The bridge modules were loaded onto a tractor-trailer using a 10-ton capacity overhead crane. Under less ideal conditions, the modules could be winched onto a trailer one at a time.

Very little site preparation was required prior to installation. The entry approach was graded and stoned, but no abutments were constructed. In fact, the bridge was simply placed on the existing stream bank after only minor grading. It is, however, recommended that at least 5 feet of bridge/ground contact be allowed on both sides of the stream, leaving an effective bridge span of 30 feet. A larger bearing area may be required for unstable stream banks.

The bridge was installed with a John Deere 450 bulldozer equipped with a winch and a Barko 275 knuckleboom loader. As each module was winched off the trailer, the loader would suspend one end to ease the module into place. Based on the experience of this installation a single bulldozer or skidder with a winch could handle the off-loading of the bridge. A loader may, however, be required to help position the modules to accept the 5 temporary steel rods that stress the modules together. A coupler between the modules allows the rods to be stressed from either side of the bridge. Each of the 5 temporary rods was stressed to 50,000 psi during installation. Approximately 2-3 hours was required for complete installation of the bridge. This does not include any re-stressing of the temporary steel rods that may be necessary. It is recommended that tension in the temporary rods be checked at least once before the bridge is placed in continuous service.

Cost

Mill-run lumber was assumed to be available at $470 per thousand board feet for a total cost of $3,000. Of course a logger or sawmiller could easily undercut the cost of lumber. Bridge hardware including steel rods, 4 steel bulkheads, couplers, nuts, bearing plates, and anchor plates totalled $2,250. Unskilled labor at $5.00 per hour totalled $1,750 for a total bridge construction cost of about $7,000. Although installation costs were not recorded, one would have to consider transportation to the site, installation equipment and manpower at the bridge site.

By comparison, a portable steel bridge 14 feet by 40 feet, with 3-inch hardwood decking, 50-ton capacity, and full length guardrail is currently available for $17,500 or 2.5 times the cost of the timber bridge[2].

The hydraulic jack and tools necessary for tensioning the steel rods was not included in the bridge costs, but can be obtained for approximately $1,000. From a cost perspective,

2. ADM Welding and Fabrication. Warren, PA.

the jack and all the bridge hardware can be reused an indefinite number of times.

PERFORMANCE EVALUATION

Bridge Deflection

Deflection was determined at the bridge centerline when loaded with a logging tractor-trailer, using a standard transit. The total truck weight was 75,600 pounds: 45,800 on the front two axles and 29,800 on the rear axles. The truck was positioned on the bridge in three ways: 1) the heaviest axles were at center span (Case A), 2) the midpoint between the front and rear axles was directly above the center of the span (Case B), and 3) the rear axle was directly above the center of the span (Case C). The results of the load test showed that for Case A deflection at the edge of the bridge was 1.375 inches and deflection at the wheel loads in the center area of the bridge was 1.5 inches. For Cases B and C edge deflections were 1.25 inches and 1.125 inches, respectively, while deflections at the wheel load were both 1.375 inches.

These deflections are based on static loading and do not measure the effect of impact on total deflection, which may be significant. In fact, vibration of the bridge during passage of a loaded tractor-trailer was quite noticeable.

Stress levels were checked two days and two weeks after the initial rod tensioning and were found to be satisfactory. The full length (temporary) rods were more highly stressed than the panel width bars. All of the bars were at a tension level less than 100 percent of the jacking force level. The full length bars were at about 80 percent, while the panel width bars were around 60 percent of the jacking force level.

No attempt was made to camber the bridge because it was thought that the use of full length steel plates would make installation of camber difficult. During the period of use the bridge developed a small degree of negative camber which indicates that it is possible to install camber during construction. In fact, it is recommended that future designs incorporate a positive camber to account for dead load deflections.

Stream Impacts

One of the primary reasons for considering a temporary bridge was the expectation of minimal environmental impact. Since physical stream channel changes or disturbances are manifested in changes in turbidity and dissolved solid concentrations, stream water turbidity, conductivity, and pH were monitored as a means of assessing stream impacts. Stream conditions at the bridge site were monitored beginning March 19, 1990, two days prior to span installation, and continued daily for three days after installation. Stream discharge during the study period was estimated to be 20 to 23 cfs. Measurements of conductivity (electrical resistance due to dissolved solids, where increasing levels of conductivity indicate greater stream impacts), pH, and turbidity (volume of suspended solids, where increasing levels indicate increased impacts and reduced stream quality) were made at sampling stations 10 m above the site and 5 m and 10 m below the site. Measurements of pH and conductivity were taken across the stream with calibrated portable instruments. Grab samples of stream water were taken for turbidity measurements with a Hach turbidometer.

Three daily samples were taken at each point above and below the bridge site for each performance variable. Conductivity ranged from 86.5 to 98.2 micro mhos/cm^2 and pH ranged from 6.1 to 6.8. Turbidity ranged from 3 to 8 JTU (Jackson turbidity units). Based on t-test results of the data no statistically significant changes occurred in conductivity, pH, or turbidity.

CONCLUSION

Longitudinally stress-laminated timber bridges appear to offer a feasible alternative for temporary stream crossings. The system is cost competitive with currently available temporary bridge systems, is relatively easy to install, can be used repeatedly, the hardware can be reused indefinitely, it minimizes environmental impacts, and can be transported and installed in modules using commonly available logging and trucking equipment.

Assistance with designing and fabricating a stress-laminated timber bridge is available through West Virginia University's Division of Forestry, the Appalachian Hardwood Center, and the Constructed Facilities Center at 293-3825, 293-7550 and 293-7608, respectively.

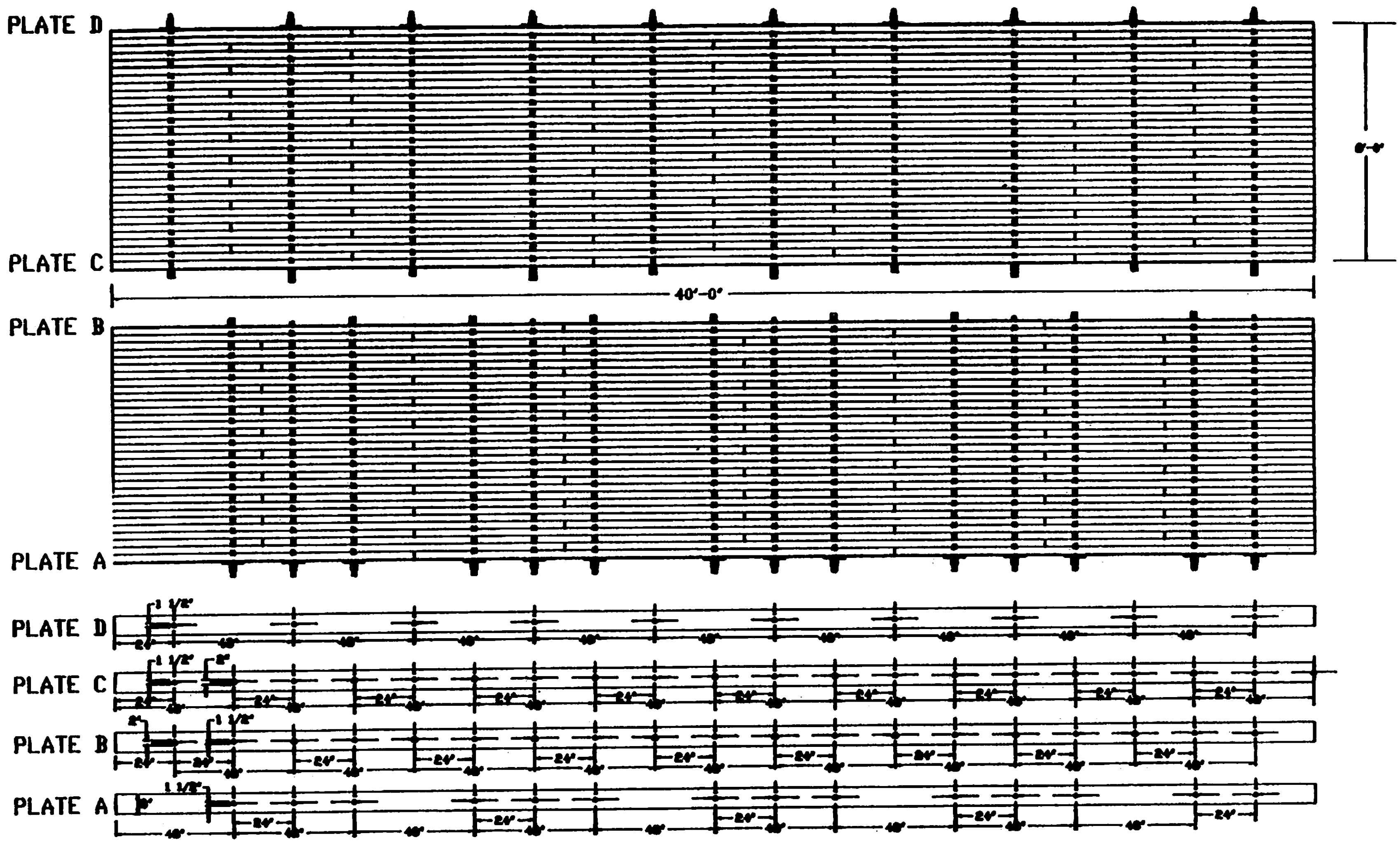

FIGURE 1 SCHEMATIC OF W.V.U. TEMPORARY BRIDGE

A ROADBUILDING ALTERNATIVE FOR SWAMP CROSSINGS

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ABSTRACT

Constructing roads over swamps or muskeg is difficult. Conventional gravel roads are heavy, and gravel is often in short supply. Catastrophic failure of the vegetative mat may occur under the dead weight of the road or with added traffic. The use of lightweight fills alleviates the problem. Chunkwood is a viable lightweight structural fill for swamp crossings.

Key Words: Forest roads, Low-volume roads, Chunkwood, Wood chips, Wetlands, Logging roads.

INTRODUCTION

Pit-run gravel is the traditional, and often preferred, material for most forest roadbuilding situations, including low-volume roads. But quality gravel is not always abundantly available within an economical transport distance. Also, for swamp or muskeg road construction, gravel availability may not be the most serious concern to the forest engineer. Low bearing and rupture strength of the vegetative mat may be the overriding concern. Gravel is heavy--about 125 pounds per cubic foot. In the case of a muskeg crossing, the total dead weight of the finished road, coupled with the weight of logging trucks, may simply be too much for the vegetative mat to support, and the end result may be catastrophic mat failure. Even if complete failure does not occur, there will likely be a gradual, continuous sinking of the vegetative mat under the dead weight of the road. Once a road surface sinks to an unacceptable level, the standard remedy is to restore the level by adding more gravel, and thus more weight. Should the vegetative mat rupture as this process goes on, the entire gravel roadbed may disappear into the underlying peat, and tremendous volumes of gravel may be required to fill up the hole. In some real-life cases, this has proven to be an impossible undertaking, not to mention an enormous waste of good gravel.

Therefore, the Forest Service and other agencies involved with building low-volume forest roads, including the military, are vitally interested in new or alternative roadbuilding materials. Of particular interest are lightweight fills for use on ground having low strength, such as swamps or muskeg. One such material recently introduced by the Forest Service is chunkwood (Arola 1984, Barwise *et al.* 1984). The bulk density of green chunkwood is in the range of 20 to 25 pounds per cubic foot, about one-fifth to one-sixth that of gravel.

Originally developed for use as a form of biomass fuel and as a raw material feedstock for manufacturing structural flakeboard, chunkwood was the focus of a cooperative research and demonstration program to explore its use as an alternative forest roadbuilding material (Arola *et al.* 1988). The program cooperators were the Forest Service's North Central Forest Experiment Station, the Chequamegon and Superior National Forests, and Michigan Technological University. Approximately 2.5 miles of test roads were constructed at four sites, one of which was a swamp with a thick peat deposit.

This paper began with reference to a class of forest roads known as "low-volume roads." Although there is no precise definition of low-volume roads, they are generally perceived as poor-quality, single-lane, unsurfaced roads that support a low volume of traffic (perhaps a few hundred vehicles per day), have low construction cost, and have a relatively short useful life.

SWAMP CROSSING

The demonstration swamp crossing site was located on the Chequamegon National Forest near Hayward, Wisconsin. This was a 600-foot crossing with a substantial depth of peat beneath the vegetative mat. In the beginning third of the crossing, the peat reached an approximate depth of 10 feet, and in the latter third the maximum depth was about 15 feet. The organic soils were classified as Carbondale. The trees were predominantly aspen, black spruce, and lowland brush. Since this crossing was a new construction, there was no existing right-of-way clearing. To help convey just how fragile this muskeg was, after the right-of-way clearing was made and the ground had thawed, it was possible to jump up and down on the vegetative mat and cause the tree tops to waver back and forth.

The principal purpose of this roadbuilding effort was to demonstrate the potential of using chunkwood as an alternative lightweight structural fill for a swamp crossing. The crossing was divided into two distinct road parts. In the first 250 feet across the swamp, where the maximum peat depth was about 10 feet, a pure chunkwood road was constructed. This design section specified 30 inches of chunkwood placed directly on top of the vegetative mat (Fig. 1). For our demonstration, this chunkwood-only road was a "minimum design."

A much higher quality design was specified for the remaining 350 feet of the crossing where the peat depth was greater. An 8-ounce geotextile fabric was first placed on top of the ungrubbed swamp mat with distributed slash, followed by 24 inches of chunkwood, then a 4-ounce geotextile fabric over the chunks, and finally a minimum depth of 12 inches of native pit-run gravel on top of the fabric as the surfacing course. For brevity, the term "composite" road section will be used henceforth to refer to this design. The function of the bottom fabric was as a separator to prevent the chunks from being lost into the vegetative mat and underlying peat. Load support was negligible because the fabric was not stretched like a membrane. The upper fabric prevented gradual loss of surface gravel to the underlying chunkwood. With this design, the chunkwood was completely enveloped by fabric and covered with gravel. This eliminated exposure of the chunkwood to the atmosphere. There was no intentional compaction of the chunkwood fill other than that caused by the haul trucks and the bulldozer used for shaping the road.

The use of woven or nonwoven geotextile fabric in forest road construction is not new. The geotextile fabric we used was Supac N[1], a nonwoven fabric distributed by Phillips Fibers Corporation. Since slash was distributed on top of the vegetative mat for our swamp crossing, an 8-ounce fabric was used because of its greater strength and puncture resistance. To separate the chunkwood from the surface gravel, only a 4-ounce fabric was used. Both fabrics readily transmit water.

CHUNKWOOD PRODUCTION

Besides its light weight, the most important advantage of using chunkwood for road building is that it can be produced at or near the construction site. This helps to minimize hauling costs and may give it a competitive edge over gravel if there is a choice to be made. Although trees from the right-of-way clearing can be converted into chunkwood roadbuilding material, in most cases they would not provide an adequate volume. The remaining volume should come from the adjacent forest. Trees having commercial value as sawtimber and pulpwood should be sorted and marketed as such. The intent of converting trees into chunkwood for road building is not to use trees having established markets, but rather to chunk trees and residue having no or extremely limited commercial value. As a roadbuilding material, it does have a value, and subsequently, a potential market.

The trees for our demonstration swamp crossing came both from the right-of-way clearing and the adjacent forest. All harvesting activities, including chunkwood production, were done during the winter months prior to spring breakup. Since road construction did not take place until after spring breakup, all chunkwood was stockpiled nearby.

A tracked harvester outfitted with a knuckle-boom-mounted tree shear was used to fell and bunch the trees in both the right-of-way clearing and the adjacent forest. A choker-skidder was used to skid prebunched trees to a forest landing where the chunking machine converted them into chunkwood.

The chunking machine was a precommercial prototype chunker built by the Forest Service at its Missoula Technology and Development Center in Montana (Fig. 2). (Commercial versions of this machine are not yet available.) The wood chunking

[1] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. It does not constitute an official endorsement or approval of any product or service by the United States Department of Agriculture to the exclusion of others that may be suitable.

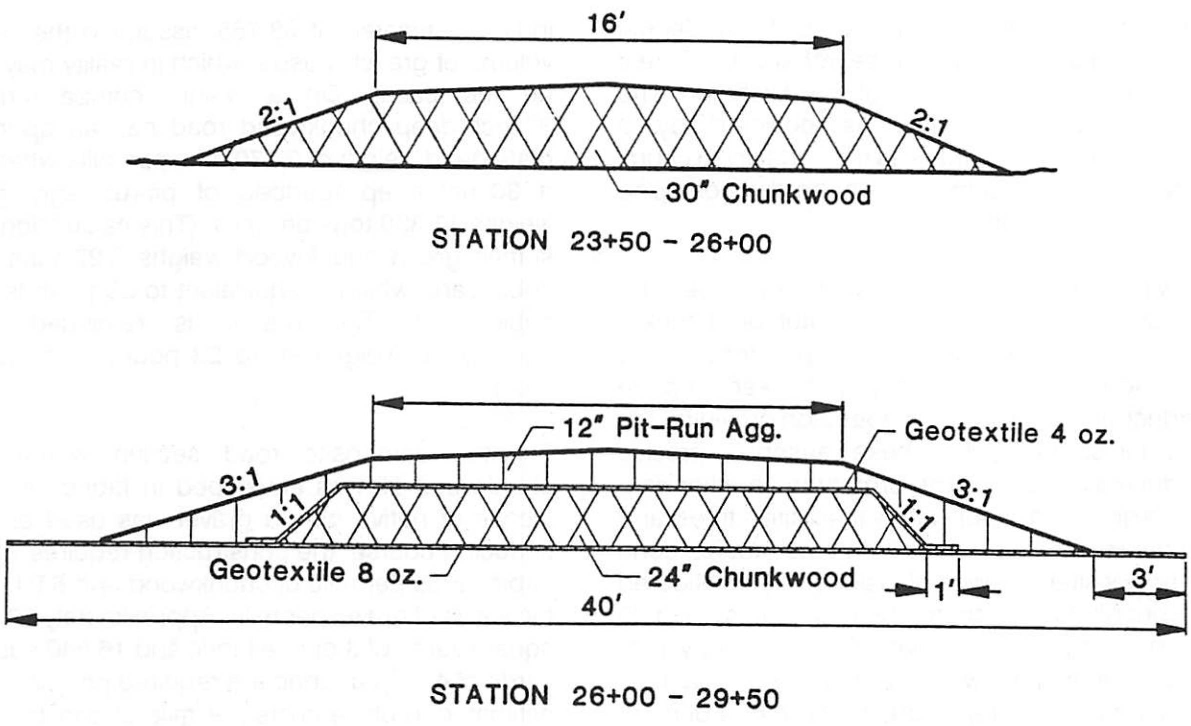

Figure 1.--Typical cross sections of chunkwood test demonstration roads.

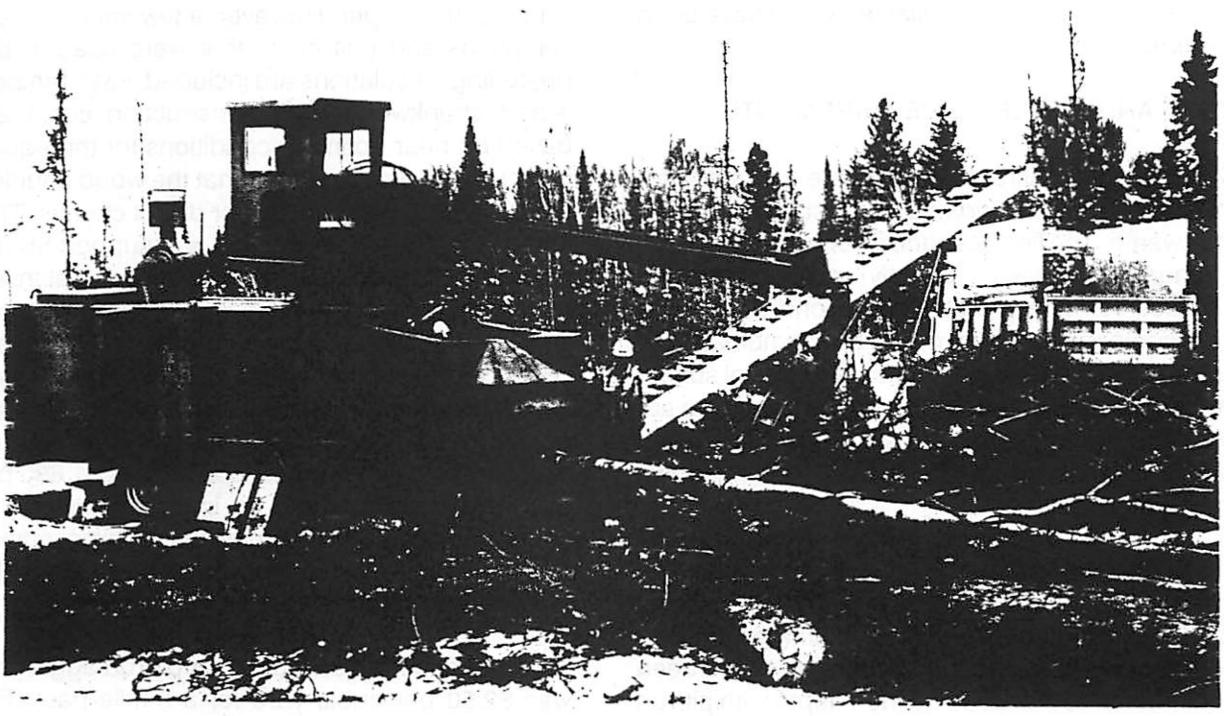

Figure 2.--USDA Forest Service, Missoula Technology and Development Center precommercial prototype wood chunker.

concept was originally developed by North Central Forest Experiment Station researchers at its Forest Engineering Project in Houghton, Michigan. The Missoula chunker, which is powered by a 300-horsepower engine, has the capacity to chunk softwood trees and low-density hardwoods up to 12 inches in diameter.

As with any commercial whole-tree chipper, the productive capacity of this prototype chunker would be expected to vary with operator skill, the size and species of trees being chunked, and the productivity of the logging operation providing the trees for chunking. For these reasons a precise productivity figure for the prototype chunker cannot be given that would apply to all sites, trees, and operators. However, based on time studies done at various sites, a range of productivity considered reasonable for this prototype machine is 25 to 30 green tons per productive hour. (A serially produced commercial whole-tree chunking machine should have a higher productivity than a demonstration prototype.)

The chunkwood was loaded directly by conveyor into standard 12-cubic-yard dump trucks with extended sides. The theoretical extended capacity of the trucks was 20 cubic yards. (Larger capacity trucks, had they been available, would have been preferred.)

COST AND MATERIAL REQUIREMENTS

Cost and material requirements are presented for the same two scenarios as our test roads across the swamp. The first scenario is for a 30-inch depth of chunkwood placed directly on top of the ungrubbed vegetative mat. The second scenario is for a composite road involving the combination of chunkwood, two levels of fabric, and gravel surfacing (Figs. 1 and 3). For convenience, the costs are presented on a per-mile basis. Thus, for a given length of swamp crossing, the following costs must be prorated.

For the 30-inch-deep chunkwood road specified, the quantity of chunkwood required per mile of road is 10,270 cubic yards. The estimated in-place cost per mile is $24,100. Had this entire road been constructed to the same 30-inch depth with pit-run aggregate with a 5-mile haul, the in-place cost would have been approximately $32,865 per mile. Thus, by producing chunkwood on-site instead of hauling pit-run aggregate, the per-mile cost savings is estimated at $8,765, assuming the same volume of gravel is used (which in reality may not be the case). On a weight comparison, a 30-inch-deep chunkwood road has an approximate dead weight of 2,770 tons per mile, whereas a 30-inch-deep roadbed of pit-run aggregate weighs 17,330 tons per mile. (This calculation assumes green chunkwood weighs 0.27 tons per cubic yard, which is equivalent to 20 pounds per cubic foot. The reader is reminded that chunkwood weighs 20 to 23 pounds per cubic foot.)

For the composite road section where the chunkwood fill was enveloped in fabric, and 12 inches of native pit-run gravel was used as the surfacing course, the construction requires 7,820 cubic yards per mile of chunkwood and 6,845 cubic yards of gravel per mile. Approximately 23,470 square yards of 8-ounce fabric and 16,840 square yards of 4-ounce fabric are required per mile. The estimated in-place costs per mile of construction are $18,400 for chunkwood, $21,900 for pit-run gravel, and $31,900 for geotextile. The total estimated cost for this composite construction is $72,200 per mile.

A detailed breakdown of costs is beyond the scope of this paper. However, a few important assumptions and unit costs that were used in the preceding calculations are included. First, the projected chunkwood road construction costs are based on near optimum conditions for the equipment used. It was assumed that the wood chunker produced 800 cubic yards per day of chunks. This means that the wood chunker and support felling, bunching, and skidding equipment are balanced to provide an average of 26.8 green tons per hour over an 8-hour day. Based on prorated costs according to estimated hours of use, the operating cost (with operator) related only to the chunkwood portion of the road building for felling, bunching, skidding, trucking, and bulldozing was $1,880 per day. This translates into an in-place unit cost of chunkwood of $2.35 per cubic yard. This assumes that the chunkwood is produced at the roadbuilding site, and the haul distance is negligible.

The load and haul cost used for pit-run aggregate was $2.50 per cubic yard for a 5-mile haul. The placement cost for pit-run aggregate was $0.70 per cubic yard. The unit cost for 8-ounce geotextile fabric was $0.88 per square yard, and for 4-ounce fabric, $0.45 per square yard. Placement costs

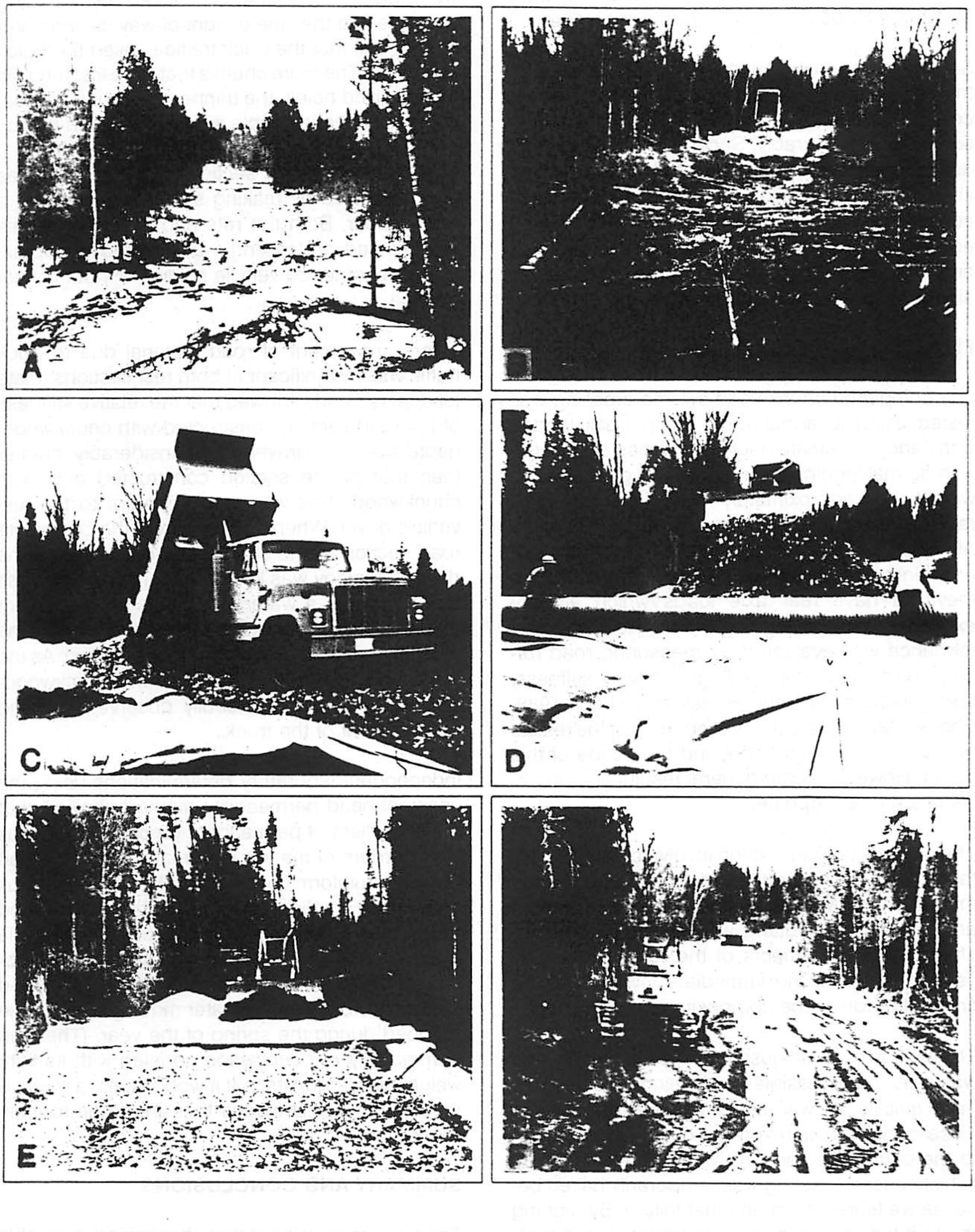

Figure 3.--Swamp crossing at FR 481 (Hayward site): A. Right-of-way clearing; B. Ungrubbed swamp in foreground; C. Dumping of chunkwood onto geotextile fabric; D. Installation of culvert; E. Application of geotextile fabric and gravel over chunkwood base; F. Nearing completion of swamp crossing.

used for the 8-ounce and 4-ounce fabrics were $0.12 and $0.05 per square yard, respectively.

Several factors must be considered in relation to the above costs. First, they are only approximate costs based on a single trial--roadbuilding situations vary considerably. Second, they are in 1987 dollars (the time of construction). Third, as the chunkwood roadbuilding technology becomes adopted practice, as chunking and roadbuilding equipment and techniques become more refined and commercially available, and as we progress along the learning curve, costs should decrease.

FIELD EVALUATION

The completed chunkwood swamp crossing was tested using a tandem-axle dump truck loaded with sand to simulate hauling activities associated with normal logging operations. The gross loaded weight was approximately 50,000 pounds, with rear axle loads approaching 20,000 pounds each. Although our test trucks didn't have a gross loaded weight as high as that of many logging trucks, they did have rear axle loads which actually exceeded those of logging trucks. Roadway performance was evaluated by measuring road rutting, roadway lateral shoving, roadway stiffness, and general settlement (Hodek and Shook 1988, Shook 1988). A detailed presentation of the results of these evaluations is beyond the scope of this paper. However, some general results and observations are appropriate.

The composite road section involving chunkwood, fabric, and gravel performed exceptionally well--more than 100 vehicle passes were made without any failures, and rutting was slight. Before-and-after test measurements of the road surface revealed there was no immediate lowering of the finished grade of the composite road.

The section built with just 30 inches of chunkwood was very compressible; it developed deep ruts fairly quickly as well as some localized failures close to the transition from the chunkwood section to the composite section. After approximately 50 vehicle passes, testing was temporarily halted because we feared complete mat failure. By digging through the chunkwood to the underlying vegetative mat at the localized failure, we found that chunkwood particles were being pumped under the load of traffic through holes in the vegetative mat into the underlying peat. The holes in the mat were believed natural or caused by skidding equipment at the time of right-of-way clearing. We did not feel that the truck traffic caused the holes in the mat. The more chunks that were lost through the localized holes, the thinner the chunk bed became, and the less able it was to support traffic.

The chunkwood-only section of the roadway was easily restored by making several passes with a road grader. Both the ruts and localized failures were leveled, and testing was resumed for approximately another 50 vehicle passes without consequence.

Lateral movement of road material due to truck traffic was insignificant in both test sections. Plate load tests clearly showed that the relative stiffness of the road section constructed with chunkwood, geotextile, and gravel was considerably greater than that of the section constructed only with chunkwood. This was also apparent to the test vehicle driver. When travelling from the composite road section to the chunkwood-only section, the driver's analogy was like driving on a stiff mattress and then onto a waterbed. It was also apparent that the rolling resistance on chunkwood was much higher than on the composite section. As the loaded dump truck travelled over the chunkwood-only road, one could readily observe a moving wave in front of the truck.

Independent laboratory determinations using the constant-head permeability method showed that the coefficient of permeability for chunkwood was many orders of magnitude greater than for clean gravels or uniform coarse sand (Hodek and Shook 1988). The implication here is that chunkwood roads may function as a continuous permeable roadbed in low-lying or swampy areas. When observed 3 years after construction, this road showed visible signs of water moving through the roadbed during the spring of the year. (The high permeability of chunkwood coupled with its light weight also suggests that it would make a good fill for stabilizing side slopes that are prone to massive slides.)

SUMMARY AND CONCLUSIONS

The main conclusion is that chunkwood is a viable lightweight structural fill for constructing low-volume forest roads over muskeg. A key potential advantage of using chunkwood for road building is that it can be produced at or near the roadbuilding site as opposed to hauling gravel over long distances. On-site production of chunkwood can be cost-competitive with gravel. Chunkwood can be used directly or stockpiled for later use.

Assuming on-site production of chunkwood and using the cost figures presented in this paper, the cost of a 30-inch-deep chunkwood road across a 1,000-foot swamp crossing is approximately $4,700. For the same road depth, a 1,000-foot road constructed of pit-run aggregate would weigh about 525 tons more than the chunkwood road. The cost for a composite road consisting of a ground fabric, 24 inches of chunkwood, fabric, and 12 inches of surfacing gravel is approximately $13,700.

A road over muskeg constructed of chunkwood, geotextile, and gravel is much stiffer and will outperform a road constructed with just chunkwood. Because of chunkwood's high compressibility, a deep bed of chunkwood will rut quite rapidly, but deep ruts alone should not be considered as constituting road failure. The loose chunkwood particles between the ruts do not present a problem for high-clearance vehicles. There is minimal lateral shoving of material in chunkwood roads. It is a natural occurrence to have holes in the vegetative mat. When chunkwood is placed directly on the vegetative mat without a ground fabric, excessive particle losses may occur and result in a localized reduction in roadbed thickness and associated strength. Chunkwood roads can be readily restored with a road grader.

PRELIMINARY RECOMMENDATIONS

Chunkwood should be included in the roadbuilder's toolbox as an alternative and lightweight roadbuilding material. Availability, bottom-line economics, or some other engineering justification will ultimately determine the choice of materials--whether it be chunkwood or conventional roadbuilding gravel.

Many questions pertaining to roadbed design and material characteristics must be answered before we can truly understand and predict chunkwood road performance. However, based on the performance of trial chunkwood roads, coupled with subjective observations, some preliminary recommendations can be made regarding the use of chunkwood in several kinds of forest roadbuilding applications. As more is learned about the performance and optimum design of chunkwood roads built over swamps, the recommendations that follow can be refined and expanded.

Swamp or muskeg crossings stand out as a natural application for lightweight chunkwood fills. In such applications, we recommend that trees and slash from the right-of-way clearing that are not recovered for chunking be concentrated beneath the intended road. Unless the road is to have an extremely short life, a geotextile fabric with good puncture resistance should be placed over the concentrated slash before applying the chunkwood. The distributed slash will add strength, and the fabric will minimize the loss of chunkwood particles to the underlying peat through natural holes in the vegetative mat. Without the fabric separator, the chunks inevitably will be forced through these holes under the load of traffic, and the roadbed will be weakened.

In a swamp crossing application, the load-supporting capability of the road is critical and is directly related to the overall depth of the road. There must be a sufficient depth of chunkwood to develop a safe distribution of pressure beneath the tires. A chunkwood lift of at least 30 inches is recommended if the entire road is to be built only of chunkwood. Where the chunkwood is to be enveloped in geotextile fabric and covered with a gravel surfacing course, a minimum chunkwood depth of at least 24 inches is recommended.

Definitive data on life expectancy of chunkwood roads are not yet available. However, intuition tells us that a road built only of chunkwood will have a shorter life than one where chunkwood is completely enveloped in geotextile fabric and then covered with a surfacing course of gravel. It is a known fact that wood lying on the ground will rot much faster than wood buried in water-saturated soil. (Many individuals have uncovered sound logs from old corduroy roads that have been buried for many years.) Future research should address techniques to extend the life of chunkwood. The use of additives, such as borate, may warrant exploration.

If a road over a muskeg crossing is intended for use by logging or other high-clearance vehicles for only one or a few seasons, then road life is not critical, and the practical choice may be a chunkwood road with geotextile fabric on the vegetative mat to minimize particle loss. The road can be regraded as needed to eliminate excessive rutting. On all chunkwood roadbuilding sites, it is definitely recommended that a nearby stockpile of chunkwood be available to fill in low spots and for routine maintenance.

If the road is intended for a longer service life, or if low-clearance vehicles will use the road, then the practical choice is to envelope the chunkwood fill in a bottom and top fabric, and then apply a surfacing gravel as the traffic-bearing course. The uninformed user of this road would not even know that chunkwood was used as the main structural fill.

Our initial research with chunkwood was successful in that it introduced the concept and demonstrated its potential as an alternative roadbuilding material. Additional roads must now be built and tested in a much broader research program designed to provide guidelines for a variety of applications and to determine chunkwood's engineering characteristics. These are absolutely necessary before roadway design procedures can be developed for chunkwood just as they have been for natural soil and rock.

CONVERSIONS

1 foot = 30.48 centimeters
1 inch = 2.54 centimeters
1 pound = 16 ounces = 0.4536 kilogram
1 ton (2,000 pounds) = 0.9072 tonne (907.194 kilograms)
1 cubic foot = 0.0283 cubic meter = 28.3206 liters
1 cubic yard = 0.7646 cubic meter
1 square yard = 0.8361 square meter
1 pound/cubic foot = 16.0184 kilograms/cubic meter
1 horsepower = 0.7457 kilowatt

LITERATURE SEARCH

Arola, Rodger A. 1984. Chunking of small trees - an alternative to chipping. In: Robertson, Doris, proc. coord. Harvesting the South's small trees; 1983 April 18-20; Biloxi, MS. Proc. 7340. Madison, WI: Forest Products Research Society: 117-127.

Arola, Rodger A.; Hodek, Ralph J.; Bowman, John K.; Schulze, Gary B. 1988. Forest roads built with chunkwood. In: Production, storage and utilization of wood fuels: Proceedings of IEA/BE conference task 3/activity 6 and 7; 1988 December 6-7; Uppsala, Sweden. Res. Notes 133/1988. Garpenberg, Sweden: The Swedish University of Agricultural Sciences, Department of Operational Efficiency: 1: 128-149.

Barwise, Robert D.; Arola, Rodger A.; Matson, Edsel D., inventors; the United States of America as represented by the Secretary of Agriculture, Washington, D.C., assignee. 1984. Involuted disc slicer. U.S. patent 4,431,039. February 14. 11 p. Int. Cl.[3] B27L 11/02. U.S. Cl. 144/176.

Hodek, Ralph J.; Shook, Larry W. 1988. Evaluation of chunkwood as a low-volume road building material. Draft final report. U.S. Department of Agriculture, Forest Service, Chequamegon National Forest, Park Falls, WI. Contract No. 53-56A2-7-00015. Houghton, MI: Michigan Technological University. 62 p., appendices A-E.

Shook, Larry W. 1988. An investigation of selected geotechnical engineering properties of chunkwood. Houghton, MI: Michigan Technological University. 77 p. M.S. thesis.

DESIGN CONSIDERATIONS FOR STREAMSIDE MANAGEMENT ZONES TO PROTECT WATER QUALITY IN FORESTED WATERSHEDS OF THE SOUTHEASTERN UNITED STATES

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ABSTRACT

The streamside management zone (SMZ) has become a standard recommended practice for protecting water quality from the adverse impacts of silvicultural operations, however, research on SMZ effectiveness is lacking. This paper discusses key design and management criteria for SMZs and presents a review of recent literature (post 1983) on the SMZ as a NPS pollution control practice for silvicultural operations in the southeastern United States. SMZ criteria recommended by seven southeastern states are presented.

Key Words: Streamside Management Zone, Best Management Practices, Buffer Strip, Nonpoint Source Pollution, Water Quality.

INTRODUCTION

Today's forest management takes place in an era of increasing environmental awareness and desire for a high level of environmental quality. The role of silviculture as a nonpoint source (NPS) of water pollution has come under close scrutiny since section 208 of the 1977 Clean Water Act amendments initiated a process of NPS assessment and management planning by the states. The techniques developed to control NPS pollution are called best management practices (BMPs). Silvicultural BMPs represent the currently available knowledge of effective NPS pollution control and, therefore, have been accepted by states as the appropriate basis for silvicultural NPS control programs.

BMPs are subject to change as new information becomes available. The objectives of this paper are to review the current literature on one BMP, the streamside management zone (SMZ), discuss SMZ criteria recommended for silvicultural NPS control in seven southeastern states, and offer insights on research needs that will advance the knowledge of SMZ design for maximum effectiveness in NPS control.

The streamside zone is the riparian area bordering drainage channels and open waterbodies where natural vegetation is left partially undisturbed to protect the water resource from silvicultural NPS. Riparian areas are critical areas for NPS control and for multiple-use forest management. Riparian vegetation traps and stabilizes pollutants originating on upslope areas and stabilizes streambanks (Megahan and King, 1985). Fish and wildlife depend on the high primary productivity and diverse habitat provided by the riparian zone (Brinson et al., 1981). The focus of many recreational uses of forests is the riparian area, partly because of the high aesthetic value of the streamside environment (Megahan and King, 1985). The SMZ is designed to maintain and enhance these valuable functions of riparian areas. However, procedures for designing and managing SMZs are not well established.

Water Quality Impacts of Silviculture

To understand the application of the SMZ, it is important to consider first the types of water quality impacts the SMZ is designed to mitigate. Silvicultural impacts on water quality have been documented and discussed by several authors (Brown, 1980; Brown, 1985; Lynch et al., 1985; Lynch and Corbett, 1990; Neary et al., 1989; Pope, 1977; Riekerk, 1982; Riekerk et al., 1989). NPS water quality problems attributed to silviculture are stream sedimentation, increased in-stream temperature, destabilization of streambanks, loss of aquatic habitat, and increased nutrient loading.

Sediment is the most significant NPS pollutant by volume in the southern United States (Neary et al., 1989). In the southern United States the water quality impacts of forestry are generally localized and relatively minor compared to agriculture (Neary et al., 1989). However, silvicultural NPS can be significant depending on when a problem occurs, the extent of occurrence, and the type of water use that is affected. Exposure of bare soil resulting from timber harvesting, site preparation, and road building is a primary source of sediment from silvicultural operations. Disturbance of the forest floor with heavy equipment during harvesting can create wheel ruts and scoured or compacted areas that serve as sources of runoff and soil erosion. Soil particles can become detached and may be transported in runoff through rills, gullies, and channels to surface waters (Brown, 1980). When streambank vegetation is removed the bank becomes unstable and prone to sloughing into the stream, which can add to sedimentation and turbidity problems.

Water quality impacts not related to sediment can also result from silvicultural activities. A change in wildlife habitat may occur when streamside vegetation is lost. Loss of streambank vegetation can also cause in-stream temperatures to increase with potentially lethal effects on aquatic organisms, especially fish species such as trout that require cool temperatures. Aquatic organisms can also be severely affected by pesticide and fertilizer applications that come in direct contact with streams or lakes.

NPS degradation of water quality can impair water uses such as drinking water supplies, aesthetic enjoyment, aquatic habitat for fish and wildlife, and recreation. Also, forests are typically headwaters areas of high quality streams depended on for a variety of downstream uses. Degradation of water quality in the headwaters may increase the cost of obtaining the benefits of high quality water used at a downstream location.

THE STREAMSIDE MANAGEMENT ZONE

The SMZ is sometimes called a buffer or filter strip. These terms reflect the primary function of the SMZ as a buffer area between upland activities that generate NPS pollutants and watercourses that require protection. Vegetation in the SMZ traps sediment and nutrients before these pollutants can reach the watercourse. Other purposes for the SMZ include stabilizing streambanks, providing shade to maintain stream temperatures, and providing habitat for wildlife.

There are many different specifications for SMZ design. Determining which specifications are appropriate depends on management objectives. The literature search conducted for this paper focused on SMZ design for maximum effectiveness in controlling sediment yield from forestry operations. No published articles on research results of SMZ design for sediment control were found. Several articles and papers were found that describe or mention SMZs as a silvicultural BMP and even provide examples of widths (Lynch et al., 1985; Lynch and Corbett, 1990; Nutter and Gaskin, 1989; Leven, 1984; Melo, 1984; Harper, 1979). But these authors do not present the criteria or quantitative data used to develop SMZ specifications. Some papers focusing on wildlife issues discuss SMZ width as a function of habitat ranges needed for different species (Wittwer, 1983; Brinson et al., 1981; Howard and Allen, 1989). Many authors state that SMZ design for silvicultural NPS control should be determined on a case-by-case basis in the field.

SMZ DESIGN CONSIDERATIONS

There appear to be three key criteria in SMZ design for controlling soil erosion and sediment yield from forestry operations: width, extent of the zone along watercourses, and management practices within the zone. Determination of these design criteria is significantly influenced by natural variability in soils, precipitation, drainage density, topography, and vegetation, and by management objectives.

Width

SMZ width for sediment control is generally based on two site characteristics: slope and soil erodibility of adjacent lands. Design width should increase as slope and erodibility increase. Width should be sufficient to stabilize streambanks and trap sediment in runoff. Trapping efficiency for sediment and nutrients within the SMZ also depends on soil infiltration properties (Nutter and Gaskin, 1989). In addition, since fine soil particles are transported in runoff farther than coarse particles (Hewlett, 1982), the width of the SMZ needed to cause deposition of fine sediment will generally be wider than for coarse sediment deposition.

Some SMZ designs consist of two zones, a primary and secondary zone. The primary zone is the area immediately adjacent to the stream or open waterbody. The secondary zone begins at the outer edge of the primary zone. SMZs always have a primary zone because of its close proximity to the watercourse. However, a secondary zone may or may not be needed depending on specific site characteristics. For example, in steeply sloped areas a secondary zone provides extended NPS control, but this may not be necessary in a flatland setting.

Extent Along Drainage Channels

Erosion of forest soils occurs in rills, gullies and channels, not as sheet flow (Brown, 1980); therefore, the protection provided to drainage channels by the extent of the SMZ along these channels can be a very important factor in SMZ effectiveness. Timber harvesting increases stream discharge and can cause intermittent streams to become perennial temporarily (Lynch et al., 1985). This suggests that the SMZ should extend along intermittent channels, and in some cases ephemeral channels, too. These are sensitive management areas. Minimal disturbance of the soil surface in ephemeral and intermittent channels, especially in wet weather, is important for sediment control. In dry weather it may be difficult to identify ephemeral channels and avoid them during timber harvest.

Management Practices

A third key criteria in SMZ design is

the type of management practices allowed within the zone. Authors generally agree that partial timber harvesting is compatible with SMZ water quality objectives. Harvesting helps to maintain a stand of healthy vegetation that will actively take-up nutrients indefinitely, thereby preventing these nutrients from reaching streams in surface runoff or shallow subsurface flow. Fail et al. (1987) and Omernik et al. (1981) suggest that a mature forest has a significantly reduced capacity for nutrient uptake. Regular harvesting of mature trees in the SMZ would be critical to maintaining active nutrient uptake by SMZ vegetation. Specific information on how many trees can be taken and still maintain maximum nutrient uptake is not available in the literature.

The primary concern with harvesting and other silvicultural practices is the potential impact on the forest floor. The percent of mineral soil exposed by different practices is a common basis for SMZ management recommendations. Megahan and King (1985) summarized the percent of area disturbed by different logging systems as follows: tractor - 35 percent; ground cable - 23 percent; skyline - 9 percent; and aerial - 5 percent. Cable retrieval of logs is recommended in the SMZ specifications of southern states. Generally, wheel and track vehicles, roads and skid trails, mechanical site preparation, log decks and sawmills are not acceptable practices within the SMZ. Natural regeneration or hand planting are recommended.

It is important to remember that the SMZ's effectiveness for sediment control can be enhanced by minimizing soil disturbance in harvesting areas outside the SMZ and following other BMPs as specified for roads and stream crossings. The SMZ is part of a system of silvicultural BMPs that reduce NPS pollution when implemented properly (Lynch et al., 1985; Lynch and Corbett, 1990).

LITERATURE SEARCH ON SMZ DESIGN METHODOLGY

An objective of this paper is to review the literature on SMZs since the work of Barker and Gregory (1983a and 1983b) and discuss advancements in the state-of-the-art of this BMP. Barker and Gregory (1983b) provided a thorough review of the existing literature on buffer/filter strips in southern forestry and noted a general lack of research studies on this topic. Results of a field study in the North Carolina Piedmont on the effectiveness of different buffer strip designs were published by Barker and Gregory (1983a).

The literature search conducted for this paper employed the Agricola database maintained by the National Agricultural Library at Beltsville, Maryland. This database includes articles from an extensive list of research periodicals including all the major forestry/forest management journals published in the United States.

In general, there is a dearth of field research on SMZ effectiveness. The literature search for this paper was by no means exhaustive, however, it appears that no recent research results are available to provide guidance in establishing SMZ criteria for the southeastern United States. The lack of published information on this topic has been cited by others. Nutter and Gaskin (1989) did not find any studies or guidelines to verify SMZ widths. Personal communication with personnel in state forestry programs indicated that actual field evaluation of various SMZ designs is lacking (J. Vowell, Florida Dept. of

Forestry, personal communication; F. Green, Georgia Dept. of Forestry, personal communication).

Economic evaluations on SMZ design are also absent from the literature. No studies were found that examined the impact of variations in SMZ width, extent along channels, and management practices in terms of costs to the landowner versus water quality benefits achieved.[1] These variables are very difficult to measure. Several factors come into play -- size of tract, value of harvestable trees within the SMZ and changes in that value with different SMZ widths and channel lengths, increased time required to complete a job due to special precautions in the SMZ, other revenue-generating activities such as hunting or fishing leases that are enhanced by the SMZ, and downstream impacts of NPS pollution that would require remediation costs if impaired by the silvicultural operation. This topic warrants far greater attention than it has received in the body of existing literature. Both the effectiveness of SMZ design and the use of various criteria in NPS control programs would benefit from research on economic factors in SMZ design and management.

Summary of Published Articles on SMZ Design Criteria

Two papers have a southeastern setting: one paper (Neuman, 1987) discussed in some detail the method used to design SMZs in Florida, another study (Swift, 1986) presented field results on buffer strips for forest roads in the southern Appalachians. Two recent field studies (Steinblums et al., 1984; Budd et al., 1987) in the Pacific Northwest discussed procedures and specific criteria for designing SMZs.

Neuman (1987) presented the site sensitivity class (SSC) index used in the state of Florida to determine SMZ total width and recommended practices. The SSC is a rating of sedimentation potential based on soil erodibility, degree of slope, and proximity to a watercourse. It can be determined from maps or field measurements. The SSC applies to the land area within 300 feet of a watercourse called the discretionary zone. Soil erodibility is determined by the Soil Conservation Service's K-factor used in the Universal Soil Loss Equation. Soil erodibility combined with percent slope gives a matrix of SSC indices as shown in Table 1.

Specific SMZ widths are given for each SSC. Florida uses a fixed primary SMZ on both sides of perennial streams and around lakes (≥ 10 acres), and a variable secondary SMZ. The primary SMZ is 35 feet wide. There is no discussion of how the primary SMZ width was established. The secondary SMZ may extend from 0 (SSC-A1) to 105 (SSC-C6) feet beyond the outer edge of the primary SMZ (Neuman, 1987).

Swift (1986) reported results from a study that compared filter strip specifications to field measurements of sediment movement from forest roads in the southern Appalachian Mountains. The specifications were those defined by Trimble and Sartz (1957)[2], generally recognized as the original work on this topic, and the USDA Forest Service (1973). Swift (1986) measured the distance sediment was transported downslope from the toe of road fill. The objective of the study was to examine the effect of brush and other blocking materials on sediment transport across the forest floor. Recommendations for determining filter strip widths were based on the sediment transport data.

Table 1. Florida's site sensitivity classes (A1 ... C6) as indicated by soil erodibility and percent slope (as shown by Neuman, 1987).

K Factor (soil erodibility)	0-2	3-7	8-12	13-17	18-22	>22
			(site sensitivity classes)			
≤ .20 (low)	A1	A2	A3	A4	A5	A6
.21-.27 (moderate)	B1	B2	B3	B4	B5	B6
≥ .28 (high)	C1	C2	C3	C4	C5	C6

Swift (1986) found that percent slope was the most important predictor of soil deposition distance and that grass, forest litter, and brush barriers can reduce the necessary width of a filter strip for forest roads. He recommended that filter strip width be based on extreme sediment flow distances and offered equations 1 and 2 as practical guidelines for determining strip width. Slope distance is the distance sediment will travel across the forest floor from the toe of road fill.

(no brush barrier)
slope distance (ft) =
43 + 1.39(slope %) (eq. 1)

(brush barrier)
slope distance (ft) =
32 + 0.40(slope %) (eq. 2)

These equations were used to generate Table 2.

Swift (1986) cautioned that the data represent only the downslope distance traveled by coarse sediment and that fine particles may be carried farther downslope. He concluded that the majority of transported sediment distances were "much less than the 210 feet specified for slight erosion hazard soils on 60% slope" (Swift, 1986). Furthermore, he noted that "all but data for the unfinished road in winter are less than Trimble and Sartz (1957) guidelines for general forest management areas, and all distances are less than their municipal watershed guidelines" (Swift, 1986). These results suggest that filter strip widths in the tradition of Trimble and Sartz (1957) have been conservative and narrower strips may not sacrifice effectiveness, especially if brush barriers are used.

Steinblums et al. (1984) studied the environmental factors that affect streamside buffer strip stability and stream shading in the Cascade Mountains of western Oregon. Buffer strip stability refers to the volume of stock remaining after losses due to blowdown, logging damage, insects, and disease. The authors did not find a significant relationship between buffer strip width and stability. Stability was a function of six topographic factors and one vegetation factor. Shading was a function of buffer strip width, original basal area of timber in the strip, slope of the clearcut adjacent to the strip, and slope of the streambank within the strip.

Table 2. Minimum filter strip width for graveled forest roads (Swift 1986).

Width of Filter Strip	0	10	20	30	40	50	60	70	80
			Percent Slope (slope distance in feet)						
no brush	43	57	71	85	99	112	126	140	154
brush	32	36	40	44	48	52	56	60	64

The reader is referred to the article for the regression equations used by the authors to predict buffer strip stability and shading. A site survey is required to obtain data for the variables used in these equations. In terms of stability, a range of values for distance to the cutting line in the direction of damaging winds may be used in the equations to determine the best .pacompromise between harvesting efficiency and buffer strip survival (Steinblums et al., 1984).

Steinblums et al. (1984) pointed out that "professional judgment" is an important aspect of buffer strip design. Application of the predictive equations used in this study for the southeastern United States is likely limited to the Blue Ridge geographic area and may require significant adjustment.

Guidelines for determining stream corridor widths were reported by Budd et al. (1987). Stream corridor is an environmental planning term used to describe the waterbody and adjacent riparian area. This article discusses stream corridor width determination in King County, Washington, where land development is increasing and, therefore, riparian area protection is a growing concern. It has limited application for use of SMZs to prevent silvicultural NPS, however, two important points made by the authors are well taken: 1) stream buffer width is a function of management objectives; and 2) a field survey of the stream system combined with an analysis of soils, vegetation, physiography, and land use is an efficient method for practical determination of stream corridor width.

Summary

A review of the recent literature on SMZs and more detailed look at the articles discussed above indicate that a generic approach to SMZ design does not exist. The absence of such an approach appears to be due to the high degree of variability encountered in riparian ecosystems and their management. Management objectives vary widely over time and for different geographic areas, forest owners, and managers. Also, results of field research are generally not transferable among geographic regions because of physical and hydrological variations between them. These considerations emphasize the need for "professional judgment" and site investigation as the basis for effective SMZ design.

STATE FORESTRY PROGRAM SMZ GUIDELINES IN THE SOUTHEASTERN U.S.

The BMP guidance manuals of seven southeastern states (Virginia, Tennessee, North Carolina, South Carolina, Alabama, Georgia, and Florida) were reviewed for their SMZ criteria. With the exception of North Carolina, all of these states have non-regulatory programs of BMP implementation on forest lands. The landowner is encouraged, but not required, to use the BMPs specified in state guidelines. Although Florida's program is non-regulatory, silvicultural BMPs are mandatory under certain situations involving the jurisdiction of local water management districts. The North Carolina program continues to rely on a non-regulatory approach to BMP implementation. However, beginning January 1, 1990, forest operations that do not comply with the nine performance standards specified in Forest Practices Guidelines Related to Water Quality (15A NCAC 1I .0101-.0209) are subject to penalties under the State Erosion and Sediment Control Law.

The SMZ criteria found in each state's BMP guidance manual are shown in Table 3. Although management objectives are fairly consistent among these states, widths and practices allowed within the SMZ vary. The primary water quality objective of the SMZ in southeastern states is to prevent sediment from polluting forest streams after timber harvest. Recommended management practices for the SMZ reflect this objective through their focus on minimizing soil disturbance in the SMZ.

State guidelines indicate that timber harvesting is compatible with water quality objectives as long as harvesting is conducted in such as way as to reduce the potential for sediment transport

by reducing the most severe source areas of sediment. Exclusion of practices that have a high potential for sediment production such as roads, skid trails, use of wheel and track vehicles, mechanical site preparation, and sawmills and log decks is recommended for the SMZ. Recommended alternative practices are cable retrieval of logs and hand planting or natural regeneration.

Only Florida and Virginia have specific recommendations for the volume of timber that can be harvested from the SMZ. None of the states specifies a frequency for harvesting within the SMZ. Florida and North Carolina specify the amount of bare ground exposure that can be left after harvesting. North Carolina and Tennessee state a minimum percent of pre-harvest canopy that must be left to provide stream shade.

Recommended SMZ widths are quite variable. Alabama has no specific recommendation and leaves this decision up to the manager. The other six states have specific recommendations for width based largely on slope. Florida, Georgia, and South Carolina recommend a primary and secondary SMZ. The secondary SMZ provides extra protection on steep slopes and/or for more erodible soils. Some management practices that are not recommended for the primary SMZ may be allowed in the secondary SMZ. For example, Florida's guidelines state that complete timber harvest may be appropriate for the secondary SMZ.

The SMZ widths shown in Table 3 raise questions about what is appropriate for a minimum width. In the lower coastal plain of Georgia, a minimum primary SMZ of 20 feet is recommended. The minimum primary SMZ width for South Carolina's forest wetlands areas of less than 5 percent slope is 40 feet, and in North Carolina the minimum is 50 feet for slopes less than 5 percent.

There are also differences among these states on the extent of the SMZ along drainages. Only three states (Florida, Georgia, and North Carolina) recommend the SMZ for use along both perennial and intermittent streams. North Carolina is the only state that provides a recommendation for extra precaution in the areas

Table 3. Streamside Management Zone Guidelines for Seven Southeastern States.

ALABAMA

Sources: Alabama Forestry Commission. Alabama's Handbook of Water Quality Best Management Practices for Silviculture, 1989. / Water Quality Management Guidelines and Best Management Practices for Alabama Wetlands, 1989

WATER QUALITY OBJECTIVE	SMZ WIDTH AND EXTENT	MANAGEMENT PRACTICES
- protect streambanks and beds - protect against sediment production	- varies by on-site evaluation of slope adjacent, soil erodibility, precipitation, knowledge of area, sensitivity of stream - width may vary as these factors change along a stream - perennial streams	Recommended: - timber removal by "the method which causes the least damage, consistent with the equipment reasonably available to the logger" - site preparation that minimizes disturbance - avoid roads - roads and landings outside the SMZ - avoid felling trees in streams

FLORIDA

Source: Florida Division of Forestry. Silviculture Best Management Practices Manual. 1989.

WATER QUALITY OBJECTIVE	SMZ WIDTH AND EXTENT	MANAGEMENT PRACTICES
- protect water from excessive sediment, nutrients, logging debris, forest chemicals, and temperature fluctuations	- fixed primary of 35 ft. on perennial streams and lakes > 10 acres - variable secondary 0-105 ft. depending on site sensitivity class (intermittent streams should be included in secondary SMZ) - perennial and intermittent streams and lakes ≥ 10 acres	Primary Zone - harvesting that leaves a volume ≥ 1/2 the volume of a fully stocked stand (average dbh should be residual volume) Secondary Zone - complete timber harvest Both Zones Recommended: - direct seeding, hand planting, or machine planting on contour - prescribed burn except on slopes ≥ 18% - basal application of herbicides and insecticides (continued on next page) Not Recommended: - mechanical site preparation - fertilization - aerial application or mist blowing of herbicides and insecticides - loading decks/landings/log bunching points - access roads (except when leading directly to a stream crossing) - firelines (except for emergency only)

Table 3. Streamside Management Zone Guidelines for Seven Southeastern States (continued).

GEORGIA Source: Georgia Forestry Commission. Recommended Best Management Practices for Forestry in Georgia. 1988.

WATER QUALITY OBJECTIVE	SMZ WIDTH & EXTENT	MANAGEMENT PRACTICES
- protect streams from NPS pollution	Primary / Secondary (feet) Lower Coastal Plain: 20 / 0 Upper Coastal Plain: 40 / 40* *excluding bottomlands Piedmont & Mountains: 80 / 80 • perennial and intermittent streams, and ponds and lakes	Primary Zone Recommended: • any type of cutting (including clearcutting except in mts. if it affects trout waters) • cable retrieval of logs • hand planting and direct seeding Not Recommended: • wheel or track vehicles • slash in water • roads/trails unless absolutely necessary • fire • mechanical site preparation/machine planting • sawmill and log deck locations • aerial spraying of pesticides or herbicides Secondary Zone Recommended: • any cutting including clearcutting • careful use of wheel and track vehicles • roller chopping • fire • any type of planting that does not remove forest floor or expose mineral soil Not Recommended: • roads or trails unless absolutely necessary • sawmills and log decks • harrowing, root raking, or bulldozing • gully leveling (unless immediately seeded and mulched) • slash in water

NORTH CAROLINA

Source: North Carolina Div. of Forest Resources. Forestry Best Management Practices Manual. 1989.

WATER QUALITY OBJECTIVE	SMZ WIDTH AND EXTENT	MANAGEMENT PRACTICES
• protect streams from sedimentation • provide shade and buffer from fertilizer and pesticide applications	• 50 ft. minimum on each side of perennial and intermittent streams, and perennial waterbodies for all slope classes • 50 (0-5% slope) to 125 ft. (>46% slope) for perennial trout streams • width must always be adequate for sediment control • manager may "expand or contract the distances yet fully protect the stream channel and water quality"	Recommended: limited cutting • logs removed by cable • max. 20% bare ground exposure along perennial streams • max. 40% bare ground exposure along intermittent streams • leave crown cover to provide min. 75% of pre-harvest shade • careful application of fertilizer and pesticide Not Recommended: • wheel or track vehicles within zone of ephemeral intersection with intermittent or perennial stream • high intensity, broadcast burning • sawmill or log deck locations • chemical or fuel storage or resupply areas

Table 3. Streamside Management Zone Guidelines for Seven Southeastern States (continued).

SOUTH CAROLINA

Source: South Carolina Forestry Commission. Best Management Practices for South Carolina's Forest Wetlands. 1989.

WATER QUALITY OBJECTIVE	SMZ WIDTH AND EXTENT	MANAGEMENT PRACTICES
· protect bank edges and water quality	Primary Zone % Slope / Width (ft) < 5 — 40 5-20 — 40 > 20 — 80 Secondary Zone % Slope / Width (ft) < 5 — 0 5-20 — 40 > 20 — 80 · navigable streams listed on the state water resources navigable streams inventory (identified as well defined banks and channels)	Primary Zone Recommended: · selective cutting · cable retrieval of logs · hand planting or direct seeding Not Recommended: · wheel or track vehicles · slash in stream · mechanical site preparation · sawmills or log decks Secondary Zone Recommended: · any harvest cuts · site preparation that does not significantly disturb soil · prescribed fire · hand or machine planting or direct seeding Not Recommended: · sawmills or log decks · gully leveling (unless immediately seeded and ditched) · site preparation that significantly disturbs soil

VIRGINIA

Source: Virginia Dept. of Forestry. Forestry Best Management Practices for Water Quality in Virginia. 1989.

WATER QUALITY OBJECTIVE	SMZ WIDTH AND EXTENT	MANAGEMENT PRACTICES
· filter sediment from overland flow · maintain stream temperature	· 50 ft. on both sides of perennial streams and open waters (lakes, ponds, springs, reservoirs) Use / % Slope / Width (ft.) trout (cold water fishery): 0-10 — 66; 11-20 — 75; 21-45 — 100; >45 — 125 warm water fishery & all others (incl. wetlands): 0-10 — 50; 11-20 — 50; 21-45 — 50; >45 — 50 municipal water supplies: 0-10 — 100; 11-20 — 150; 21-45 — 150; >45 — 200	Recommended: · partial harvesting · dispersed skidding, cable and winch retrieval · leave forest floor undisturbed (do not break through organic litter layer to expose mineral soil) · leave min. 50% crown cover or 50 ft.² basal area per acre evenly distributed (may desire to leave up to 80% crown cover for trout streams) · access roads, if necessary, may cross at right angles to stream (drainage structures should be installed on roads prior to their entry into the SMZ) Not Recommended: · sawmills or log deck locations · slash in streams

Table 3. Streamside Management Zone Guidelines for Seven Southeastern States (continued).

TENNESSEE

Source: Tennessee Dept. of Conservation, Div. of Forestry. Best Management Practices for Silvicultural and Other Forest Activities in Tennessee. 1989.

WATER QUALITY OBJECTIVE	SMZ WIDTH AND EXTENT		MANAGEMENT PRACTICES
• protect stream channels and banks from disturbance	% Slope	Width (ft.)	Recommended:
• trap sediment and other eroded material	0	25	timber harvest
	10	45	• minimal soil disturbance
	20	65	• leave 50-75% of crown canopy for shade
	30	85	• winching or animal skidding of logs
	40	105	• keep slash out of streams natural regeneration (can lop undesirable species with chainsaw)
	50	125	
	60	145	
	• perennial streams		Not Recommended:
			• wheel or track vehicles
			• mechanical site preparation

where ephemeral streams intersect with perennial or intermittent streams. Use of wheel or track vehicles is not recommended for this area (North Carolina Division of Forest Resources, 1989).

Assessment of SMZ compliance and effectiveness in these state programs is not well documented. At least one state, Florida, conducts a regular BMP monitoring program consisting of site visits once every two years to determine compliance with the state guidelines. The data are qualitative. According to personnel with the program, where the SMZ criteria are applied there have been no water quality problems, but where problems do exist the lack of an SMZ is often a major factor (J. Vowell, Florida Dept. of Forestry, 1990, personal communication). A BMP compliance survey is planned for June 1990 in the state of Georgia (F. Green, Georgia Dept. of Forestry, personal communication). Virginia's Dept. of Forestry is also implementing a plan to evaluate silvicultural BMPs that will include site compliance checks and intensive watershed monitoring studies (S. Austin, Southern Forest Hydrology Work Group, Riparian Areas Workshop, Oct.31-Nov. 2, 1989, Asheville, NC).

Changes in the State-of-the-Art Since 1983

Barker and Gregory (1983b) reviewed the buffer strip criteria in 208 plans of eight southern states (Alabama, Florida, Georgia, North Carolina, Oklahoma, South Carolina, Texas, Virginia). Of those states in common with this paper, only North Carolina, South Carolina, and Virginia have changed their SMZ criteria. North Carolina previously recommended the SMZ widths proposed by Trimble and Sartz (1957) (see footnote page 9), but has since established a single width value of 50 feet that is wider than the previous minimum width but narrower than previously allowed on steeper slopes. North Carolina has also developed different widths for trout streams. South Carolina now makes recommendations for specific primary and secondary SMZ widths. Virginia has changed its recommendations for SMZ width to values based on slope and water uses.

Review of the recent literature leads to the conclusion that there have been few advances in the state-of-the-art of SMZ design for silvicultural NPS control during the last seven years. Much valuable information has probably been gained from the practical experience of implementing the SMZ criteria that were initially developed as part of the state 208 plans. Unfortunately, little of this information is available in published documents. Analysis and publication of silvicultural BMP assessment surveys, such as those conducted in Florida and planned in Georgia and Virginia should significantly add to the current knowledge of SMZ practicability and effectiveness as a tool for water quality protection.

CONCLUSION

The proper basis for any pollution control program that seeks to regulate land management or change the behavior of land owners and managers is sound scientific research on the water quality problem, its causes, and appropriate mitigation techniques. In light of the considerations discussed in this paper, it seems that procedures for SMZ design are on solid footing based on years of practical experience, but much quantitative work needs to be done to understand better the ecological role of the SMZ, the effectiveness of different SMZ designs as pollution control practices, and the economic tradeoffs associated with use of SMZs to control silvicultural NPS.

There is a critical need for field studies of SMZ effectiveness complete with water quality monitoring similar to the study attempted by Barker and Gregory (1983a). The objective should not be to establish a table of SMZ widths for broad applications but to understand better the variations in water quality protection afforded by different SMZ designs so that this information can be passed on with confidence to forest land owners and managers.

NOTES

[1] Since this paper was completed a report by the USDA Forest Service on the economics of silvicultural BMPs has been identified. The report includes analysis procedures for estimating the economic benefits of soil and water resource management. The citation for this report is: Dissmeyer, G.E., et al., 1987. Soil and Water Resource Management: A Cost or a Benefit? Approaches to Watershed Economics Through Example. Vol. 1 and 2. USDA Forest Service, Watershed and Air Management Staff, Washington, DC.

[2] Trimble and Sartz (1957) recommended a starting filter strip width of 25 feet on level land with an increase of 2 feet for each 1 percent increase in slope. They recommended doubling these values for municipal watersheds.

LITERATURE CITED

Alabama Forestry Commission. Alabama's Handbook of Water Quality Best Management Practices for Silviculture. 1989.

Alabama Forestry Commission. Water Quality Management Guidelines and Best Management Practices for Alabama Wetlands. 1989.

Barker, S.E., and J.D. Gregory. 1983a. Effects of streamside buffer-zone configuration on sedimentation. Research Notes Series, 1983, No. 17. Small Woodlot Forestry R & D Program, North Carolina State University, Raleigh, NC.

Barker, S.E., and J.D. Gregory. 1983b. Buffer strips in southern forestry: A perspective. Research Notes Series, 1983, No. 18. Small Woodlot Forestry R & D Program, North Carolina State University, Raleigh.

Brinson, M.M., B.L. Swift, R.C. Plantico, and J.S. Barclay. Riparian Ecosystems: Their Ecology and Status. FWS/OBS-81/17. Eastern Energy and Land Use Team, National Water Resources Analysis Group, U.S. Fish and Wildlife Service, Kearneysville, WV. 1981.

Brown, G.W. Controlling nonpoint source pollution from silvicultural operations: what we know and don't know. In Perspectives on Nonpoint Source Pollution. EPA 440/5-85-001. Proceedings of a National Conference, Kansas City, Missouri, May 19-22, 1985. U.S. Environmental Protection Agency, Washington, DC. 1985. p.332-333.

Brown, G.W. Forestry and Water Quality. Oregon State University Book Stores, Inc., Corvallis, OR. 1980.

Budd, W.W., P.L. Cohen, P.R. Saunders, and F.R. Steiner. 1987. Stream corridor management in the Pacific Northwest: I. Determination of stream-corridor widths. Environmental Management, 11(5):587-597.

Fail, Jr., J.L., B.L. Haines, and R.L. Todd. 1987. Riparian forest communities and their role in nutrient conservation in an agricultural watershed. American J. of Alternative Agriculture, 2(3):114-121.

Florida Division of Forestry. Silviculture Best Management Practices Manual. 1989.

Georgia Forestry Commission. Recommended Best Management Practices for Forestry in Georgia. 1988.

Hewlett, J.D. Pinciples of Forest Hydrology. The University of Georgia Press, Athens, GA. 1982.

Howard, R.J., and J.A. Allen. Streamside habitats in southern forested wetlands: their role and implications for management. In Proceedings of the symposium: The forested wetlands of the Southern United States; 1988 July 12-14; Orlando, FL. General Technical Report SE-50. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 1989.

Leven, A.A. Riparian area management in the Pacific southwest region of the Forest Service. In California Riparian Systems: Ecology, Conservation, and Productive Management. Eds., R.E. Warner and K.M. Hendrix. University of California Press, Berkeley, CA. 1984. p.800-807.

Lynch, J.A., E.S. Corbett, and K. Mussallem. 1985. Best management practices for controlling nonpoint-source pollution on forested watersheds. J. Soil and Water Conservation, 40(1):164-167.

Lynch, J.A., and E.S. Corbett. 1990. Evaluation of best management practices for controlling nonpoint pollution from silvicultural operations. Water Resources Bulletin, 26(1):41-52.

Megahan, W.F., and P.N. King. 1985. Identification of critical areas on forest lands for control of nonpoint sources of pollution. Environmental Management, 9(1):7-18.

Melo, J.L. Timber operations along California streams. In California Riparian Systems: Ecology, Conservation, and Productive Management. Eds., R.E. Warner and K.M. Hendrix. University of California Press, Berkeley, CA. 1984.

Neary, D.G., W.T. Swank, and H. Riekerk. An overview of nonpoint source pollution in the southern United States. In Proceedings of the symposium: The forested wetlands of the Southern United States; 1988 July 12-14; Orlando, FL. General Technical Report SE-50. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 1989.

Neuman, L. Silviculture and best management practices. In Erosion Control: You're Gambling Without It. Proceedings of Conference XVIII International Erosion Control Association, February 26-27, 1987, Reno, NV. The Association, Pinole, CA. 1987. p.145-155.

North Carolina Division of Forest Resources, Department of Environment, Health, and Natural Resources. Forestry Best Management Practices Manual. 1989.

Nutter, W.L., and J.W. Gaskin. Role of streamside management zones in controllings discharges to wetlands. In Proceedings of the symposium: The forested wetlands of the Southern United States; 1988 July 12-14; Orlando, FL. General Technical Report SE-50. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 1989.

Omernik, J.M., A.R. Abernathy, and L.M. Male. 1981. Stream nutrient levels and proximity of agricultural and forest land to streams: some relationships. J. Soil and Water Conservation, July-August 1981:227-231.

Pope, P.E. Water Quality and Forestry: A Review of Water Quality Legislation and the Impact of Forestry Practices on Water Quality. Station Bulletin No. 161. Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN. 1977.

Riekerk, H., and D.K. Winter. Forest management principles in Florida. In Environmentally Sound Water and Soil Management. Eds., E.G. Kruse, C.R. Burdick, Y.A. Yousef. Proceedings of the Specialty Conference on Environmentally Sound Water and Soil Management, Orlando, FL, July 20-23, 1982. American Society of Civil Engineers, New York, NY. 1982.

Riekerk, H., D.G. Neary, and W.T. Swank. The magnitude of upland silviculture nonpoint source pollution in the south. In Proceedings of the symposium: The forested wetlands of the Southern United States; 1988 July 12-14; Orlando, FL. General Technical Report SE-50. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 1989.

South Carolina Forestry Commission. Best Management Practices for South Carolina's Forest Wetlands. 1989.

Steinblums, I.J., H.A. Froehlich, and J.K. Lyons. 1984. Designing stable buffer strips for stream protection. J. Forestry, Jan. 1984.

Swift, Jr., L.W. 1986. Filter strip widths for forest roads in the southern Appalachians. Southern J. of Applied Forestry, 10(1986):27-34.

Tennessee Department of Conservation, Division of Forestry. Best Management Practices for Silvicultural and Other Forest Activities in Tennessee. 1989.

Trimble, Jr., G.R., and R.S. Sartz. 1957. How far from a stream should a logging road be located? J. Forestry, 55(5):339-341.

USDA Forest Service. 1973. Guide for Managing the National Forests in the Appalachians. 2d. ed. Eastern and Southern Regions. FSH 2123. 37p.

Virginia Department of Forestry. Forestry Best Management Practices for Water Quality in Virginia. 1989.

Wittwer, R.F., ed. Proceedings of a Conference: Creating Good Wildlife Habitat Through Forest Management and Conservation. August 11-12, 1983, Oklahoma City, Oklahoma. Division of Agriculture, Oklahoma State University, Stillwater, OK.

The Impact of Environmental Constraints on Harvesting in the Marlborough Sounds Region of New Zealand.

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Abstract

The effect of increasing levels of environmental constraint on five variables - net revenue, logging costs, total costs, total sediment yield, and fine sediment yield - were examined.

Key words: Sediment yield, Enviromental impact, Costs, Plantation logging

Introduction

The Marlborough Sounds were formed about 6500 years ago at the end of the last glacial period when the sea level rose, drowning river valleys. Almost 90% of the catchment has slopes exceeding 20 degrees. A 1985 Marlborough Catchment and Regional Water Board survey showed that plantation forests occupy about 20,000 hectares in the Sounds. More than 95% of the plantations consist of Pinus radiata planted since 1974. Most of the plantings are sited on slopes over 25 degrees. The slope soils have high clay content, low aggregate stability, and are susceptible to erosion and flowage during heavy storms. Intense rainstorms producing more than 100mm in 12-18 hours appear to occur about once every 2 to 3 years.

The waters of the Marlborough Sounds are intensively used by salmon and mussel marine farmers, pleasure boaters, and tourists.

Although forestry occupies a small proportion of the Sound's land-base it has been sited as an activity which can cause major disturbances of the land surface and a significant localised impact of land-derived sediment on Sounds water quality. Roading and tree harvesting have been specifically identified.

The environmental impacts of harvesting and restrictions to harvesting practices may be the most important factors affecting the profitability of forestry in the Marlborough Sounds. Concerned about these possible impacts, seven industry groups, including forest companies, forest associations, environmental agencies, and research organisations, initiated a project to provide a much better data-base for decision-making.

Computer-aided planning

In order to demonstrate the economic and environmental impact of increasing harvesting constraints a computer-aided paper planning approach was used to model timber-related

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activities. This research method has been effectively used in the past to address environmental issues (Sauder and Nagy, 1977; Opie and Thomson, 1978; Reutebuch and Murphy, 1985; Olsen et al., 1987).

Five levels of constraint were modelled on three forest blocks controlled by three different landowners. The three blocks were selected to cover a range of harvesting conditions and to allow replication for statistical analysis purposes. To protect the interests of the landowners the blocks have been given alphabetic codes. It was assumed that harvesting of all blocks began when the trees were thirty years old.

Block A	109 ha
Block B	450 ha
Block C	300 ha

The five levels of constraint ranged from current common practice (Level 1) to examples of those imposed on some forests in North America (Level 5).

Level 1. No restriction on roading. Large landings allowed. Highlead cable logging or skidders/tractors used.

Level 2. No restriction on roading. Large landings allowed. No ground-based systems on sensitive soils. Partial suspension required for cable systems.

Level 3. Ridge top roading where possible. No new coastal roads. Large landings allowed. Partial suspension.

Level 4. Ridge top roading. No valley or new coastal roads. Partial suspension. Large landings allowed. Minimise visual impact of roads and landings.

Level 5. Ridge top roading. No landings. Full suspension of logs. Patch cutting (< 10ha) required.

Harvesting and transportation requirements were determined for each constraint level for each of the three study areas. Extensive use of the F.R.I. CABLE HAULER PLANNING PACKAGE was made to produce the 15 harvest plans required. The forest owners and environmental agencies were then given the opportunity to review the paper plans and suggest modifications before economic and environmental impacts were determined.

For each harvesting system used, production levels, costs, and revenues were modelled using standard procedures developed by the F.R.I. Harvest Planning group and may not reflect actual values for individual forest owners. They are, however, based on the best information available and serve well for comparative purposes. A spreadsheet model (SCHEDULE) was developed to carry out the production and economic analyses for each of the plans.

Environmental impacts are quantified in terms of two variables - fine and total sediment yields derived from new roads, upgrading existing roads and contour tracking. The estimated sediment yields are based on research experiments located in one of the three study areas by the F.R.I. Forest Land-use Impacts group (unpublished data).

Results

1. Harvesting systems

The logging systems required to harvest each of the study areas was considerably different for each of the restriction levels. Table 1 shows the changes in landings, roads, and contour tracks for the three areas combined.

Table 1. Harvesting systems

Variable	Restriction level 1	2	3	4	5
Landings	163	88	60	40	0
New roads (km)	36	24	18	11	11
Upgraded roads (km)	16	14	12	9	8
Contour tracks (km)	47	17	0	0	0

The logging equipment mix that was used for each of the restriction levels is shown in Table 2.

Table 2. Equipment Mix

Restr-iction Level	Forest Block A	B	C
1	C,W	C,W	C,W
2	C,M	C,M	C,M
3	T	M,T	M,T
4	T	T,H	M,T,G,H
5	M,H	T,H	M,T,G,H

C = Caterpillar 528 **
W = Wilson 2.8W highlead
M = Madill 071 slackline
T = Thunderbird TY90 slackline
G = Gantner "European" long-span system
H = Boeing Vertol 107 helicopter.
(** Note: Use of product names does not imply endorsement).

2. Revenue

An average sale revenue of NZ$55 per cubic metre for logs delivered to a common sale point was assumed. This was reduced by $5 per cubic metre if logs had to be bucked at the stump due to poorer log-making. A "net" revenue value on a per hectare basis was calculated by subtracting logging, roading, landing construction, and transport-to-forest-edge costs. Forest establishment, tending, management, and transport costs from forest edge to sale point were not subtracted.

Table 3. shows the mean "net" revenue figures for each restriction level. A Fisher's Protected Least Significant Difference (FPLSD) test was used to determine statistically significant differences in restriction level means at the 95% level. Those means with different lower case letters under them are significantly different.

Net revenue could be expected to decrease sustantially (ca. 40%) if harvesting restrictions were increased from Level 1 (status quo) to Level 2. A 60% reduction in net revenue would be expected for Level 5 restrictions.

Table 3. Average results for economic and environmental variables

Variable	Restriction level				
	1	2	3	4	5
Net revenue ($1000/ha)	14.6 a	8.5 b	8.1 b,c	7.5 c	5.4 d
Logging costs ($1000/ha)	7.4 a	13.8 b	14.7 c	15.3 c	18.4 d
Total costs ($1000/ha)	9.8 a	16.0 b	16.3 b	16.8 b	20.2 c
Total sediment yield (t/ha/yr)	4.9 a	2.9 b	2.2 c	1.8 c	1.8 c
Fine sediment yield (t/ha/yr)	0.5 a	0.2 b	0.1 c	0.1 c	0.1 c

3. Logging Costs

Logging costs include all costs from felling to loading on truck. Table 3 shows the increases in logging costs. Logging costs were 85 to 150% greater for higher restriction levels than for the status quo (Level 1). The majority of the cost increase was incurred in moving from Level 1 to Level 2 restrictions.

4. Total Costs

Logging costs alone, although a large component, do not account for all the costs incurred in harvesting each of the study areas. Roading, contour tracking, landing construction, truck to the forest edge, and other minor costs are also incurred.

Figure 1. and Table 3. show the changes that occur in total costs as restriction levels increase. Total costs were significantly higher (60 to 105%) for restriction levels 2 to 5 than for restriction level 1. Although some savings were made in reduced earthmoving and construction costs they were not enough to overcome the substantial increases in logging costs.

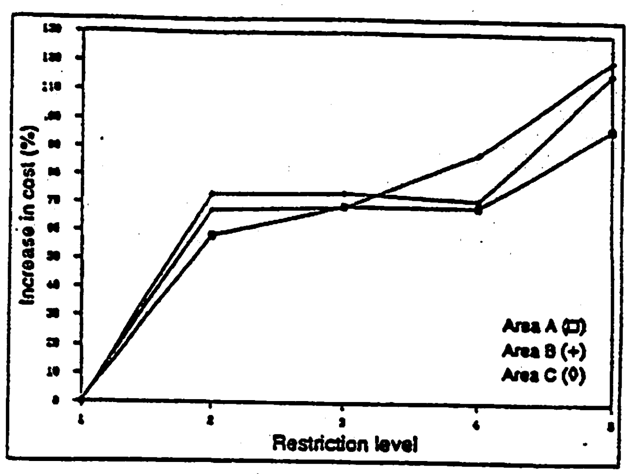

Figure 1. Total cost increases for each area as a percentage based on Level 1.

5. Total sediment yield

The total sediment yield from existing tracks, new road construction, contour tracking, and upgrading existing roads has been calculated for each restriction level on each of the three study blocks. The calculated figure does not include sediment from landslide sources which is more difficult to predict. Nor is it an estimate of the input to the Sounds marine environment near the study areas.

Level 1. restriction gives an additional 5 tonnes per hectare per year sediment over an estimated background rate of 6 tonnes per hectare per year. An increase of this magnitude, however, may only be sustained for a year or so, after which a gradual return to pre-logging levels could be expected.

Total sediment yields (Table 3.) could be expected to halve compared with the status quo (Level 1) if higher restriction levels were imposed. Most of the reduction in total sediment yield, however, occurs between restriction levels 1 and 2.

6. Fine sediment yields

Sediment in the silt and clay range has the potential to be particularly damaging to aquatic life it it enters adjacent marine embayments in large quantities. Fine sediment yields could be expected to drop substantially (ca. 200 to 500%) for the higher restriction levels compared with level 1 (Table 3) - from 0.5 to 0.1 tonnes per hectare per year.

Conclusions

Increasing levels of environmental restriction on harvesting practices in the Marlborough Sounds region of New Zealand will alter the logging equipment mix and skill requirements, the economics of forestry, and the environmental impacts incurred.

The major changes to harvesting economics and sediment yields result from small changes in restriction from Level 1 to Level 2 or 3. These are basically a move from ground-based systems or simple cable logging systems to more complex skyline systems.

This study has provided a useful data-base for informed decision-making and has allowed the forest industry and environmental agencies to focus on directions for future research needs and action.

References

Olsen, E.D., Keough, D.S., La Course, D.K. 1987. Economic impact of proposed Oregon Forest Practices Rules on industrial forest lands in the Oregon Coast Range: A case study. Oregon State University, Forest Research Laboratory, Research Bulletin 61. 15pp.

Opie, J.E., Thomson, I.S. 1978. Costs associated with constraints on harvesting Eucalypt forests. Aust. For. 41(4):232-247.

Reutebuch, S.E., Murphy, G.E. 1985. Using a computer-aided planning package to assess the impact of environmental restrictions on harvesting systems. In Proceedings of a Council on Forest Engineering seminar on "Forest Operations in Politically and Environmentally Sensitive Areas" held at Tahoe City, California, August 1985. p16-25.

Sauder, B.J., Nagy, M.M. 1977. Coast logging: highlead versus long-reach alternatives. Forest Engineering Research Institute of Canada. Technical Report No. TR-19. 51p.

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