HIGH TECHNOLOGY IN FOREST ENGINEERING

Proceedings of the
COUNCIL ON FOREST ENGINEERING
10th Annual Meeting

COFE

August 3 to August 6, 1987
Syracuse, New York

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PREFACE

The Council on Forest Engineering (COFE) was formed in 1978 and is headquartered in Corvallis, Oregon. The basic objectives of COFE are to foster the development of forest engineering in industry, government, and in university teaching, research, and extension programs in order to promote the best methods of managing and operating forests, both private and public; to service the Council and its members in such matters; to serve the forestry profession on matters of policy in the area of forest engineering and to disseminate technical information in forest engineering subjects.

COFE membership is open to anyone with an interest in the above objectives. Members receive a quarterly newsletter and a membership directory.

Each year the activities of COFE are highlighted by an annual meeting which serves to bring the members to focus on a timely theme. "High Technology in Forest Engineering" was the 1987 meeting theme and engineers and scientists from 21 states, Canada, Finland and Ireland gathered in Syracuse, New York, to focus on the current and future impacts of high technology on forest engineering.

Special thanks go to the staff and my colleagues at SUNY College of Environmental Science and Forestry for their time and efforts in the planning and conduct of the 1987 COFE meeting. The dedicated efforts throughout the 1987 year of Joyce Carpenter at SUNY-ESF, Forest Engineering and Sylvia Aulerich in the COFE headquarters in Corvallis, Oregon, are acknowledged and deeply appreciated. The primary recognition and thanks are given to the authors of the papers in these proceedings and to their organizations that have supported the 1987 COFE activities.

The enclosed proceedings are available for $25 from the Office of Continuing Education, SUNY-ESF, Syracuse, New York 13210. Make checks payable to SUNY Research Foundation.

Robert Brock, *Chairman*
COFE 1987

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REPORT FROM THE WEST

by

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Logging Activity

All the western states I surveyed reported a high level of activity in the wood products sector. Harvest levels in the past twelve months were at record or near record highs. Loggers are busy and some new contractors are getting into the business. Some areas lament that log prices are not as strong as they could be. Recent declines in housing starts have not yet dampened the high seasonal activity. Two years of high production levels have given a measure of stability and cautious optimism to western loggers.

Timber Supply Issues and Ecotage

United States Forest Service National Forest plans are in various stages of review and comment; however, the court system is the ultimate decision arena unless Congressional action is somehow involved. Roadless areas in the Intermountain region, a proposed National Park in southern Oregon, and various local controversies are pitting industrial supporters against a variety of local and national organizations.

At the mills and logging sites, the confrontations are becoming violent and ugly. Earth First! (a preservation organization) has been identified for its detailed instructions on how to sabotage (ecotage) milling and harvesting operations. In California a 23 year old worker nearly lost his life (and suffered severe disfiguration) when a band saw hit an eleven inch spike and metal shrapnel was sent flying. In the same general area, decapitated dogs have been left on logging and roadbuilding operator's controls as a warning. In retaliation for a spiking incident, a tree-sitter in southern Oregon woke up to the sound of an undercut being put in the tree he was "protecting." The tree-sitter climbed down later in the morning before the wind blew any stronger. Additional violent actions by both sides are expected.

Riparian Areas and Cummulative Effects

Whenever protectionists can make a new term a household word (through using the media), new regulations are bound to follow. "Riparian" areas and "Cumulative" effects are two such words. Oregon and Washington's Forest Practice Rules covering private land were recently stiffened with new and costly requirements (California was already stiff). Pressures are evident in other states. Agencies are already operating under tight constraints. In some cases where scientific information exists, it has been badly over extended and misused. Some "models" are driving major land management decisions without scientific "cause and effect" relationships established or without ever being validated in an acceptable fashion.

Industry Structure, Labor Force, and Mechanization

The trend toward mid-size contractors continues in the western states as large timberland move away from their own logging crews. Notable exceptions are those companies making effective use of incentive systems to capture productivity gains. As new contractors and new employees enter the logging business, especially in cutting, the safety record in logging worsens. Worker Compensation rates run from a low of $20 per $100 of payroll to $86 per $100 of payroll. Oregon is at $38 with firms + 20% of that figure. Training is becoming a high priority but schemes to reduce the high insurance and accident rates are having difficulty getting started. They include legislative reforms, training efforts and safety incentive programs. Much more work needs to be done in this area.

Optimal bucking technology is being developed to aid log manufacturers at the stump. Mechanization continues as localized areas are seeing more steep slope feller-bunchers, slide-boom delimbers, and long distance forwarders. Chain flail debarkers are appearing in some areas as are tree processors. Some organizations are trying thinnings again as log prices permit (including cable thinning). There is some concentration of yarder manufacturers as two firms were bought out by other yarder manufacturers.

Professional Education

Enrollments throughout Forestry are at record lows. Forest engineering programs in the west are part of this trend. In some programs only 2 or 3 students graduated this past spring. All schools believed they were at the bottom of the cycle and were actively recruiting students. None of the programs I contacted were in jeopardy of dissolution. A major topic for discussion at this meeting might be recruiting efforts by association members.

Summer and other short term job opportunities were at a high level with 2 or more jobs per student. Permanent hiring was reported slower as firms and agencies have not begun major hiring efforts after previous downsizing. With low enrollment and high demand for forest engineering skills, it is possible that forest engineering needs will go unmet in the near term.

As a profession, forest engineering is emerging from the recent hard times into an era where promotional activities are needed in two places. Employers must recognize potential contributions of forest engineers and incoming students must recognize potential career opportunities. In our profession, we cannot ignore the market or the regeneration process for either timber or our students.

STATUS OF THE LAKE STATES FORESTS

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Abstract: The current status and future outlook for the Lake States forests are very good. The annual growth of timber in the region is currently double the harvest, and forest industry is expanding to take advantage of this resource. State and local governments are encouraging the forest sector with incentive programs that are beginning to pay off in terms of jobs and capital investment.

Keywords: timber, forest industry, research, harvesting

The forests of the Lake States have recently assumed a much greater role in the economy of the region. The recession of the early 1980's was especially hard on the Lake States of Michigan, Minnesota, and Wisconsin due to their heavy reliance on the automotive and mining industries, which did not fare well during this time. The States then turned their attention back to the extensive, but somewhat forgotten, timber resources in the region. State governments began aggressively promoting forest development, offering seed money and providing business incentives for new industry and mill expansions.

In Michigan, a goal of 50,000 new jobs was set for the forest industry sector. A training program was initiated to provide leadership skills for managers in the forest industry. In Minnesota, this thrust led to the creation of the Natural Resources Research Institute (NRRI) at the University of Minnesota in Duluth. Its mission is to promote employment in Minnesota by developing the State's resources in an environmentally sound manner.

All three upper Great Lake States have supported cooperative efforts to improve management and to promote wise use of forest land. This commitment is exemplified by the recent "Upper Great Lakes Governors' Conference on Forestry," where government and industry leaders gathered to discuss ways to encourage further forest industry development in the region. These efforts will undoubtedly continue and will have a profound effect on the future of the Lake States forests.

The purpose of this paper is to provide an update of the Lake States Regional Report presented at the 1986 COFE meeting (Sturos, 1987). The status of the resource, logging, forest industry, and research in the Lake States will be discussed.

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[1]Presented at the 10th Annual Council on Forest Engineering Meeting, Syracuse, NY, August 3-6, 1987.

[2]Associate Engineer and Principal Mechanical Engineer, respectively.

TIMBER

Michigan, Wisconsin, and Minnesota comprise about 122 million acres of land, of which 46 million acres (37 percent) are classified as commercial forest land. Nearly 40 percent of this commercial forest land is owned by Federal, State, and County governments. Another 50 percent is owned by private, nonindustrial landowners.

This ownership pattern makes the region's timber supply especially sensitive to public attitudes concerning preferred uses of the forests. Although the grass roots environmental movement in the region has not become as militant as in the West, there is increasing pressure to set aside more land for nontimber uses. Fortunately, the State governments have adopted an aggressive approach to encourage development of the region's forest industry.

Nearly three-quarters of the 46 billion cubic feet of growing-stock volume in the Lake States is hardwoods. A large portion of this volume is low-grade aspen, maple, and birch. Utilization of this material has been poor in the past but it is improving as new markets are developed and mill quality standards are lowered. There is still much room for improvement, however. The annual volume growth in the region is currently double the harvest. This underutilized resource represents a good opportunity for the pulp and paper, waferboard, and energy producing industries that can make the best use of this material.

In many areas of the Midwest, forest products companies rely heavily on national forests for a continuing supply of wood. Therefore, the status of the mandated national forest plans is of particular interest to these firms. All plans in the Lake States have been completed, but several are being appealed by special interest groups. Many of the conflicts between environmental and industrial concerns are still being debated; however, there are indications that these will be settled through negotiation. All parties are taking a positive approach to the discussions, showing that special interest groups and federal managers can work together to settle disputes involving competing uses of national forest lands.

Several insect and disease problems are increasing in the Lake States (U.S. Department of Agriculture, Forest Service 1987). The spruce budworm defoliated nearly a half million acres in northeastern Minnesota in 1986, up from 300,000 acres in 1985. The gypsy moth defoliated more than 60,000 acres in lower Michigan in 1986, up from 18,500 acres in 1985. The forest tent caterpillar has also been a problem in Minnesota and parts of upper Michigan, defoliating more than 60,000 acres in Minnesota alone. This represents a fourfold increase in damage from 1985. In addition, diseases such as oak wilt and maple decline are having serious impacts throughout the region, especially in localized high-value stands.

A positive development in the western part of the Upper Peninsula of Michigan has been the formation of the Forest Improvement District

(FID). This organization consists of more than 245 local landowners who collectively own more than 84,000 acres of forest land. The group members contract for forest management services as a unit, which allows them to manage their forests more cheaply and market their products more effectively than they could individually. A percentage of each sale is withheld to pay for management and organization costs. During the organizational period, the FID is being supported by the State of Michigan, with financial autonomy expected within 5 years. It is hoped that this organization of landowners will ensure a raw material supply in northwestern Michigan, encouraging further forest industry development in the area.

LOGGING

Most of the logging in the Lake States is done by small (two- to three-person), independent crews with a few chain saws and a cable skidder or forwarder. The popularity of forwarding seems to be increasing in relation to skidding, most likely due to the lesser stand damage associated with forwarding in partial cuts. Trucking is often contracted out by these small operators. The use of highly mechanized systems is increasing in the Lake States. Feller/ bunchers, grapple skidders, whole-tree chippers, slashers, and processors are becoming common. However, small operators still greatly outnumber the mechanized operations.

In the past few years, there has been a movement away from company crew logging in the Lake States. This is most likely due to government regulations pertaining to employees and the associated costs of these regulations. The once rapidly rising liability insurance rates for loggers appear to be stabilizing. However, workmen's compensation rates are beginning to skyrocket. These added costs are making it difficult for many loggers to show profits.

INDUSTRY

The status of the forest industry in the Lake States is good. Markets are strong, and optimism prevails. The Lake States regional report from the 1986 Council on Forest Engineering meeting (Sturos 1987) contains a thorough analysis of mill activity to that date. Therefore, only the most recent industry expansions in the region will be discussed here.

Champion International now plans to add a $200 million paper machine to the $500 million pulp mill completed in late 1985 in Quinnesec, MI. This machine should produce 300,000 tons of coated paper annually. The project is scheduled for completion in late 1989. Mead Corporation in Escanaba, MI, plans a similar addition.

Blandin Paper Company in Grand Rapids, MN, has announced a $350 million modernization and expansion project that should be completed by late 1989. The project will include construction of a new paper machine that should increase Blandin's capacity to produce lightweight coated papers by 79 percent, to 500,000 tons per year. Mill jobs are expected to drop by 45 due to efficiency gains, but woods jobs should increase by about 115.

The $400 million Lake Superior Paper Industries mill in Duluth, MN, is on schedule and expects to produce paper in December 1987. The mill should produce about 240,000 tons of supercalendered paper each year. It is expected to employ 600 people, divided equally between the mill and the woods. This project has had and will continue to have a tremendous economic impact on Duluth and northeastern Minnesota.

Scott Paper Company in Muskegon, MI, is spending $120 million to rebuild a paper machine and a cogeneration unit. The paper machine will produce high-quality coated paper and should be completed in the fall of 1988. The cogeneration unit is designed to burn biomass and pulverized coal and will make the mill self-sufficient in electrical power. This project should be completed by the fall of 1989.

Two 16-megawatt wood-fired power plants are under construction in lower Michigan at McBain and Lincoln. Both should be operational by the fall of 1988. These plants will be supplied with wood from two major sources: 40 percent from sawmill wastes and 60 percent from logging residues. This may have some effect on harvesting practices in these areas.

In addition to these projects, many expansions and smaller, new construction projects are underway that will collectively have a major economic impact in the Lake States.

As industry expands in the region, markets for the raw material have steadily improved. Most of the expansions have been geared to utilizing the surplus low-grade material for which few markets have existed. This will help promote better forest management practices in many areas.

The overseas market has also recently improved. European and Pacific-rim countries, in particular, want to import wood to meet their raw material requirements. For example, in Minnesota Norway is interested in buying significant amounts of birch pulpwood in 3-meter lengths. This will help make good use of an extensive resource that is now poorly utilized in the region, while creating jobs in the logging community.

The pulpwood market in the Lake States is currently strong and stable. However, the effect of imported eucalyptus pulp is being felt, primarily in the Green Bay, WI, area. The quality of eucalyptus pulp is currently superior to domestic hardwood pulp (Ahlfeld 1986). Therefore, eucalyptus is expected to capture an increasing share of the domestic hardwood pulp market in the future unless manufacturing methods to better control product quality are developed for domestic hardwood pulping.

High-quality hardwood logs, such as maple (especially with bird's-eye or curly grain), red oak, yellow birch, and cherry are at a premium in the Lake States, due to increasing demand and an inadequate supply. Most dimension hardwood mills are operating at capacity with a minimum 3-month backlog of orders. This situation is expected to continue for at least the next few years.

RESEARCH AND DEVELOPMENT

Several cooperative research studies have been initiated between the North Central Forest Experiment Station (NCFES), industry, and three national forests in Region 9 (the Eastern Region of the National Forest System). A national research and demonstration program is currently underway for central tire inflation (CTI), which allows an operator to control tire pressure from within the truck's cab. This would allow lower tire pressures on low-bearing strength woods roads and higher pressures on paved roads. Two national forests in the Lake States and the Forestry Sciences Laboratory in Houghton, MI have set up projects to analyze the CTI concept. Their main objectives are to look at CTI for winter conditions and for 11-axle trucks that are unique to Michigan.

Another promising concept in the area of transportation is chunkwood roads. In cooperation with Region 9, Michigan Technological University, and the Chequamegon National Forest, the Forestry Sciences Laboratory is currently looking at the feasibility, performance, and cost of using chunkwood by itself or in combination with fabric and various aggregate materials to build logging roads. A preliminary field portion of the study was completed in the summer of 1987: laboratory study and data analysis continue. Preliminary results have shown that chunkwood can make a good roadbed in some situations, such as in combination with fabric for swamp crossings and as a binder in sandy soil. A long-term study project is being planned.

A national demonstration project for cultivating, planting, tending, and harvesting short-rotation intensive culture (SRIC) plantations is currently underway. NCFES is cooperating with the U.S. Department of Energy and the Northern States Power Company on this 10-year project to evaluate several clones of hybrid poplar in various soil types in the Lake States. Northern States Power plans to burn the material in whole-tree form. The Forestry Sciences Laboratory is designing and building a harvester with computer-assisted functions and continuous felling ability to harvest these plantations.

NCFES is also involved in a national project to assess the effect of technological change in harvesting and processing on wood supply and cost through the year 2040. Associated with the Resources Planning Act, this analysis will be presented as a new chapter in the 1990 assessment of forest and range land in the United States.

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NE Regional Report

This report is not a statistical expose. Instead it is based on observations that have been extrapolated into "apparent" trends within the region. As such there may be some lack of agreement with the "apparentness" of the following statements.

The northeast region will be considered as that area north and east of Pennsylvania including PA itself. Although it can be argued that natural boundaries differ from this political one, most of the statements in the report can be extended to a larger territory if need be.

Forestry, and therefore forest engineering, is finding it necessary to modify some operational definitions in this region. Fifty-five years ago, a large portion of the region was changing over from an extensive family-based agricultural land use exemplified by numerous contiguous farms with wood lots for fuel, to an abandoned farm aspect. Many acres were placed under public domain by tax defaults, but most just lay fallow. In the 50's, the situation was aggravated by improvements in agriculture and agricultural engineering which favored large farms, and the small acreages that had come out of the abandoned ranks during the war years once again gave up on agriculture. Much of the public lands were planted to trees but most of the private holdings succumbed to natural ecological succession. As the population started exploding in the 60's, the outlook for land use changed from one of long-term natural succession (or in some cases tree farming) to land speculation as the developers started moving further out from the cities. The outward appearance is now one of succession, but the goal is more often development, not timber.

Granted, some of the region still boasts of a primarily timber-based economy, but several analyses indicate that this is shrinking. The large industrial timber holdings are in northern Maine, the Canadian provinces, and the "mountainous" regions of the lower States; several MMBF are also available off federal and state lands; and MMBF are "locked up" (perhaps needlessly so) in public parks and preserves. But by far, most of the timber resource lies on tracts averaging less than 100 acres.

The region is blessed with water and good soil (albeit a mean winter climate) and will grow "trees" everywhere and anywhere, if left alone. Although trees don't necessarily equate to usable timber, there is still a forest-based industry in existence, even in the populated sections of the NE. Within 75 miles of Syracuse there are several large wood using (lumber) plants -- furniture from Ethan Allen in Booneville, Stickley in Manlius, and Harden near Rome; 5MMBF/yr. mills at Gutchess and Cotton Hanlon south of the city. The engineering challenges for these people are not bigger or more powerful feller-bunchers or skidders, or extensive logging-road networks. Their problems have more to do with integrating operations into the tight mix of "people-needs" within their operating zones. How to find trees (not forests), how to maintain quality between seedling and log yard, how to move equipment efficiently from tree-to-tree and site-to-site, how to appear non-destructive to the logging area, how to satisfy or overcome town ordinances -- these are some of the tough questions of this region.

The predominant forest types of the region are composed of hardwoods, although evergreens prevail in the harsher climates to the north and at higher elevations. Virgin stands are a rarity and "natural" stands are meaningless since selective cutting and high-grading has changed stand characteristics several times over. Commercial lumber/veneer species are maple, oak, cherry, some birch, beech, ash, basswood with a minimum harvesting age of an optimistic 40 years ranging up to over 100 years. Spruce, pine and hemlock are also used where available in size and grade. Hardwoods for pulp have become important since their introduction back in the 50's and now constitute approximately 50% of the use, by volume. Typical species in this category are the ones above plus aspens and poplars. Of course, the other 50% is made up of the long-fibered softwoods, spruce being most important in this region. Firewood also reclaimed a position in the timber market during the "oil crunch" of the 70's, but has subsided somewhat in the last few years. The total industry could be, and often is, an integrated harvesting enterprize -- products moving to the appropriate markets off a common logging operation -- although occasional conflict arises at the silvicultural level (e.g. potential lumber stems removed early for pulpwood).

Lately, however, strange terms such as environmental management, urban forestry, urban wildlife, biomass, waste management, etc., are creeping into the lexicon. Veneer and lumber buyers are looking around suburbia for their high quality raw materials as much as in the outlying forests. Serious research is being conducted into the use of "rural" (forest) lands for receipt of sludge from our waste treatment plants, and for the production of energy as our fossil fuel supplies dwindle. Recreation that used to be only justifiable through public funds, is now financially attractive to private investors. And more-and-more of the populace is finding it psychologically and often financially attractive to hold acreage for just plain escape and elbow-room. And many of these new owners are preconditioned to single-purpose management -- usually not timber.

Added to these changes in land use are the economies of alternative materials for traditional wood uses. Our own wood-products professionals would, if cornered, recommend vinyl siding. Many supermarkets and department stores now "bag" in non-paper containers. Wooden bridges and buildings are specialty items; there are even "plastic" matches on the market. Hopefully the costs of maintenance, replacement, and/or disposal of these non-biodegradable materials will over-weigh the economy of initial cost?

We can fight these trends, and some of them may be short-lived, but it appears that our world is changing. Perhaps some forest engineers should become involved with tree improvement problems -- tree cabling, transplanting, pruning, control of overhead utility line passageways, fertilization, etc. Or with the use and control of trees for aesthetics with an end view to efficient salvage as wood products. Or with the design of micro-climates and hydrology for water/air quality through applications of engineered biological and physical systems. Or with the use of forest areas for receipt and modification of the wastes produced by civilization.

In summary it appears that the old Forest Service notion of multiple use management needs broadening -- multiple-use in both time and space, even down to multiple-use of individual trees, both on public and private lands. Forest engineering might be well advised to quickly follow.

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Regional Report - Southern Region

Presented at the 1987
Annual Council on Forest Engineering

The South continues to prosper in terms of forestry and great strides are being made to increase fiber and wood product supply across the southern states. Programs like the Conservation Reserve Program (CRP) have encouraged farmers and other land owners to convert idle land to plantation forests. In Georgia alone, over 800,000 acres of marginal farm land was converted to planted pine in 1987 through CRP.

In recent months, forest industry has been in a state of turmoil in several southern states because of mergers, sales, and buyouts. In spite of this, plans for several new mills were announced this summer. New mill construction emphasizes oriented strand board (OSB) products that use a mix of hardwood and pine.

In addition, many southern pulp and paper mills are beginning to use a greater mix of hardwood furnish for pulp and paper production. As a result, the demand for hardwood is increasing across the South. Several mills located in the coastal plain region are experimenting with different wetland harvesting systems to identify low cost, productive approaches to wetland logging. Wetland sites are also coming under heavier regulation in several southern states, potentially reducing the amount of hardwood available in coastal plain areas.

The southern forest industry also faces timber transport problems. Safety related trucking problems have prompted the development of driver training programs in several southern states. Truck load weight regulation on state and federal highways has encouraged studies into the use of on-board weight scales and the development of a highly accurate loader scale device for logging use.

Shear related damage in southern yellow pine sawtimber is prompting studies into the use of saw type felling heads for feller-bunchers. Two different sawhead designs currently offered on the southern market include a chainsaw feller, the Bell Model T, and a disk saw feller-buncher, the Koehring front cut sawhead mounted on a Barko 775. While relatively few sawmills in the South currently require all timber to be saw felled, many are looking at sawhead feller-bunchers as a viable option to felling timber with shears.

In summary, the southern wood industry continues to expand, but not without some problems. Government regulation threatens to plague the southern wood industry and will probably continue to be a problem as long population growth continues in the South. Hardwood promises to be a more valuable resource in the future, but may be available in only limited quantities. And finally, operational problems, such as sawhead design and development, make the South one of the most interesting locations for a forest engineer to work.

-Joseph F. McNeel
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HARVESTING EQUIPMENT AND SYSTEMS DEVELOPED IN JAPAN FOR HARVESTING SMALL TREES

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Abstract: Harvesting small trees and forest residues is presently limited because of the lack of technically sound, economically efficient, and environmentally acceptable equipment and systems in the Pacific Northwest. Harvesting equipment and systems developed in Japan may help solve some of these harvesting problems. This paper will introduce and discuss three pieces of equipment and systems: (1) radio-controlled, cable conveyer system; (2) radio-controlled, self-powered carriage; and (3) radio-controlled, tree pruning machine.

INTRODUCTION

In the United States, harvesting small trees on steep terrain presents special problems that require the use of equipment adapted for that purpose. The Pacific Northwest contains 40 million acres (about 16 million hectare (ha)) of commercial forest land. Over half of these forests are pole-timber stands. Thinning is appropriate in many of them. A typical young-growth stand averages 12 inches (in; 30 centimeter (cm)) dbh, 28 cubic feet (ft^3; 0.80 cubic meter (m^3)) per tree, and contains about 300 trees per acre (745 trees per ha) (Jorgensen 1979). Operations in the low-value young stands, however, are presently limited by the lack of technically sound, economically efficient, and environmentally acceptable equipment and systems capable of harvesting the small, low-value material. Steep slopes, fragile soils, limited road systems, and low stand volumes are characteristics that contribute to adverse working conditions in the Pacific Northwest. This paper discusses several new systems and equipment being used in Japan that may have application in the United States.

Because of the working conditions of the Pacific Northwest, the low value of the material, and the size and weight of trees to be handled, the following characteristics are needed for equipment and systems to be effective:

- Low initial costs.
- Low hourly machine costs.
- No deflection limitation.
- Easy transport and set-up.
- Uphill and downhill yarding capacity.
- Up to 2,500 feet of yarding capacity.
- Capacity to transport small trees from precommercial and commmercial thinning operations.
- Productivity equal to or better than the small yarders already available in the United States.

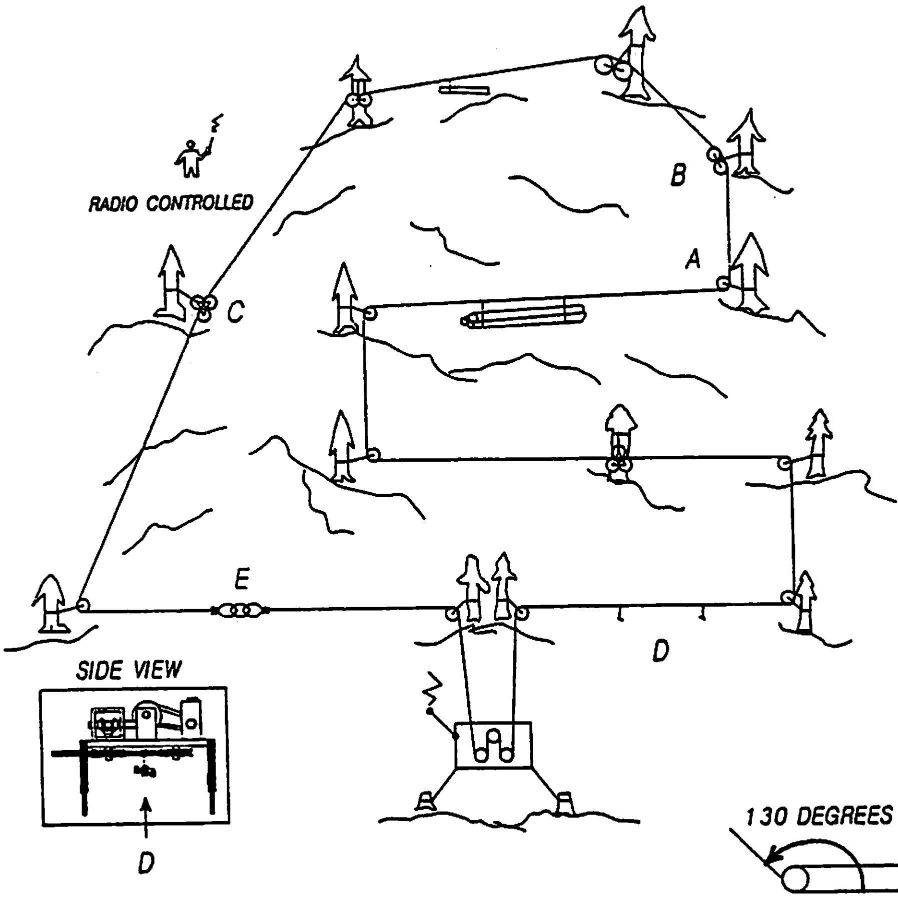
A review of over 200 publications on various harvesting machines and systems within and outside of the United States suggested the monocable zig-zag system appeared to be most likely to be successful in the Pacific Northwest. Results of a field trial were reported at the 9th Annual Meeting, Council on Forest Engineering, in 1986 (Miyata et al. 1987).

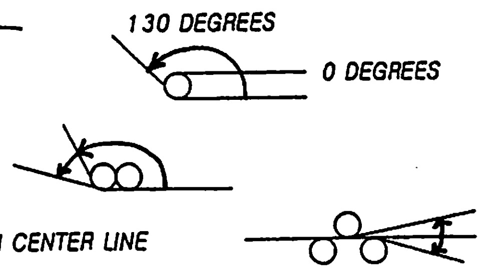
The monocable system is now being purchased by at least two organizations in the United States, and its use is expected to increase dramatically over the next several years. Based on field observations in 1986, some other opportunities to increase harvesting efficiency currently being applied in Japan are of interest: radio-controlled cable conveyer system; (2) radio-controlled, self-powered carriage; and (3) radio-controlled, tree pruning machine.

<u>Radio-Controlled Cable Conveyer System</u>: This system (Figure 1) consists of a monocable (3/8 in (9 mm) in diameter), which runs through a series of open-sided blocks hung on short intermediate supports. It can operate on steep slopes, over fragile soils, or even over streams or rivers. The cable is driven by three drive wheels powered by a 7-horsepower (hp) gasoline engine. The total length of the cable may be extended to over 3,000 feet (ft; 1,000 m). The blocks are made of aluminum and weigh about 15 pounds (lb; 7 kilogram (kg)) each. The choker hooks, made of steel wire 3/16 in (5 mm) in diameter, are attached to the cable with a clip.

Logs are attached to the moving cable by hooking chokers to the choker hooks (Fig. 1-D); consequently, the loads travel continuously from the hooking locations to the landing. Various materials such as cord, nylon rope, baling twine, cable, or wire could be used as chokers. When the logs reach the landing, the hook is hit with a stick to drop the logs to the ground or directly into the truck or trailer bed. Cable used with this system is similar to that of a ski lift; however, a unique method is used to connect the cables (Fig. 1-E). Three different lengths of cable; 200 ft (60 m), 80 ft (24 m), and 40 ft (12 m) are used. Each cable has an eye at both ends; thus, if 2,000 ft of cable are needed for a harvesting operation, then ten 200-ft cable lengths will be connected. This cable connecting technique allows changes in yarding distances more easily than conventional splicing methods. It also allows for rapid changes in the yarding layout.

Figure 1. The radio-controlled cable conveyer system.





A. BLOCK NO.1 CABLE ANGLE - 0~130 DEGREES

B. BLOCK NO.2 CABLE ANGLE - 120~160 DEGREES

C. BLOCK NO.3 CABLE ANGLE - 0~30 DEGREES FROM CENTER LINE

D. CHOKER HOOK PASSES THROUGH WINCH

CHOKER EYE IS HOOKED ONTO THIS DEVICE

E. MOLLY TYPE CONNECTION

The cable conveyer system was demonstrated in the Hiroshima Prefecture, Japan. A 27-year-old, second-growth stand of Sugi (Japanese ceder) was thinned for this demonstration. The average dbh was about 6.3 in (16 cm), and log length was about 10 ft (3 m). The average weight of the log was 165 lb (about 75 kg). About two hours were required for two people to rig the system. The total length of cable was 640 ft (195 m); that is, three 200-ft (60-m) cables and one 40-ft (12-m) cable were used for this operation. According to the demonstrator, one 8-hour day with two workers is needed to rig the total length of 2,000 to 3,000 ft, and about half that time is needed to take it down. Two people can operate this system because of a radio-controlled device for starting and stopping the monocable and changing its speed. Although productivity depends on various factors such as worker's experience, size and weight of the load, and characteristics of the harvesting site, two workers can transport about 530-700 ft^3 (15-20 m^3) of material per day (6 productive hours).

A typical cable conveyer system consists of:

- 1 yarder;
- 5 No. 1 blocks;
- 40 No. 2 blocks;
- 1 No. 3 block;
- 9 200-ft (60-m) sections of 3/8-in (9-mm) cable;
- 1 80-ft (24-m) section of 3/8-in (9-m) cable;
- 2 40-ft (12-m) sections of 3/8-in (9-mm) cable;
- 120 choker hooks;
- 200 32-in (80 cm) long wire; and
- all tools for asssembly.

The price for this set is about $14,000 (@ one U.S. dollar = 150 yen)

<u>Radio-Controlled Self-Powered Carriage</u>: The radio-controlled self-powered carriage (Fig. 2) consists of an engine (6.5 hp), a drive pulley/capstan drum to travel on the cable, and a winch-drum to lift a load.

Using a straw line (nylon rope), for example, two men could rig a 500-ft (152-m) span in a few hours. A radio-controlled device is used to start/stop engine, change the speed, and operate the winch drum for lifting a load and for lateral yarding (maximum 60 ft). The winch drum has a capacity of 164 ft (50 m) with 5/16-in (8-mm) cable or 262 ft (80 m) with 1/4-in (6.4-mm) cable. Because the carriage is self-powered, the operation is not limited by deflection and can yard uphill, downhill, or on flat ground.

The demonstration site was in the Shizuoka Prefecture in Japan. Figure 3 shows the cable layout. The site was a 50-year-old second-growth stand of Hinoki (Japanese cypress) with average dbh of 10 in (25 cm) and log length of 65 ft (20 m). The operation was clear cutting. The carriage haul speed was about 165 ft (50 m) per minute. According to the demonstrator, the productivity was about 600-700 ft^3 (17-20 m^3) per day (6 productive hours) with two workers. The price of this carriage was about $10,000 (@ one U.S. dollar = 150 yen).

Figure 2. Layout configurations of the radio-controlled self-powered carriage.

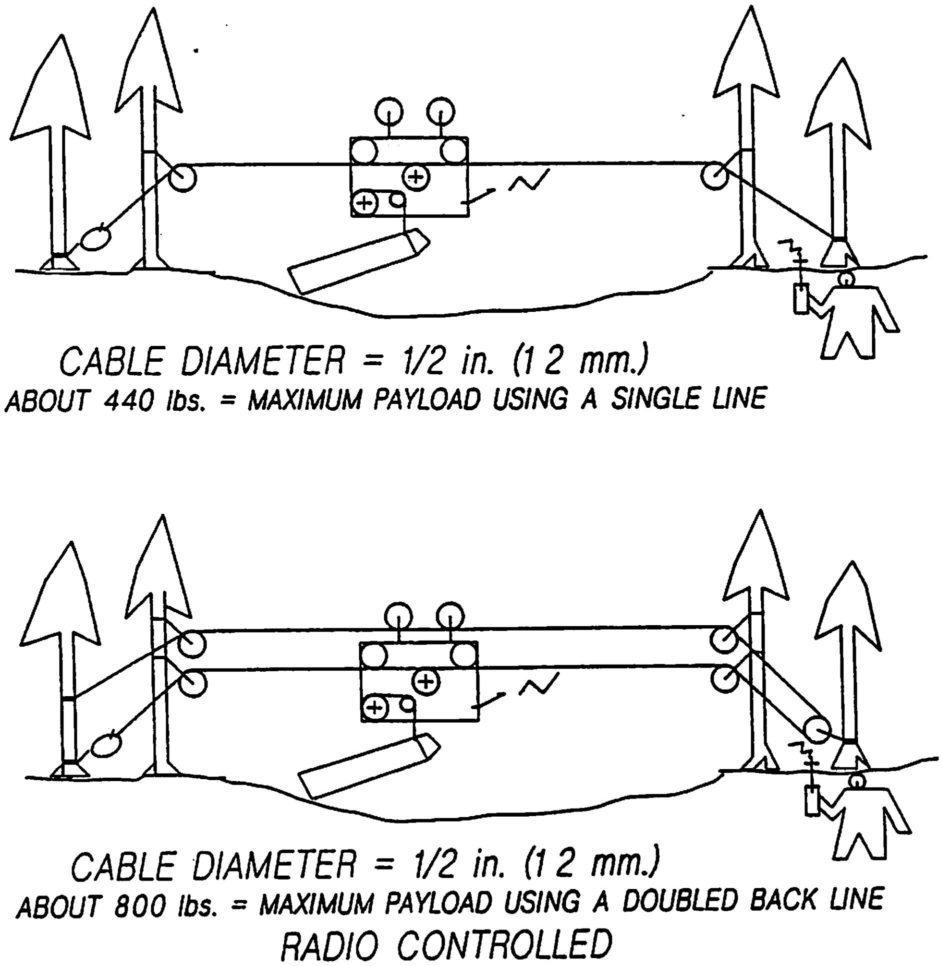
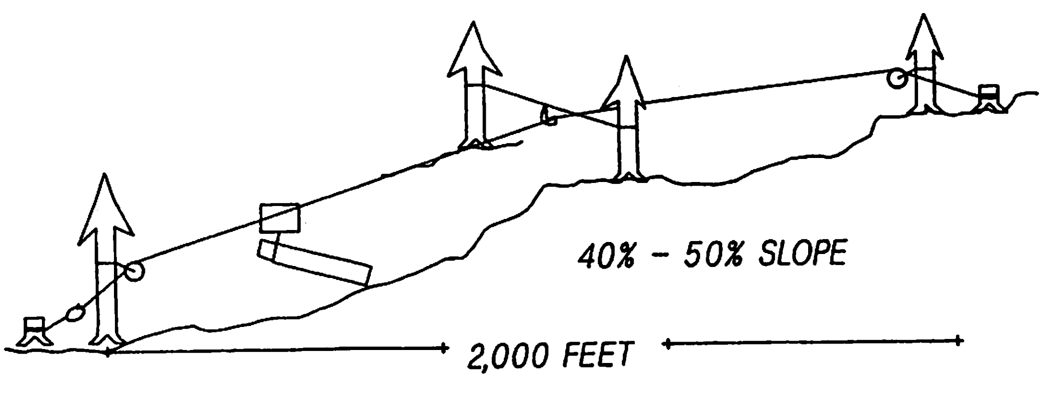


Figure 3. Shizuoka demonstration site.



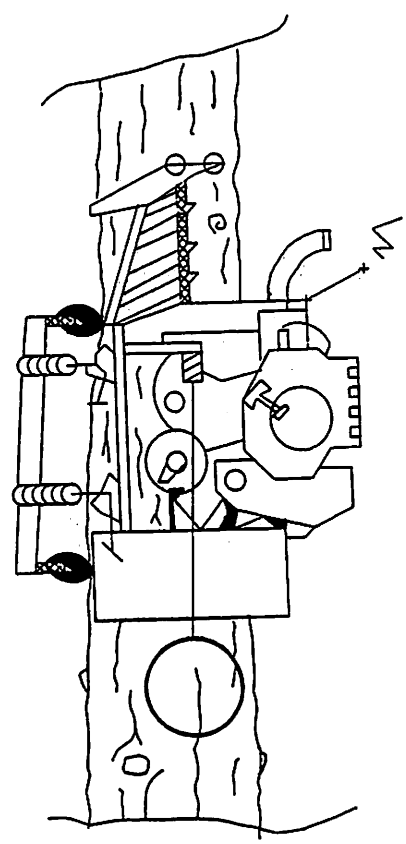
Radio-Controlled Tree Pruning Machine: The primary objective of pruning is to produce knot-free clear wood by removing the lower dead limbs and live branches while trees are young (15-20 years old). Knots not only reduce wood strength and dimensional stability, they also can give the final product a lower market value; therefore, in Japan as in other parts of the world, pruning is considered to be as important as thinning. Pruned trees also make thinning and final harvesting operations easier and more economical because fewer dead limbs and live branches must be contended with.

This machine (Fig. 4) can operate on trees between 3 in (8 cm) and 10 in (25 cm) in diameter. The machine weighs 44 lb (20 kg) so one worker can easily move it from tree to tree. The cycle time (setting the machine, pruning, and moving to the next tree) is less than 5 minutes. One worker could operate two machines to increase productivity because of the machine's portability, ease of operation and skill needed.

Figure 4. The radio-controlled tree pruning machine.

The tree pruning machine has a 3.2-in^3 (52-cc) engine with a small chain saw which spirally climbs the stem, cutting limbs, branches, and stubs as it ascends. The machine is equipped with ten rubber-tired wheels; four are gear-driven, and the other six are free-wheeling to help guide the machine. The wheels are spring-loaded to help keep the machine on the tree stem without damaging the stem.

The pruning machine was demonstrated in the Kumamoto Prefecture, Japan. The site was a 30- to 35-year-old, second-growth stand of Sugi (Japanese cedar). The average dbh was about 7 in (18 cm). According to the demonstrator, the machine can prune branches up to 2.4 in (6 cm) in diameter with an ascending speed of 8.2 ft (2.5 m) per minute. The productivity ranges from 10 to 15 trees per hour with a single machine. The price is $2,600 (@ one U.S. dollar = 150 yen).



DISCUSSION AND SUMMARY

Based on our field observations, information obtained from demonstrations, and publications reviewed (The Forestry Mechanization Society, 1982, 1985, and 1986), we have reviewed three pieces of machinery now being used in Japan to improve the quality of timber and to harvest materials efficiently. As more and more second-growth stands require thinning and harvesting, the need increases for economical harvesting techniques. We need to look outside of the United States for these new technologies because forest workers in other countries have had much experience with adapting machinery to harvest small-diameter trees from steep, difficult terrain.

These machines have several characteristics in common:

- They can be added to or used in conjunction with existing systems in a modular way. The radio control can be used with the zig-zag system; the pruning machine can be used independently or in conjunction with either the zig-zag or carriage harvesting systems.

- They are not capital intensive. Each machine costs relatively little, giving it two advantages in forestry operations. First, operations with these machines can be begun relatively easily, because a large amount of money is not required to purchase the system. Second, the low fixed cost of the machinery allows the work to be done carefully enough so that neither the forest nor the machinery is damaged.

- The machines are small. Consequently, they can be transported, set up, repaired, and operated relatively easily and with relatively little damage to the forest.

The Pacific Northwest has forests of sizes to be thinned, to produce both low-quality wood from current thinnings and high-quality wood in the future; however, the stands can only be thinned and pruned economically with appropriate systems. The United States has changed from a period of high labor costs and low machinery costs in the 1960's and early 1970's to high costs of both labor and machinery. Present and future machinery will probably be most effective in managing Pacific Northwest forests if it is low in cost, innovative, and adapted to be used by labor in a modular fashion, such as the machines described in this paper.

ACKNOWLEDGMENTS

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INTENSIVE UTILIZATION IN ROLLING TOPOGRAPHY

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ABSTRACT

The cost of harvesting wood for fuel (energywood) in conjunction with a pulpwood harvest, in steep terrain, was tested. The energywood was chipped on the site and utilized for fuel; the pulpwood was removed from the site in both chips and longwood form. A Mortran drum screen was used in the field to enhance the quality of the pine pulp chips. Costs were determined for each aspect of the harvesting operation, and one-way analysis of variance tests were conducted to determine if the costs between the different methods were significant. The costs to fell and skid the material increased as the slope of the topography increased. The feasibility of the energywood harvest was marginal on most of the blocks, with the availability of markets in close proximity to the harvesting site being a determining factor.

INTRODUCTION

Efficiency in harvesting operations is increasing in importance as forest industry emphasizes cost reductions. One way to increase harvesting efficiency is to utilize the wood residues that are normally left after logging a site. The most important use for these residues is for fuel or energy, and the best candidate for this use is the forest products industries. In the most recent energy survey of the pulp and paper industry, Kluender (1980) reported that the pulp and paper industry depended on fossil fuels for 52 percent of its energy needs. Current estimates are that wood residues provide over 75 percent of this industry's energy needs.

Dependency upon fossil fuels has been steadily declining, due to the ample supplies of biomass that are available. The amount of "commercial" forest land in the U. S. is approximately 482 million acres. This includes public forest lands, and industrial and private holdings which are capable of producing new growth at a minimum rate of 20 ft^3/acre/year (USDA Forest Service 1982). Investigations by Clark and Taras (1974) showed that for southern pines, residue left behind after harvest could equal 18 percent of the total above-ground weight of a tree. Undesirable understory species can contribute as much as 60 green tons/acre in stands that have never been prescribe burned (Miller, et al. 1986). With this biomass now having a monetary value, the recovery of undesirable or submerchantable tree species becomes feasible. The material that was previously a nuisance can now be utilized. The harvest of the undesirable species gives the land a higher per acre value. Nelson (1976) stated in a study of nonindustrial private landowners that tracts as small as 10 acres could be harvested economically and that overrun as high as 100 percent over conventional yields were obtained when the residue material was harvested.

The use of wood as an energy source has spread from the fireplace into other areas such as steam and electrical generation, and industrial and institutional heat and process applications. Wood energy consumption has been increasing at an annual rate of 10-15 percent in recent years (Moshofsky 1980) and currently amounts to a total of 1.4-1.7 quads - or about 2 percent of the nation's total energy needs (OTA 1980). Much of this increasing demand for wood energy stems from recent social, political, and economic conditions, including a rising public awareness of the vulnerability, limitations, and undesirable consequences of fossil fuel dependence, and rapidly increasing costs of oil, natural gas, and coal. By all indications, the demands being placed on the forest as an energy source will continue to increase in the future (DOE 1984).

A major problem or limitation of using biomass for energy is the ability to obtain and deliver the product to a user at an acceptable cost. This represents not only technological limitations, but several others as well, including economic and environmental constraints. Currently, the cost of producing energy chips, from stump to point of use, using modified conventional systems, can be expected to range from about $11-23/green ton. Harvesting costs alone (from stump to chips) account for at least half of the total cost. Transportation is also a significant factor; costs ranging from 11-28 cents/ton/mile limit the maximum economical trucking radius (DOE 1984). The farther the harvesting site is from the consumer's delivery point, the more expensive and less competitive the energywood is as a source of fuel.

The utilization of biomass has other benefits, such as a reduction in site preparation costs. These costs can be reduced by as much as 60 to 80 percent when an increased utilization of the above-ground biomass is accomplished during harvest (Watson and Stokes 1984). The savings generated by reduced site preparation costs can make marginal stands at greater distances from the mill economical to harvest.

The successful energy wood harvesting crews in operation have been those using conventional logging equipment in combination with a portable chipper. Arola and Miyata (1981) and Sturos (1982) have observed biomass harvesting operations of this type in the Lake States. Those operations obtained biomass for energy at a cost which was competitive with alternative fuels. In northern Idaho the chipping of logging residuals as an integrated part of a sawlog operation presented opportunities for significant increases in fiber yields with total savings in felling and skidding costs (Johnson and Arkills 1976).

This study involves the analysis of the costs of an intensive utilization operation in steep terrain in the South. Similar studies have been carried out in the lower coastal plains of Mississippi and Alabama, but a cost differential should exist between the two due to the logging conditions. The energywood obtained from this intensive utilization must be competitive with residue material (sawdust, etc.) that is produced by various sawmills in the surrounding area.

METHODS

The research was conducted in Tishomingo county, located in the northeastern part of Mississippi, where three different types of harvesting treatments were tested. All of the harvested material was delivered to the Tennessee River Pulp and Paper mill in Counce, Tennessee.

In the first test, a conventional harvest, all of the pines 5 inches DBH and above, were utilized. The trees were delimbed with a delimbing gate, and loaded and removed from the site in longwood form.

The second harvest method tested involved a moderate utilization, where just the understory material was chipped. Here all stems 1 inch DBH and larger were utilized. The pines (between 1 and 5 inches DBH) and all the hardwoods were felled and bunched separately and skidded to the chipper. All pine stems greater than 5 inches were conventionally harvested in longwood form.

The third treatment was an intensive utilization, where all the biomass was chipped but the merchantable pine delimbed first. Again, all the stems 1 inch DBH and above were harvested. The pine stems 5 inches DBH and greater were chipped for pulp production with a Mortran auger screen being used on the site to enhance the quality of the pine pulp chips. The smaller pines and all the hardwoods were felled and bunched separately and chipped to be used for energywood. The second and third harvest methods tested were essentially a two-pass harvesting operation, with the energywood harvested in the first pass through the stand, and the pulpwood in the second pass.

Preharvest Inventory

In setting up the study area, 5-acre blocks were established. About half of the blocks consisted of plantations, with the remaining blocks comprised of natural stands. The average age of the trees was about 30 years, with the predominant species being loblolly and shortleaf pine. Each block formed a rectangle of five chains by ten chains, with a loading deck located near the middle of one of the ten-chain sides so that average skid distances between the treatments would be similar. A conventional harvest was performed on four of the blocks. Four additional blocks received moderate utilization, and an intensive utilization was carried out on five of the blocks.

An inventory for volume was conducted by establishing ten 1/10-acre plots on each block for sampling trees larger than the 3-inch DBH class. Within these plots, 1/200-acre subplots were established to determine the standing biomass for all trees in the 1-3 inch DBH classes. In the 1/200-acre plots destructive sampling was used to get the total green weight and the height for each tree. To calculate the volume present on the blocks, a computer package called the Total-Tree Multi-Product Cruise Program (TTMPCP) was used (Clark, et al. 1984). It accepts cruise data and provides per acre or per area estimates of total-tree and component biomass and forest product yields for trees 1 inch DBH and larger. These estimates are given in tons, cords, or cunits, and in board feet using either the Doyle, Scribner, or International 1/4" rules for sawlog volumes.

Shown in Table 1 is the inventory for each of the blocks, in green tons per acre. The total biomass was separated into two categories. The pine 5 inches DBH and greater was specified as pulpwood, and all of the hardwoods and the pine below 5 inches DBH were specified as energywood.

Production Study

The energywood crew, supplied by Mississippi State University, began felling and bunching the submerchantable volume a few weeks prior to the arrival of the contract logger. The reasons for this were to (1) get a large number of bundles of energywood cut so that when the logger began to skid the energywood to the chipper the skidders would stay busy and keep the chipper productive by not having to wait on wood, and to (2) give the felled energywood an opportunity to dry so that it would yield more BTU's per given volume when utilized as fuel. The equipment supplied by the energywood crew consisted of two feller-bunchers: a Clark Bobcat and a Caterpillar 910, a Morbark 23" chipper, a Mortran auger screen used to enhance the chip quality, and four chip vans. The feller-bunchers that were leased for the study did not produce the small energywood at an acceptable level, thus Hydro-Ax 411 feller-bunchers were used at a later date, with the felling cost data being substituted for

Table 1. Plantation and natural stands cruise summary.

Treatment	Block	Pine 5"+	Hardwood and Pine < 5"	Total
		(green tons/acre)		
	17	60.6	31.1	91.7
Conventional	18	57.2	27.5	84.7
	19	68.1	33.3	101.4
	20	43.6	31.2	74.8
	2	121.8	18.8	140.6
Chip Understory	4	104.1	10.0	114.1
	11	94.8	19.4	114.2
	12	64.5	32.5	97.0
	5	98.0	18.6	116.6
Chip All - Delimb Pine	13	84.8	17.8	102.6
	14	49.1	38.1	87.2
	15	88.5	36.0	124.5
	16	42.8	34.3	77.1

the observed energywood felling data obtained in this study. The revised felling cost data were obtained by monitoring a Scott Paper Company energywood crew.

The merchantable volume was felled and harvested along with the energywood by an independent logger contracted through Tennessee River Pulp and Paper Company. The logger performed the skidding with three Caterpillar 518 grapple skidders. He also provided a Hydro-Ax 611 for the felling phase and the merchantable material was loaded in longwood form with a Barko 160 knuckleboom loader. The tractor-trucks and longwood trailers were supplied by the logger.

Mill tickets were also obtained by product and block to determine the total volume removed (Table 2). In examining Table 2 it is apparent that the percentage of the cruised biomass that was recovered during the harvest was lowest in those blocks that received a conventional harvest. The blocks where the total biomass (both pulpwood and energywood) was chipped had the highest percentage of the cruised material recovered. In most of the cases the cruised pulpwood was the largest component of the total standing biomass. The volume that is classified as rejects was comprised of oversized and undersized chips and a bark component. This material was separated from the desirable pulp chips by an auger screen that was placed alongside the chipper for the specified treatments.

Table 2. Harvested green tons per acre.

Treatment	Block	Pine Pulp	Rejects	Hardwood & Pine < 5"	Total	Percent[a]
	17	45.7	--	--	45.7	49.8
Conventional	18	52.0	--	--	52.0	61.4
	19	55.1	--	--	55.1	54.3
	20	39.7	--	--	39.7	53.1
	2	89.2	--	17.4	106.6	75.8
Chip Understory	4	84.0	--	16.6	100.6	88.2
	11	72.3	--	23.4	95.7	83.8
	12	51.7	--	27.3	79.0	81.4
	5	69.6	5.4	34.9	109.9	94.3
Chip All -	13	54.8	5.4	23.5	83.7	81.6
Delimb Pine	14	41.1	4.0	48.3	93.4	107.1
	15	64.5	--	28.4	92.9	74.6
	16	43.5	--	29.7	73.2	94.9

[a]Percent of cruised total standing biomass.

On block 14, where an intensive utilization was performed, the percent of biomass recovery during harvest was over 100 percent. This is due to randomness in the sample plot selection. For block 14 the cruised volume was not representative of the actual volume on the block; it was underestimated.

To determine the total productive time of each machine during the harvesting operation, Servis recorders were attached to each machine. On the removeable paper disks the actual hours worked each day were recorded. The actual hours were compared to the total hours worked to obtain the productivity of each piece of equipment on each block.

Cost Analysis

Machine and labor costs are presented in Table 3. The machine rates that were developed for each specific machine use new replacement costs and a 12 percent interest rate for financing. All of the skidders were mounted with hydraulic grapples and both the skidders and feller-bunchers came equipped with standard Forestry Special tires. A useful life of 4 years was specified for most of the woods equipment. A standard hourly labor rate for the crew members was assigned because the crew was paid on a commission based upon the amount of volume that was harvested. The number of crew hours per year was assumed to be 2000. Labor rates

Table 3. Machine and labor rates.

Function	Machine	Machine Rate Per Operating Hour	Labor Rate[a] Per Scheduled Hour
		------------($, dollars)---------	
Felling	Feller-buncher[b]	44.31-52.88	10.50
Utility & Trimming	Chainsaws	5.00	8.50
Skidding	Skidders	42.08	10.50
Chipping	23-in. Chipper	72.62	10.50
Screening	Drum Screen	33.65	10.50
Loading	Knuckle-boom	22.78	10.50

[a]Includes fringe benefits

[b]Cost depended on the type of feller-buncher used. Models used were Hydro-Ax 411 and 611, respectively.

included fringe benefits. Various assumptions on the machine rates were based upon published sources by Miyata (1980) and Cubbage (1981). All of the energywood was felled with Hydro-Ax 411 feller-bunchers. The hourly cost estimate used in the calculations was a rental rate, which was 36 percent higher than the machine rate. The rental rate was divided by the number of tons of biomass per productive hour to arrive at a felling cost per ton.

Standardized hourly labor rates were used in conjunction with machine usage information to arrive at a total cost for harvesting each block. A cost per green ton was calculated using the total harvesting cost along with the volume of material harvested. In looking at the costs for each block, the energywood and the pulpwood costs were listed separately.

The cost of each harvesting aspect of the energywood operation is presented next (Table 4), along with the total cost. A standard felling cost was assigned for each of the energywood blocks. The set felling costs were obtained through the use of time studies. The felling of the energywood and pulpwood in block 4 occurred simultaneously and the costs could not be determined separately. The costs incurred in obtaining the merchantable pulpwood are also broken down into each aspect of the operation for each block (Table 5). The blocks that were harvested by

Table 4. Energywood harvesting costs per ton.

Treatment	Block	Fell	Skid	Chip	Total
		(\$, dollars)			
Chip Understory	2	3.11	7.08	3.82	14.01
	4	*	3.92	3.96	*
	11	3.11	8.46	2.37	13.94
	12	3.11	5.23	2.65	10.99
Chip All - Delimb Pine	5	3.11	2.69	1.27	7.07
	13	3.11	4.05	2.30	9.46
	14	3.11	4.76	1.93	9.80
	15	3.11	4.32	1.91	9.34
	16	3.11	5.46	2.17	10.74

*Costs could not be separated.

conventional and moderate utilization methods did not encounter any chipping and screening costs in the processing of the pulpwood.

Table 5. Pulpwood harvesting costs per ton.

Treatment	Block	Fell	Trim	Skid	Load	Chip	Screen	Total
		(\$, dollars)						
Conventional	17	2.31	.37	4.48	.80			7.96
	18	2.06	.43	4.96	.80			8.25
	19	2.72	.41	3.38	.99			7.50
	20	3.65	.47	4.53	1.20			9.85
Chip Understory	2	1.62	.30	2.74	.72			5.38
	4	*	.25	2.51	.53			*
	11	2.07	.47	4.37	1.18			8.09
	12	2.43	.46	4.27	1.16			8.32
Chip All - Delimb Pine	5	2.12		4.52		1.47	.56	8.67
	13	2.89		5.23		1.60	.90	10.62
	14	3.11		3.98		1.64	.73	9.46
	15	2.75		5.54		1.93		10.22
	16	2.08		4.93		2.00		9.01

*Costs could not be separated.

When performing the intensive utilization method, the merchantable pulpwood was delimbed with a stationary gate and then chipped, thus no trimming or loading costs were incurred. For the first two blocks that were harvested by the intensive utilization method, the quality of the pulp chips were not enhanced, so there were no screening costs.

To keep the moving costs to a minimum, the blocks that received the same treatments were located near one another. Because of the down-time encountered in moving the chipper, those blocks that required chipping would have the biomass skidded to a central location where the chipper could accommodate the blocks involved without having to move.

To test for statistical differences in the energywood and pulpwood costs, a one-way analysis of variance was performed on the total, felling, skidding costs, and percent utilization. The treatments included in the analysis were (1) conventional, (2) moderate utilization, (3) intensive utilization with screen, and (4) intensive utilization without screen. The resulting analysis of variance are shown in Table 6.

In comparing the total costs for harvesting the energywood, the costs for the moderate utilization method were significantly higher. Both methods harvested the energywood in the same manner, but the blocks that received an intensive utilization had a higher volume of energywood per acre, thus a lower cost per ton. There were no significant differences in the skidding costs between the two methods. This is important because it shows that skidding costs do not change by stem size if the feller-bunchers can build full loads for the skidders.

When harvesting the pulpwood, the total costs were significantly higher for the intensive utilization method as compared to the conventional and moderate utilization methods. This was because the pulpwood was chipped in the intensive utilization method, whereas the pulpwood was loaded in longwood form for the other two methods. Although chipping the pulpwood causes a higher total cost, it produces a higher valued product in the field and reduces the amount of processing that the pulpwood must go through at the mill.

There were no significant differences in the felling costs per ton for the pulpwood, but the conventional method had the highest average cost of the three methods. This was because the feller-buncher had to maneuver around the standing submerchantable material to get to the merchantable pulpwood. In those blocks with the understory removed, it was much easier for the feller-buncher to maneuver in the stand.

The skidding costs involved in harvesting the pulpwood were not significantly different although the highest costs were associated with the intensive utilization method. The reason was because the skidders would have to get the tree-length pulpwood near the feed deck before the knuckleboom grapple on the chipper could reach the material. This required slightly more time than just dropping the material at the loading deck.

Table 6. Analysis of variance (one-way).

Source	Treatment	Error d.f.[a]	Mean Sq. Error	F-statistic	Significance[b]
Total Cost Energywood	Moderate Util. Intensive Util.	6	2.21	11.60	S
Total Cost Pulpwood	Conventional Moderate Util. Intensive Util.	9	1.24	4.24	S
Total Cost Pulpwood	Intensive Util. w/screen Intensive Util. w/out screen	8	1.39	2.51	NS
Total Cost Pulpwood	Conventional Moderate Util.	5	1.70	1.28	NS
Felling Cost Pulpwood	Conventional Moderate Util.	5	0.36	1.99	NS
Skidding Cost Energywood	Moderate Util. Intensive Util.	7	2.32	3.52	NS
Skidding Cost Pulpwood	Conventional Moderate Util. Intensive Util.	10	0.58	3.64	NS
% Utilization	Conventional Moderate Util. Intensive Util.	10	79.3	19.05	S

[a]d.f. = degrees of freedom

[b]S = significant at the .05 level; NS = not significant

In looking at the percent utilization for each treatment, the amount of total biomass recovered by the moderate and intensive utilization methods was significantly higher than for the conventional method.

The intensive utilization method has a few drawbacks when the screen is not used in conjunction with the chipper. When the pulp chips were sent to the mill without first being processed through the screen, the quality of the chips was not acceptable at the mill. The pulp chips would then have to be screened at the mill at an additional cost before being sent for further processing.

Post-harvest Inventory

After harvest, the blocks were inventoried again to determine the level of logging residue left on the site (Table 7). A 1/10 acre plot was used to inventory the standing trees larger than 4" DBH. A 1/200 acre plot was used to assess the volume in the standing trees less than 4" DBH, and to get the weight of the logging residues left on the ground.

Table 7. Residual volume for the various blocks.

Treatment	Block	Standing Residue	Debris on Ground	Total Residue
		(green tons/acre)		
Conventional	17	14.9	8.2	23.1
	18	22.9	9.5	32.4
	19	17.9	8.0	25.9
	20	8.8	9.4	18.2
Chip Understory	2	0.1	6.5	6.6
	4	0.0	6.8	6.8
	11	0.0	6.3	6.3
	12	0.0	3.3	3.3
Chip All - Delimb Pine	5	0.0	6.2	6.2
	13	0.0	7.6	7.6
	14	0.0	6.4	6.4
	15	2.7	6.6	9.3
	16	0.0	4.3	4.3

The blocks on which the energywood was harvested were very clean with little residue remaining. The tops, as a result of being run through the delimbing gate, were located in large piles. The conventional harvest method left considerably more material to be disposed of during the site preparation, both in standing and debris form, than did the other two methods.

CONCLUSIONS

The costs to harvest the energywood proved to be comparable between the moderate and intensive utilization methods when dealing with similar amounts of volume per acre.

The harvesting of pulpwood by the moderate utilization method tended to be more feasible with the current technology available. The screening process in the intensive utilization method needs to be improved so that a higher quality pulp chip can be achieved in the field. At present, it is easier and more economical for the pulp chips to be screened once they arrive at their destination.

A major concern in any energywood harvest is the availability of markets that can utilize the product. Because energywood is not a highly valued product, the industries or institutions that can use the submerchantable material must be located close to the harvesting site.

The costs calculated for the pulpwood harvest were very reasonable, with none of the blocks costing more than $11.00/green ton to harvest. This enabled the merchantable material to be transported considerable distances and still prove to be profitable.

The going rate in northeast Mississippi for energywood was $10.00/green ton (delivered). This made the harvest of the energywood marginal on a few of the blocks and prohibitive on others. With the constantly changing prices of alternative fuels, this situation could quickly reverse itself in the future, with the harvested energywood being given a higher value. Also, with improvements in the energywood harvesting technology, the costs/ton to harvest the material should decline.

When the energywood is harvested from the understory before the merchantable timber is felled, it makes it much easier for the feller-buncher operators or sawyers to maneuver in the stand. This reduces equipment damage and accidents, and increases productivity.

When comparing this study to similar tests performed in the flat terrain of southern Mississippi and Alabama, certain harvesting aspects exhibited cost differences. A previous energywood harvest on 20-acre test blocks produced lower skidding costs per ton even though the skidding distances were much greater as compared to the current 5-acre blocks that were tested. This indicates that skidding costs increase as the terrain increases in slope. In steeper terrain the fuel consumption also increased, but comparative figures are not available. The average felling costs to harvest the energywood were somewhat lower for the current test because of the ideal harvesting conditions encountered and due to the fact that the feller-buncher operators were more experienced, thus more productive.

Overall, there was an increase in the total harvesting costs for the study conducted in the steep terrain. This was due in whole to the steeper topography, because equipment costs and fuel costs have leveled off or decreased since the test in the lower coastal plains was performed.

Aside from the direct benefit of capturing the available energywood, the moderate and intensive utilization methods also create indirect benefits such as reducing site preparation costs and giving the cleared land a higher post-harvest value. In many cases if the energywood does not pay for itself, the intensified harvest can still be justified through site preparation savings. With the new tax laws there are also implications that if the energywood harvest was performed at a loss, then that loss can be expensed and deducted in the year in which it occurred, instead of having to be carried until the first thinning or the end of the rotation.

Also, an intensively utilized stand has a much better appearance, and aesthetics are important when dealing with the public.

When a company chooses to construct an energywood facility, they do so as a hedge against expected higher-priced alternative fuel sources. With such a large capital investment involved, it brings into being a long-term obligation by the company to acquire the submerchantable material needed, thus creating a market for the energywood products.

The practice of increased utilization is likely to expand in the future because efficiency in harvesting operations is a growing concern, and if the stand in question meets the qualifications in tons of understory biomass per acre and if there is a consumer for the material, then it can be done profitably. There will always be a need for an economical source of energy, and in forestry we have that abundant, renewable resource available.

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COMMERCIAL THINNING SYSTEMS FOR SOUTHERN PINE PLANTATIONS

by

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Abstract

Three thinning patterns - selective forwarder, selective skidder and fifth row/selective skidder - were examined over a range of first thinning stand and removal combinations. Within each pattern, different feller-bunchers and skidders were compared for thinning quality and cost per cord. Selective thinning applications resulted in residual stands with larger average diameters than row/selective patterns. The selective with forwarder pattern using a Bobcat feller-buncher, manual chainsaw processing and Gafner Iron Mule forwarding was the least expensive option.

Introduction

Thinning of the South's third and fourth forests is currently an unanswered question in the minds of many foresters. Without getting into the pro's and con's of thinning, it is important to address what may be the key concerns of the thinning controversy - quality and cost. Can stands be thinned in a silviculturally sound fashion with acceptable costs?

Since 1980 we have examined numerous thinning alternatives. Our goal has been to develop thinning systems which give lowest unit costs with the tree sizes typical to thinning operations. Recognizing that thinning is mainly done for the sake of residual stand improvement, thinning system alternatives which strive for thinning from below or low thinnings were favored.

While our research program has addressed thinning in general, this report is limited to first commercial thinnings. We will discuss the original stand conditions and residual stands after thinning. Of the many thinning patterns tried, the three most applicable are examined along with the appropriate machines. Finally, the costs which resulted are compared for each thinning system.

Study Methods

Most of the available thinning machines have been time and production studied in many different plantations. Typically, rectangular plots, usually 1/2 chain by 2 chains (1/10 acre), were installed, and each tree's DBH, species and location were recorded. A sub-sample of trees were measured for height, clear bole and diameter of largest limb also. Chainsaw operators, feller-bunchers, processors, skidders and forwarders were timed as they worked through these plots.

To make overall system comparisons, costs and production rates for individual machines were combined giving system estimates for particular stands. Stand maps which represented a wide range of original stand densities were picked and duplicated into the acre size stand, that is, the 1/10-acre plots were copied and joined side by side to make an acre stand. Regression estimates from the time studies made on each machine served to predict performance of machines under the various stand conditions.

Stand Conditions

Stands selected ranged in age from 15 to 18 years since planting. During the course of the study stands from 12 to 18 were thinned. Site index and original stocking mainly control the timing of first thinnings. Typically, on average sites with planting densities commonly used in the South, stands should be thinned at ages 14 to 15.

Stands with initial densities at time of thinning of 400, 600 and 800 trees per acre encompass most stands which are thinned operationally. A stand of 400 tree per acre was difficult to find and the one used in this comparison (Table 1) was inferior in site quality compared to the other two. High density stands were also uncommon; most stands which are being commercially first thinned fit the 600 trees per acre category. Figure 1 shows a plot of trees and their locations for 600 trees per acre prior to thinning.

Different levels of thinning density were tested by removing trees through interactive simulation (Greene and Lanford 1984). Each stand was thinned back to three residual levels of 250, 300 and 350 trees per acre (Figure 2). Based on predetermined thinning patterns, trees were removed from the stand to achieve the desired residual densities. Where rows or corridors were required, trees in these access ways were removed first before selectively cutting (thinning from below) the remainder of the stand.

Thinning Patterns

Three thinning patterns were applied to the nine combinations of initial and residual stands. Because these patterns are very closely tied to the type of machine systems used, they were named selective forwarder, selective skidder and fifth-row/selective skidder.

Selective forwarder system

Within the residual densities of this study, narrow forwarders were capable of removing wood in log or product length form without cutting extra trees for access. Therefore, this system is completely selective, that is, only trees which need to be removed for the future performance of the stand are harvested. This system meets the highest standards for thinning as a silvicultural treatment. Table 2 indicates that residual stands have the largest DBH's when thinned with a forwarder system. Conversely, the harvested DBH's are smallest with the selective forwarder system. Since harvesting costs increase with decreasing DBH, the forwarder system is at a cost disadvantage compared to the other two systems.

Figure 3 displays how the example stand with 600 trees per acre initially appeared after being thinned back to 300 trees per acre with the selective forwarder system. Notice that the access corridors wind around high value trees. Even though narrow forwarders can maneuver through a selectively cut stand, it is more efficient to position piles of wood in a systematic fashion for the forwarder to pick up.

Also, it was found that access ways should be perpendicular to any existing rows. Cutting parallel with rows was found to leave holes in the stand because rows were not perfectly parallel, a common feature of both hand and machine planting.

Only three feller-bunchers were used in this report for the selective forwarder system: Mor-Bell Mark IV, Bobcat 1080C and Timbco 2518. Others were studied but are not reported for sake of brevity. Each of these three are capable of thinning selectively with minimal damage to residual trees. While performance on slopes is not quantified here, it was found that the Timbco was least affected by slope and the Mor-Bell affected the most.

Manual felling with chainsaws was also included. Hand piling was required after delimbing and bucking.

After trees were deposited at the corridor by a feller-buncher, they were delimbed and bucked into short lengths and stacked for the forwarder to pick up. Two methods of processing are available - manual and mechanical.

Manual processing required that feller-bunchers position trees parallel to the corridor (Stokes and Lanford 1986). Bunches should be placed to one side of the corridor to allow a passage way for the forwarder. Then chainsaw operators removed the limbs and bucked the bunch of trees. Care was taken that all limbs were removed and that all stems were bucked. Little if any hand piling was required since the trees were already in a pile. As an alternative, trees could be positioned in a herringbone pattern to the corridor. This required less room in the corridor for the bunches but caused the logs furthermost from the corridor to be hand piled back on the butt portions. An advantage of this alternative is that less limbs and other debris remain in the pile of wood to create down stream handling problems.

Mechanical processing required that the feller-buncher position trees perpendicular to the corridor. The processor used in this study was the Valmet 940 GP and was mounted on a Timberjack 385 skidder (Greene and Lanford 1985). The trees were picked up on one side of the corridor and processed into delimbed logs and stacked on the other side of the corridor. Limbs and tops were deposited in the corridor making a road bed for forwarder travel.

The forwarder used was the Gafner 5010 (Lanford 1982). It was selected for its narrow width and wheel tracking ability. Forwarders carry wood rather than drag it like a skidder. A forwarder loaded with logs is shorter than a loaded skidder pulling tree length wood. Since a forwarder carries at least four times as much wood as a skidder, it makes fewer trips in and out of the woods. Therefore there is less opportunity for residual stand damage. The forwarder picks up logs from processed piles and transports then to roadside. The logs are then off loaded to trailers.

Selective skidder system

Skidders require a generally straight access road to remove trees without damaging residual trees. Narrow skidders cause only a few more high valued trees to be removed than with the selective forwarder system (Figure 4). As Table 2 indicates, residual DBH's for the selective skidder were smaller than for the selective forwarder and generally larger than for the fifth-row/selective system. Trees which were removed for corridor access were replaced by trees in the between corridor area of the stand.

Trees were felled and bunched in a herringbone pattern to the access corridor. All trees were removed from access corridors. Between corridors trees were selectively cut. Since grapple skidders were used, manual felling was not possible. Trees were delimbed and topped with chainsaws prior to skidding. All trees were removed with a single pass, that is, both trees from the corridor and between corridors were cut and skidded at the same time. Considerable care was needed by the skidder operator not to damage residual trees as the bunches were skidded into the corridor from their initial location. At roadside, tree length wood was loaded on trailers with a hydraulic knuckle-boom loader.

Three feller-bunchers - Mor-Bell, Bobcat and Timbco - were compared. Two grapple skidders were compared: the Dunham Loghog 760 and the Mor-Bell Logger. A Dunham loader put tree lengths on trailers.

Fifth-row/selective system

Fifth-row thinning is probably the most common mechanical thinning approach in current use. Silviculturally, it has some deficiencies. Every fifth row is removed for access by medium size skidders (Figure 5). Selectivity between access rows is limited because the stand has been reduced by a fifth before the selection process begins. Table 2 shows that residual trees are smallest with the fifth-row/selective system.

Since entire rows were removed, larger feller-bunchers could be used such as the Franklin 105 Feller-Buncher (Schroering et.al. 1985) and Hydro-Ax 411 (Ashmore, et.al. 1983). Two passes through the stand were required. The first removed the row trees, and the second cut trees from between rows. One feller-buncher could do both passes or different feller-bunchers could make the two passes. Other feller-bunchers compared were the Mor-Bell, Bobcat and Timbco. The skidder reported was the Franklin 105 Grapple skidder. Trees were delimbed manually and with a gate delimber. Tree length wood was loaded on trailers with a Dunham loader.

Thinning system cost comparisons

The least expensive system on a cost per cord basis was the semi-mechanical selective forwarder (Table 3). This system used a Bobcat to fell and bunch, manual chainsaw delimbing and bucking and forwarding to roadside. The most expensive was the manual selective forwarder system which did both felling and processing with chainsaw operators.

Of the skidder systems dual felling with the Hydro-Ax 411 (cutting the row) and Mor-bell (cutting selectively) and manual delimbing was the least expensive. Single felling meant that the same type of feller-buncher did both passes; dual felling used different types of feller-bunchers for each pass. Single felling with chainsaw delimbing was the most expensive.

With the exception of manual felling with the selective forwarder system, all other systems were within $1.53 per cord of each other.

Conclusions

Three harvesting systems were compared over nine stand conditions developed from three initial stands thinned back to three residual densities. The range of harvesting systems were representative of current thinning methods, and the range of stands were typical of Southern pine plantations. As measured by residual stand DBH, the selective forwarder system gave the most desirable silvicultural results. Considering unit costs, the selective forwarder system with mechanical felling and manual processing was least expensive. The skidder systems had slightly higher costs. The selective forwarder with manual felling and processing was the most expensive.

The selective forwarder using feller-bunchers and manual processing appeared to be the best approach both for quality and cost. Residual stands had larger trees with the selective forwarder approach. Costs per cord were less even though smaller size trees were being harvested and wood was being cut into short lengths.

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Table 1. Initial stand conditions.

Trees per acre	Average DBH (in)	Basal area per acre (ft^2)	Cords per acre
400	6.5	94	23
600	7.1	162	42
800	7.0	210	55

Table 2. Tree and stand characteristics.

Item		Trees per acre Initial / Residual	400 / 350	400 / 300	400 / 250	600 / 350	600 / 300	600 / 250	800 / 350	800 / 300	800 / 250
Quadratic Average DBH (in)											
	Initial		6.5	6.5	6.5	7.1	7.1	7.1	7.0	7.0	7.0
Selective Forwarder	Harvested		4.8	4.9	5.2	6.2	6.3	6.3	5.9	6.1	6.2
	Residual		6.8	7.0	7.2	7.6	7.8	8.0	8.2	8.3	8.5
Selective Skidder	Harvested		-	6.4	6.1	6.4	6.4	6.4	6.2	6.3	6.3
	Residual		-	6.6	6.8	7.5	7.6	7.8	7.9	8.0	8.2
Fifth-row Skidder	Harvested		-	5.8	5.7	6.5	6.4	6.4	6.1	6.2	6.2
	Residual		-	6.7	6.9	7.3	7.5	7.8	7.8	7.9	8.1
Cords per acre											
	Initial		23.4	23.4	23.4	41.9	41.9	41.9	54.6	54.6	54.6
Selective Forwarder	Harvested		1.2	2.6	4.7	12.5	15.4	18.3	19.1	23.2	26.7
	Residual		22.2	20.8	18.7	29.4	26.5	23.6	35.6	31.4	27.9
Selective Skidder	Harvested		-	6.0	7.6	13.4	16.3	19.3	22.4	26.0	29.3
	Residual		-	17.4	15.8	28.5	25.6	22.6	32.2	28.6	25.3
Fifth-row Skidder	Harvested		-	5.0	6.9	14.9	17.8	20.0	23.4	26.7	29.6
	Residual		-	18.4	16.5	27.0	24.4	21.9	31.2	28.0	25.0

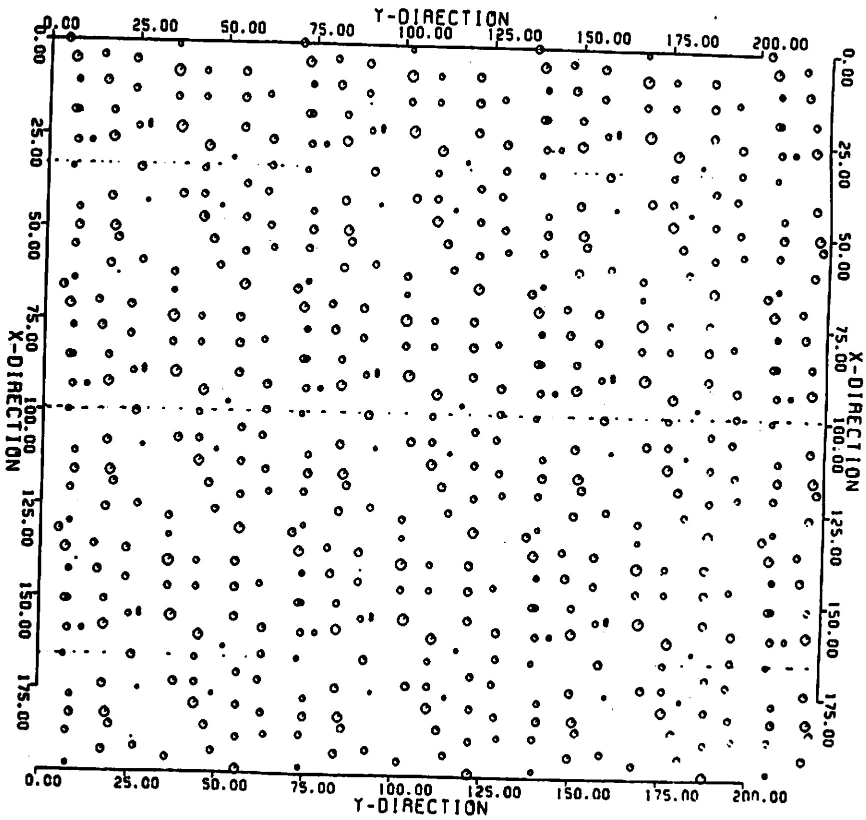

Figure 1. Plantation stand map - 600 trees per acre (distances in feet).

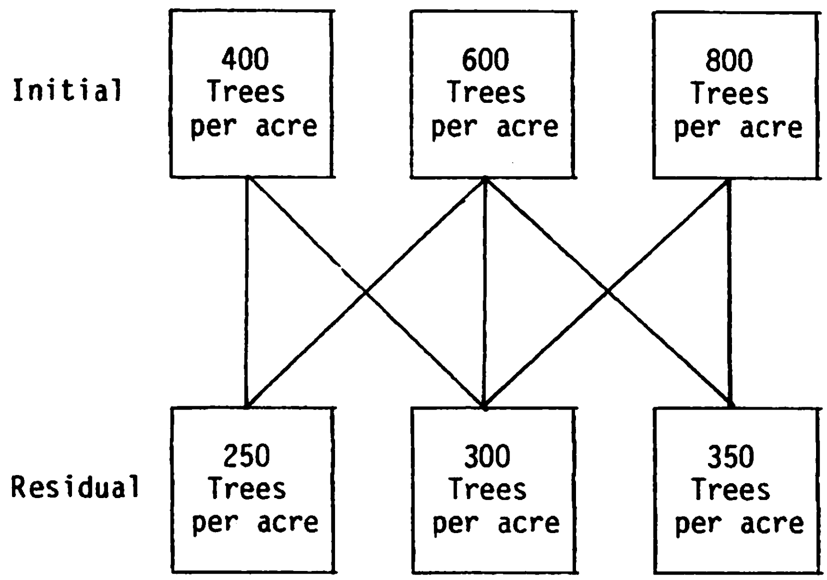

Figure 2. Stand densities.

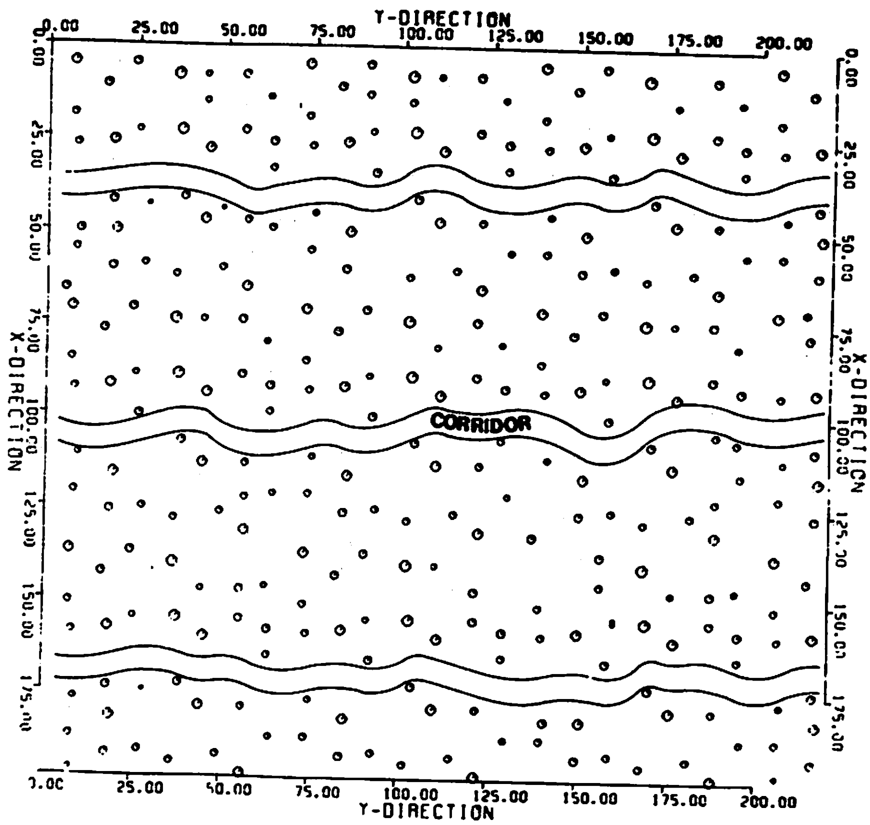

Figure 3. Plantation thinned to 300 trees per acre with selective forwarder system (distances in feet).

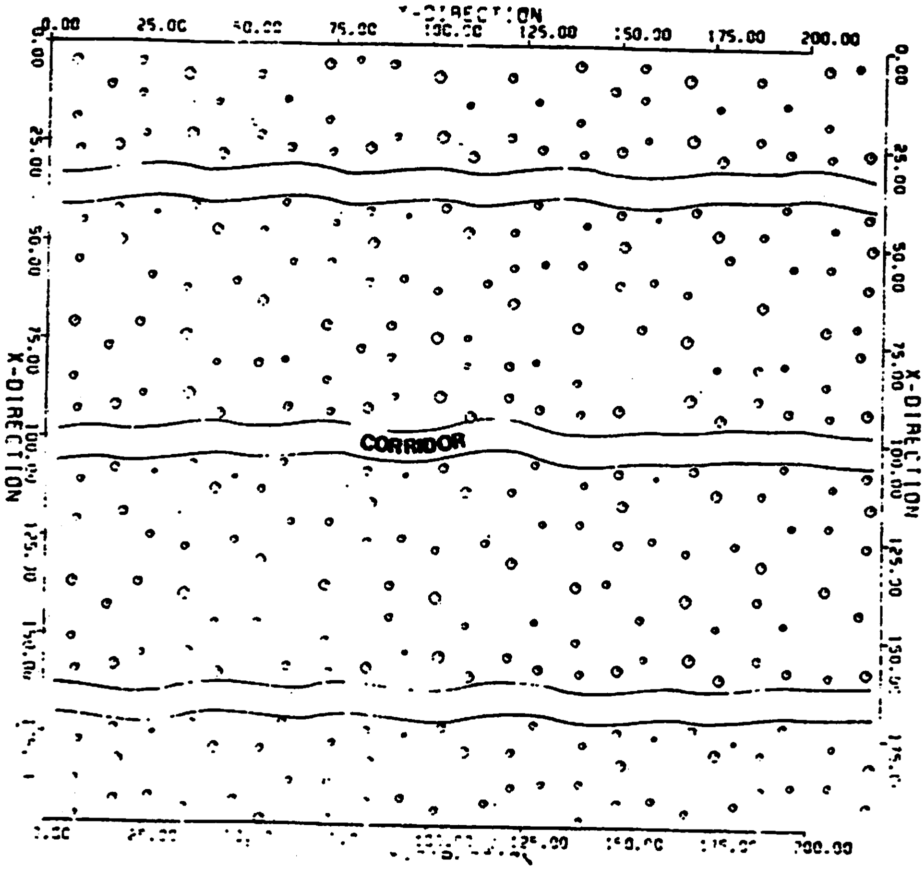

Figure 4. Plantation thinned to 300 trees per acre with selective skidder system (distances in feet).

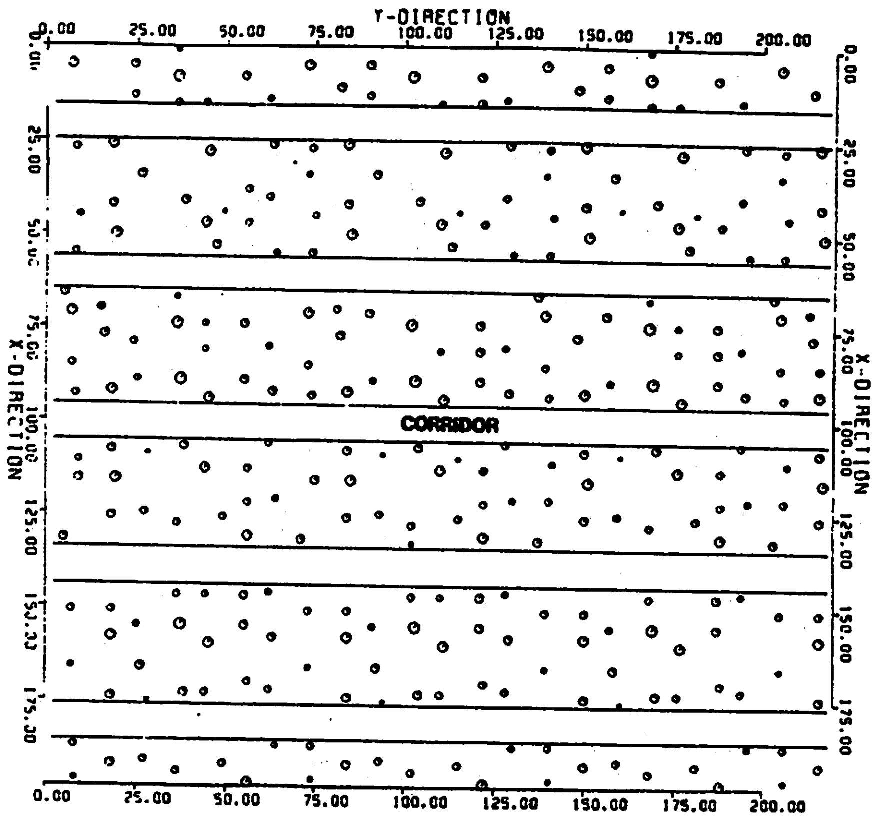

Figure 5. Plantation thinned to 300 trees per acre with fifth-row/selective skidder system (distances in feet).

Table 3. Costs of thinning systems (on board highway haul vehicles).

Thinning systems	$/cord
SELECTIVE FORWARDER	
Manual	22.38
Semi-mechanical (Bobcat)	16.45
Mechanical (Bobcat)	18.77
SELECTIVE SKIDDER	
Mor-bell Logger (Bobcat)	17.52
FIFTH-ROW/SELECTIVE SKIDDER	
Single felling	
Manual processing (Franklin)	18.08
Gate delimbing (Franklin)	17.75
Dual felling	
Manual processing (Hydro-Ax & Mor-bell)	17.14
Gate delimbing (Hydro-Ax & Franklin)	17.30

Feller-bunchers in parentheses.

CHARACTERISTICS OF INDEPENDENT LOGGING CONTRACTORS IN GEORGIA

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ABSTRACT

Independent logging contractors in Georgia were surveyed in early 1987 to identify the types of systems in use, the products produced, the productivity of labor and capital inputs, and the methods of moving between harvested tracts. Of 769 loggers contacted, 248 responded to the survey. Response was greatest from the Central and Southeast regions of the state where industry is concentrated. Responses indicated that 80 percent of Georgia loggers primarily harvest tree-length pine from clearcuts. The "average" logger in Georgia employed 6 people in the woods, had a capital investment of approximately $250,000, and delivered 279 cords per week. Harvested tract size averaged 283 acres. Moves between tracts covered 30 miles, took 6 hours to complete, and occurred about every 8 weeks. In general loggers appear to be highly productive and capital-intensive. The "average" system required $19.63 of invested capital per cord of annual production and produced 0.95 cords per man-hour of labor input. Tree-length systems produced twice as much volume per man-hour and required 22 percent less capital per cord than did shortwood systems.

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INTRODUCTION

Forest products manufacturing facilities in the South depend almost exclusively upon independent logging contractors for harvest and delivery of raw forest products such as pulpwood, sawlogs, and whole-tree chips. The characteristics of these logging businesses often determine their ability to perform certain types of harvests and their sensitivity to changes in input factors such the cost of capital, operating costs, labor availability, stand conditions, and other factors.

Several studies have sought to characterize the logging work force in the South. During the 1970's the American Pulpwood Association (APA) conducted regular censuses of the producer force in their two technical divisions in the South (Watson and others 1977, Weaver and others 1981). With the exception of a report which described high volume producers (Weaver and others 1982), these reports focused on producers who harvested pulpwood as their primary product. At the time of these surveys, pulpwood production was still largely dominated by the labor-intensive, stump-to-stump bobtail truck systems. Due to a variety of market forces over the past ten years, these bobtail systems have been reduced greatly in number. Abandonment of rural rail lines was a major factor which prompted mills to close outlying woodyards and encourage adoption of tree-length systems. The availability of dependable logging equipment has made mechanization a more attainable goal and fostered competition in the marketplace which has forced many small producers out of business (Cubbage and others 1987).

The survey of high volume producers reported by Weaver and others (1982) probably came closer to describing the typical independent logging contractor of today than did the previous surveys of pulpwood producers. High volume producers were considered to produce at least 150 cords per week. The type of product was not restricted to pulpwood but also included log and chip products. This permitted contractors who primarily produced sawlogs but also produced substantial volumes of pulpwood to be included in the high volume producer survey. The survey included 123 loggers. Sixty-two percent of the respondents were from the Southeastern Technical Division (SETD) of APA which is comprised of the non-mountainous portions of Georgia, Florida, South Carolina, North Carolina, Virginia, and Maryland. Weekly production in the Southeast averaged 409 cords with longwood accounting for 82 percent of the production. Loggers consistently reported the use of mechanized felling equipment (83 percent), rubber-tired skidders (98 percent), knuckleboom loaders (over 90 percent), and diesel powered tractor-trailers (82 percent). The majority of the equipment reported was less than 4 years old.

While these previous surveys included loggers throughout the South, no survey has been conducted which focused exclusively on Georgia loggers. The study reported here sought to characterize the independent logging contractors working in Georgia and to identify factors which could affect their profitability and productivity. Specifically, this study sought to:

(1) Identify the types of systems used and the products produced by region within the state of Georgia;

(2) Quantify the time and cost involved in moving between harvested tracts of timber; and

(3) Estimate the capital investment, labor force, and productivity of the operations.

Since this study focused on <u>independent</u> logging contractors, few small, bobtail truck producers were included in the survey. Many bobtail operators rely heavily on wood dealerships to handle the legal and financial aspects of their business and therefore do not function as truly independent businessmen. This probably was not a significant omission in terms of volume produced in Georgia. In 1979, two-thirds of the pulpwood produced in the South was produced by 25 percent of the harvesting force. No doubt the importance of large producers has increased during the past decade.

METHODS

Information was obtained via a questionnaire mailed to independent loggers in Georgia. The survey consisted of general questions regarding the counties in which loggers operated, the products produced, the types of harvests, and the species cut. An additional eight questions asked for detailed information on the methods, time spent, and costs of moving between harvested tracts. Another two questions were designed to obtain detailed information on the number of employees and the number, type, and ages of equipment used. The final four questions obtained information on topics of current interest to the logging industry in Georgia including logging regulation, overweight fines, on-board log truck scales, and use of contract hauling.

The mailing list of loggers used for this survey was obtained by editing a mailing list maintained by the Cooperative Extension Service of subscribers to the state timber harvesting newsletter. The original list contained names of loggers, procurement foresters, equipment suppliers, and others interested in timber harvesting. The list was edited to delete obvious non-loggers. This provided a list of 769 people which were mailed a survey. Questionnaires were mailed in November 1986 with a follow-up mailing in January 1987. Responses were tabulated by region using the forest survey units of the U.S. Forest Service (Figure 1) reported by Sheffield and Knight (1984).

Capital investment was determined using the depreciated value of each piece of equipment owned by the logger. Depreciated values were estimated using 1986 list prices for new equipment reported by Dorris and Cubbage (1987) with the average annual depreciation rates reported in the Green Guide for Construction Equipment (1986). The typical size of equipment used in the state and reported machine age were used to determine the depreciated value of each machine. Investment for the system was determined by summing values for each machine in the system.

RESULTS

The first mailing in November produced 176 responses from active loggers while the follow-up mailing in January provided an additional 72 responses. This provided a dataset of 248 loggers responding out of a total of 769 included in the survey. This implies a response rate of 32.2 percent which is satisfactory for an unsolicited mail survey. Even after careful editing of the mailing list, there probably remained a substantial number of non-loggers which could not be identified from mailing label data. It is probably safe to estimate that about 30 percent of the independent logging contractors in the state received and responded to the survey.

The largest percentage of responses came from loggers in the Central and Southeast regions of the state (Table 1). This was expected since both standing pine inventory and forest industry are concentrated in these areas (Sheffield and Knight 1984, Hutchins 1987). The product produced by the respondents was primarily tree-lengths (83 percent) with both product-length logs and chips each reported by less than 10 percent of those responding. Most loggers produced a mixture of species which was mostly pine (48 percent) or exclusively pine (40 percent). Most loggers (82 percent) harvested clearcuts while the other 18 percent worked in partial cuts.

Almost three-fourths of those responding (71 percent) reported use of a feller-buncher and grapple skidder in their system while 17 percent reported manual felling with chainsaws and cable skidders (Table 2). The number of employees in the woods varied greatly with most loggers using from three to seven employees. The mean number of employees for all systems statewide was 5.96 people. Investment in equipment also varied widely with most systems reported to have a capital investment of less than $500,000. The average system investment was $244,116.

Statewide statistics indicate a highly productive logging work force which regularly faces a wide variety of stand conditions (Table 3). Weekly production for all respondents averaged 279 cords from tracts which averaged 238 acres in size. The "average" system in the state required $19.63 of capital investment per cord of annual production and 1.05 man-hours of labor per cord (exclusive of hauling). Moves between tracts occurred approximately every 8 weeks with loggers estimating the cost of moves at almost $450 per move. On average, moves covered 29.6 miles of distance, required 5.84 hours of time, and were performed by 3.8 people.

The labor and capital efficiency of systems varied substantially by the type of product produced (Table 4). Shortwood systems were the least efficient users of both labor and capital among systems producing roundwood. Tree-length systems were the most efficient users of both labor and capital of all systems considered. Tree-length systems produced twice as much volume per man-hour as did shortwood systems while requiring 22 percent less capital investment per cord of annual production.

Five general types of logging systems were identified in the survey (Table 5). Shortwood skidding systems produced shortwood by felling trees manually with chainsaws and moving wood to roadside with small skidders. Wood was loaded with the assistance of a small loader of some type. The technology used in other systems is indicated by their titles. Delimbing was assumed to be performed by chainsaw with cable skidding systems and with a delimbing gate on grapple skidder systems. Systems using manual felling required the least capital investment per cord produced but were among the least productive per man-hour of labor used. Use of a directional shear instead of a chainsaw increased the amount of capital investment per cord but did not increase the productivity per man-hour. Systems using feller/bunchers and grapple skidders had the highest man-hour productivity while requiring only slightly more capital investment per cord.

Moves between tracts varied with the type of system in use (Table 6). Shortwood systems moved the shortest distance (12 miles) while other systems moved 25 to 35 miles between tracts. As expected, chipping systems reported the highest moving cost while highly mechanized roundwood systems had slightly lower moving costs. With the exception of the shortwood system, most systems took most of a working day to move and spent six to ten weeks on each tract.

Productivity of logging systems varied substantially between regions of the state (Table 7). Weekly production, tract sizes, and capital investments in equipment were highest in the Central and Southeast regions of the state. Loggers in the North region reported use of 4 people in the woods on their operations while all other regions used about 6 people in woods operations. Man-hour productivity (exclusive of hauling) was impressive in all regions with the highest productivity found in the Southeast and Central regions of the state.

Tree-length systems, which accounted for 83 percent of all systems reported, were also found to vary considerably between regions (Table 8). Loggers in the Central and Southeast regions of the state were again found to have the highest weekly production, the largest tract sizes, and the highest man-hour productivity. Capital investment per cord was lowest in the Southwest region, followed closely by the Central and Southeast, with the North and North Central loggers reporting the highest per cord capital investment.

CONCLUSIONS

Loggers operating in Georgia in early 1987 closely resembled the high-volume producers identified by Weaver and others in 1982. Highly mechanized tree-length systems still dominated the industry while weekly production averaged almost 300 cords. Most loggers in Georgia, even in the northern areas of the state, primarily produce tree-length pine from clearcuts.

The heavy reliance on tree-length systems is at least partially explained by their productivity. Tree-length systems produced twice the volume per man-hour of shortwood systems while requiring 22 percent less capital investment per cord of annual production. System productivity varied substantially between regions of the state with the most productive loggers found in the Central and Southeast regions. These regions have a large, stable forest industry and a large portion of the commercial forestland in the state.

Moves between tracts occurred about every 8 weeks with the cost estimated by the logger at $450 per move. Moves covered 30 miles of distance, took about 6 hours to complete, and were performed by 4 people. Characteristics of moves did not vary greatly by region, but did vary by the type of system used. As expected, chipping systems reported the highest moving cost while shortwood systems reported the lowest. However, the average costs were less than $1000 per move for all but the chipping systems. Most systems moved 25 to 35 miles between tracts, took most of a working day to move, and spent six to ten weeks on a tract.

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Table 1. General characteristics of independent loggers in Georgia.

Characteristic	Number of Responses	Percent of Total
Region of State		
North	17	7
North Central	37	16
Central	75	32
Southeast	70	30
Southwest	36	15
	235	100
Principal Product		
Shortwood	7	3
Log Lengths	21	8
Tree Lengths	204	83
Whole Tree Chips	15	6
	247	100
Type of Harvest		
Partial Cut	45	18
Clearcut	203	82
	248	100
Species		
Pine	96	40
Hardwood	7	3
Pine Mix	114	48
Hardwood Mix	21	9
	238	100

Table 2. Characteristics of timber harvesting systems in Georgia.

Characteristic	Number	Percent of Total
Type of System (n=233)		
Shortwood skidding	4	2
Manual felling/ cable skidder	39	17
Directional shear/ cable skidder	9	4
Feller-buncher/ grapple skidder	166	71
Chipping	15	6
Number of Employees (n=226, mean = 5.96 people)		
2 or less	20	9
3	31	14
4	46	20
5	39	17
6	29	13
7	20	9
8	5	2
9	9	4
10	6	3
11	4	2
12	5	2
13 or more	12	5
Capital Investment in Equipment (n=248, mean = $244,116)		
$ 50,000 or less	41	17
100,000	36	15
150,000	25	10
200,000	29	12
250,000	32	13
300,000	16	6
350,000	18	7
400,000	17	7
450,000	10	4
500,000	5	2
550,000	6	2
600,000	3	1
650,000	3	1
700,000	2	1
750,000	3	1
800,000 or more	2	1

Table 3. Statistics for independent contractors responding to the survey.

	N	MEAN	STD. DEV.	MIN	MAX
Employees	226	5.96	4.20	1	30
Investment ($)	248	244,116	175,621	-	934,506
Cords/Week	237	279	148	25	800
Tract Size (ac)	236	238	411	3.5	5250
Investment/Cord	237	19.63	14.88	-	145.01
Man-Hours/Cord	220	1.05	1.07	0.27	10.00
Cords/Man-Hour	220	0.95	0.94	0.10	3.70
Move Distance (miles)	239	29.6	22.1	-	133
Move Time (hours)	240	5.84	4.39	1	45
People Used to Move	239	3.76	1.87	1	12
Logger's Estimate of Moving Cost ($)	223	447	631	1	6150
Average Time on a Tract (weeks)	229	7.6	5.6	1	40

Table 4. Average productivity of harvesting systems in Georgia by product produced.

Product Form	Cords per Week	Number of Employees	Capital Investment	Tract Size (ac)	Capital per Cord	Cords per Man-Hour
Shortwood	154	2.8	$ 65,000	60	23.44	0.52
Log Lengths	142	4.1	117,000	390	22.09	0.66
Tree Lengths	289	5.9	245,000	225	18.38	1.03
Whole Tree Chips	368	10.0	506,000	308	32.24	0.72

Table 5. Average productivity of harvesting systems in Georgia.

System	Cords per Week	Number of Employees	Capital Investment	Tract Size (ac)	Capital per Cord	Cords per Man-Hour
Shortwood Skidding	162	3.0	$ 72,000	62	15.46	0.66
Manual Felling Cable Skidding	166	4.4	99,000	157	14.55	0.74
Directional Shear Cable Skidding	273	6.6	235,000	121	22.81	0.74
Feller/Buncher Grapple Skidder	302	6.1	276,000	224	19.97	1.06
Chipping	368	10.0	506,000	209	32.24	0.72

Table 6. Average characteristics of moves between tracts by type of harvesting system.

System	Tract Size	Move Time	Distance Moved	Moving Cost	Time on Tract
	(acres)	(hr)	(miles)	($)	(weeks)
Shortwood Skidding	62	4.5	12	83	4.5
Manual Felling Cable Skidding	157	8.2	26	253	8.1
Directional Shear Cable Skidding	121	5.5	26	621	5.5
Feller/Buncher Grapple Skidder	224	7.4	30	458	7.5
Chipping	209	9.4	35	691	9.7

Table 7. Average productivity of all responding independent contractors in Georgia by region.

Region	Cords per Week	Number of Employees	Capital Investment	Tract Size (ac)	Capital per Cord	Cords per Man-Hour
North	166	3.8	$ 142,000	70	18.69	0.84
North Central	199	5.9	214,000	130	21.37	0.76
Central	340	7.1	289,000	288	18.43	1.05
Southeast	313	5.8	273,000	255	20.03	1.10
Southwest	246	5.6	205,000	316	19.08	0.86

Table 8. Average productivity of tree-length logging systems in Georgia by region.

Region	Cords per Week	Number of Employees	Capital Investment	Tract Size (ac)	Capital per Cord	Cords per Man-Hour
North	174	4.0	$ 172,000	83	20.04	0.81
North Central	211	5.5	222,000	126	20.65	0.95
Central	337	6.8	278,000	286	17.07	1.14
Southeast	320	5.8	261,000	250	19.02	1.11
Southwest	251	5.8	191,000	183	16.46	0.90

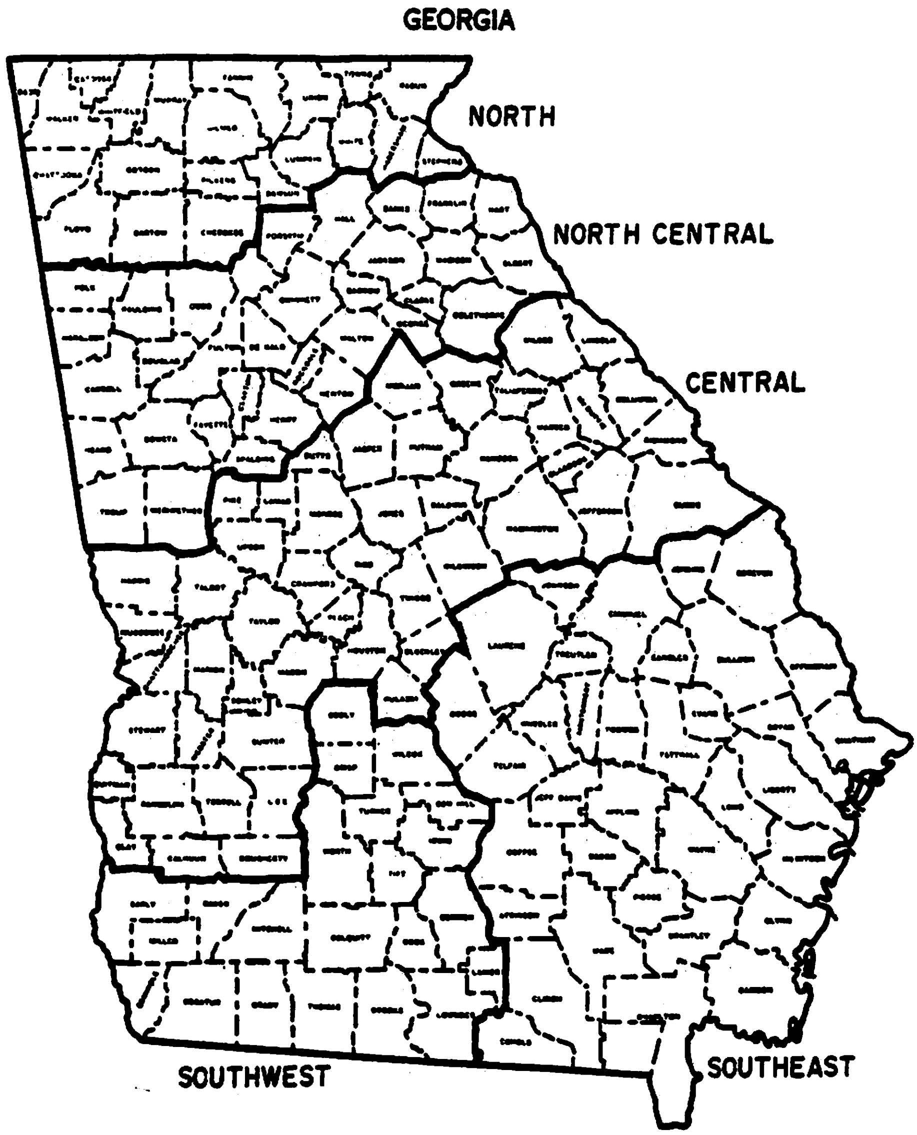

Figure 1. Forest survey regions in Georgia. (from Sheffield and Knight 1984).

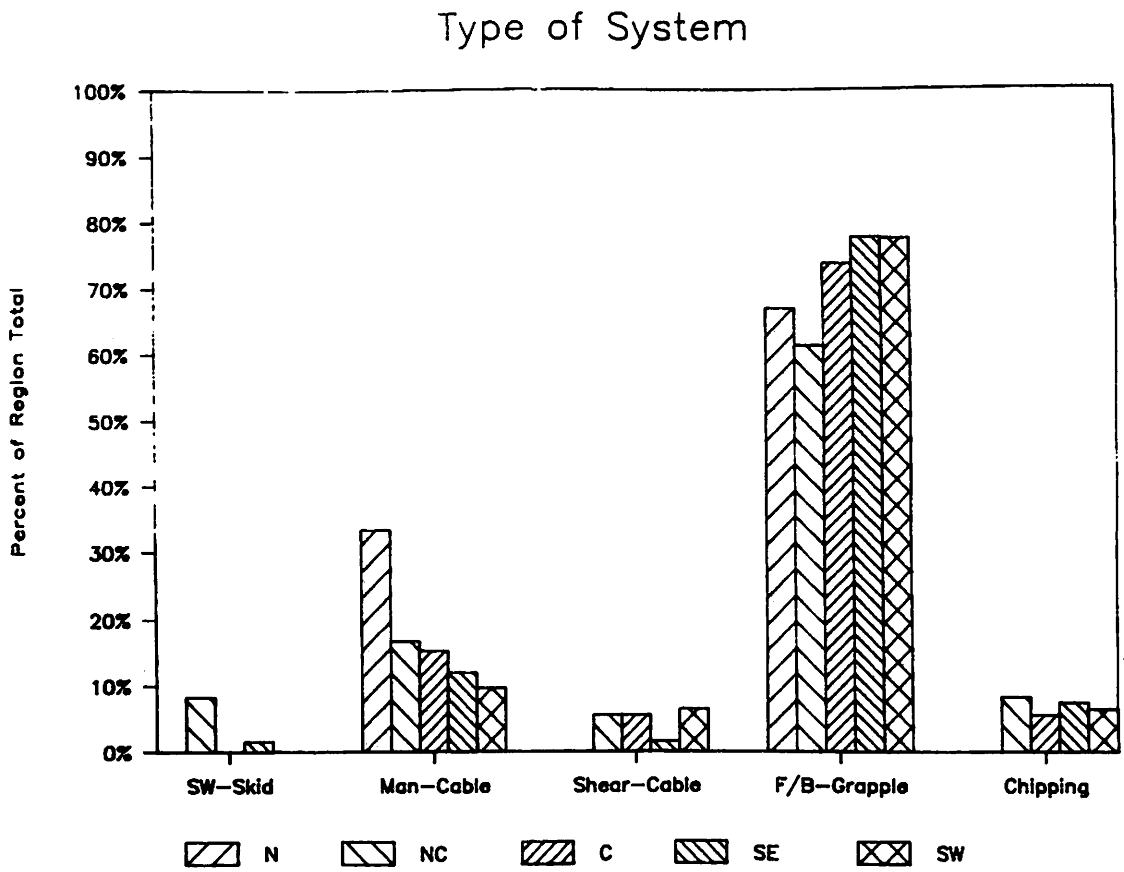

Figure 2. Harvesting system classes within the five regions of Georgia.

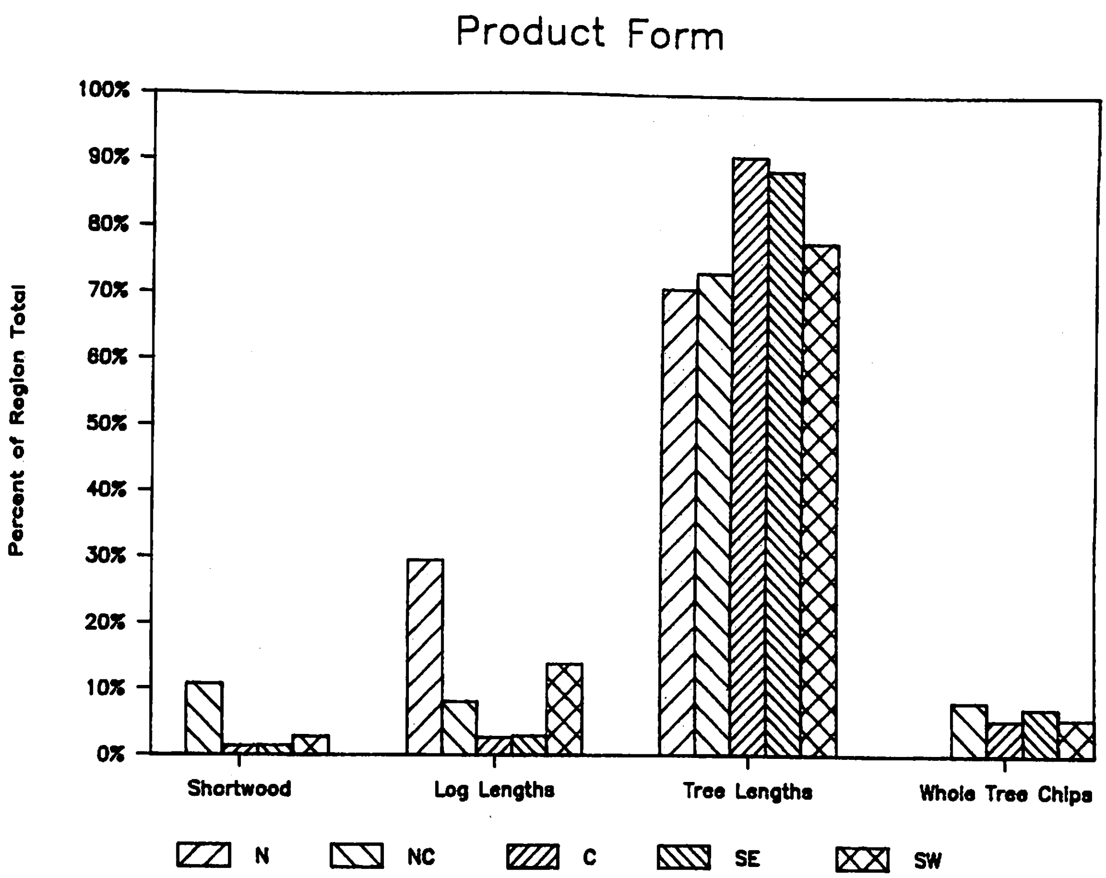

Figure 3. Product forms reported within the five regions of Georgia.

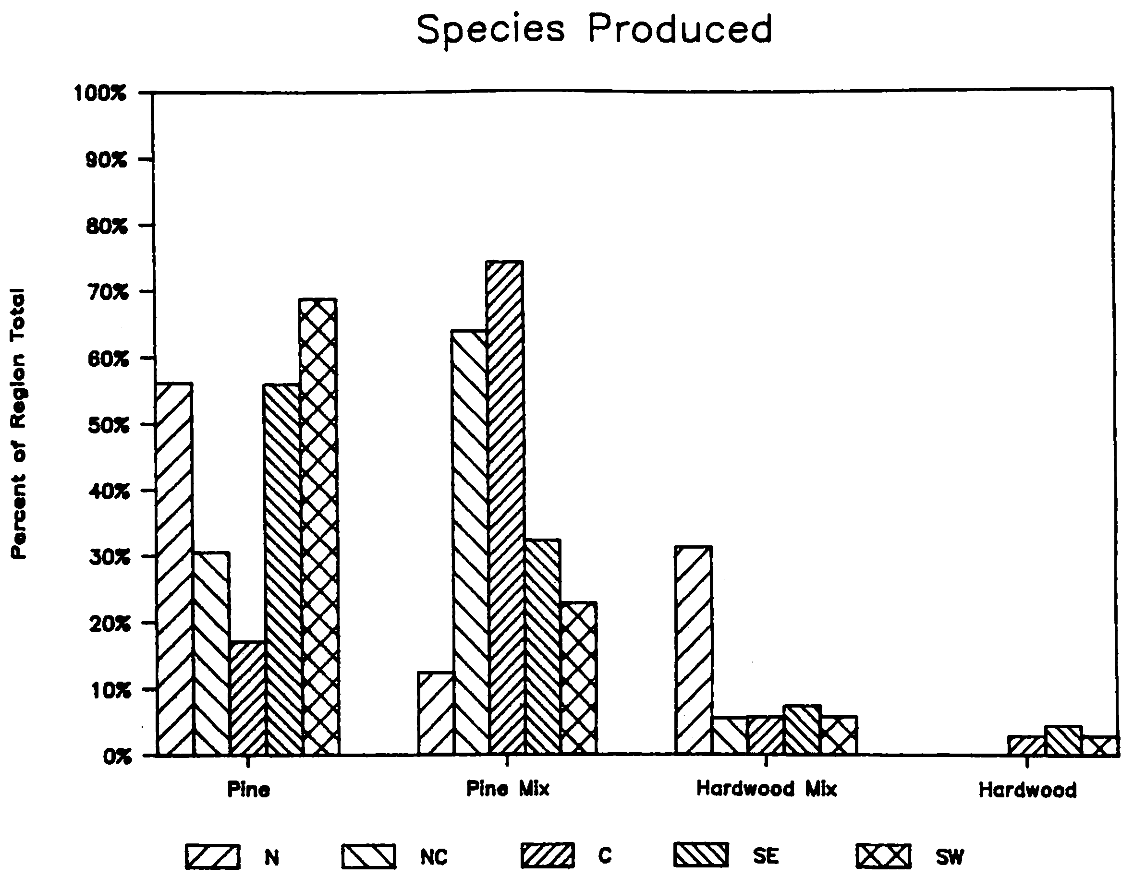

Figure 4. Species produced within the five regions of Georgia.

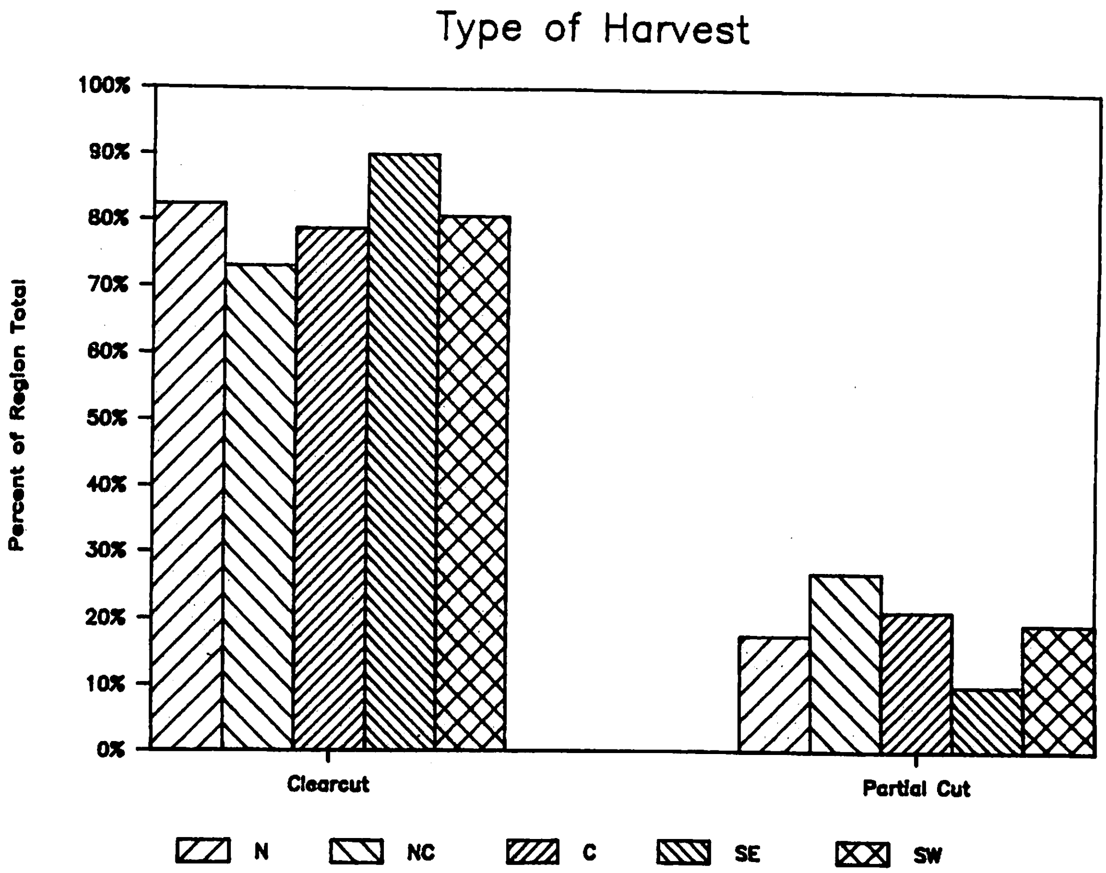

Figure 5. Types of timber harvests within the five regions of Georgia.

HARVESTING AND PROCESSING BIOMASS OF SMALL DIAMETER STANDS FOR MULTIPLE PRODUCTS IN THE NORTHWEST[1]

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ABSTRACT

Dense stands of small diameter timber (western hemlock type) are stagnated on the Olympic peninsula of western Washington. A new harvesting and processing system is being operated on these stands in search of economic methods of converting the stands to a more vigorous and manageable condition. The new system employs six pieces of woodland equipment, three of which are distinctly new. Trees are felled with a new steep-slope feller/buncher and carried to the in-woods processing system by a clam bunk grapple skidder (forwarder), where they are sorted and processed into three products: sawlogs, clean chips, and hogfuel. A prototype, multi-stem, chain flail debarker/delimber prepares some stems for chipping. A conveyor system lifts bark and branches into a prototype shredder, which processes all woody materials and debris that are not sorted out for sawlogs or clean chips into hogfuel. A study was conducted on the productivity and cost of the system in operation. Results of the study showed that the system harvested and processed study block B for a cost of $13.59 per green ton. The delivered product mix was 53% chips, 21% sawlogs, and 26% hogfuel by weight. The productivity and machine rate of each piece of harvesting and processing equipment are given.

BACKGROUND

The production and cost results presented in this paper came from two studies of new harvesting and in-woods processing equipment applied to the harvest of very dense stands of overstocked, stagnant, small trees on the Olympic peninsula in the state of Washington. These dense stands have grown from natural regeneration processes following a series of catastrophic fires, which occurred in the first quarter of this century. Trees in these dense stands have an average diameter at breast height of less than 8 inches. They occur in tree densities

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[1]Presented at the 10th Annual Council on Forest Engineering Meeting, Syracuse, New York, 4 August 1987.

ranging up to 40,000 trees per acre. The primary species are western hemlock (Tsuga heterophylla (Raf.) Sarg.), Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco. Var. Menziesii), and western redcedar (Thuja plicata Donn ex D.Don), with occasional large cedar snags that survived the earlier fires.

Land managers have desired and attempted to improve the productivity of these lands, because the crowded trees are not growing normally. Attempts to harvest or even to convert these stands have faced technically and economically limiting equipment and methods. The land has often suffered adverse environmental impacts from attempts to adapt equipment to these stands.

Some positive progress has been made, however, and products are now being removed from the stand and delivered to multiple markets at a profit. The stands are coming into normal management patterns within acceptable environmental disturbance limits. One way that this is being accomplished is with a new, in-woods processing system operated by Hermann Bros. Logging and Construction Company of Port Angeles, Washington. Hermann Bros. had attempted various methods of harvesting and processing with a concentrated effort to match products to available markets. In 1983, the Forest Service awarded an extended service contract to Hermann Bros. 1) to encourage the continued development of suitable equipment and methods for this application, and 2) to provide the basis for a comprehensive study of the technology and economic feasibility of removing and marketing the products from small diameter tree stands. The U.S. Department of Energy also became a cooperative partner in this effort by awarding a grant to Hermann Bros. through the Pacific Northwest and Alaska Bioenergy Program (administered by the Bonneville Power Administration), to assist in the development of specialized equipment.

OBJECTIVES

The overall goal of this effort was to characterize and quantify the operating parameters of the existing harvesting and processing system at work in a stand of small diameter trees. The motivation behind the effort is the need for a cost effective stand conversion methodology. Potential markets for the combined products of the stands present an opportunity for revenue to aid the conversion of these stands.
Specific objectives of this study are to:

1. Measure the quantities of respective wood products harvested and processed by the Hermann Bros. system.

2. Determine the costs and productivity of each piece of equipment used in the harvesting and processing system.

3. Identify and sum the total costs of owning and operating the harvesting and processing system during the study periods.

4. Determine the productive cost of harvesting and processing with this system as it produces the observed product mix.

SYSTEMS DESCRIPTION

Figure 1 illustrates the equipment arrangement and material flows of the doghair harvesting and processing system. The configuration of equipment that is currently used is as follows:

HARVESTING SYSTEM

Feller/Buncher: A prototype steep slope feller/buncher, model FB-1, developed by Washington Logging Equipment Company[2] was used to cut and prebunch the doghair trees.

Forwarder: A rubber tired, clam bunk skidder, Timberjack model 520A, with a self-loading grapple was used to transport the prebunched trees from the woods to the processing site.

PROCESSING SYSTEM

Mobile Loader: A self propelled, Caterpillar 225, shovel-type loader was used to sort the trees and position them for processing by the appropriate equipment, depending on their size and grade. The loader was an integral part of the clean chip operation, feeding trees through the debarker/delimber and into the reach of the grapple used by the chipper operator to feed the chipper. This loader moved various forms of woody materials to the shredder. The loader also loaded log trucks.

Debarker/Delimber: A prototype chain flail machine, built by Hermann Bros., cleaned bark and limbs from multiple stems prior to chipping so that the resulting chips would have relatively low bark content. The flail chains were mounted on twin vertical shafts.

Chipper: A Morbark Chiparvester with a 23 inch in-feed opening was used for processing the debarked trees into clean chips.

Shredder: A prototype machine with a drum chipping head and a built-in Prentice loader was used for processing the smaller trees, the bark and limbs from the debarker, the limbs and trim ends from the sawlog operation, and all other subgrade material on the landing into hogfuel.

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[2]The FB-1 is currently manufactured and marketed by Allied Systems Company of Sherwood, Oregon as the Allied Tree Harvester ATH-28.

Conveyor/Magnet System: A hydraulically driven conveyor system expelled bark and limbs from the debarker/delimber. The conveyor system continuously sorted the woody debris into three size categories: 1) large, heavy limbs; 2) small limbs, and 3) fine materials. Both categories of limbs were piled within reach of the shredder grapple, which periodically lifted the piles and loaded them into the shredder in-feed bin. The fine materials were lifted by another conveyor and dropped across an inclined magnet, which was designed to trap ferrous materials and keep them from damaging the cutting teeth inside the shredder.

SUPPORT SYSTEM

Road and Landing Construction Equipment: Sundry equipments were needed in various capacities and for varied lengths of time to prepare and maintain the landing at the processing site and the road that leads to it. Items in this category included earth moving trucks, front end loaders, bull dozers, and motor graders.

Maintenance Equipment: Service vehicles with welders, hoists, and spare parts were required to maintain the processing equipment in operating condition. Fuel and oil vehicles were also needed on a regular basis. Some maintenance equipment was scheduled on regular intervals; most maintenance tasks were scheduled after normal operating hours, but this equipment was also on call to remedy occasional, unexpected maintenance items during regular operational periods.

Crew transportation: A six-passenger pickup truck was used to transport the work crew to the work site each day.

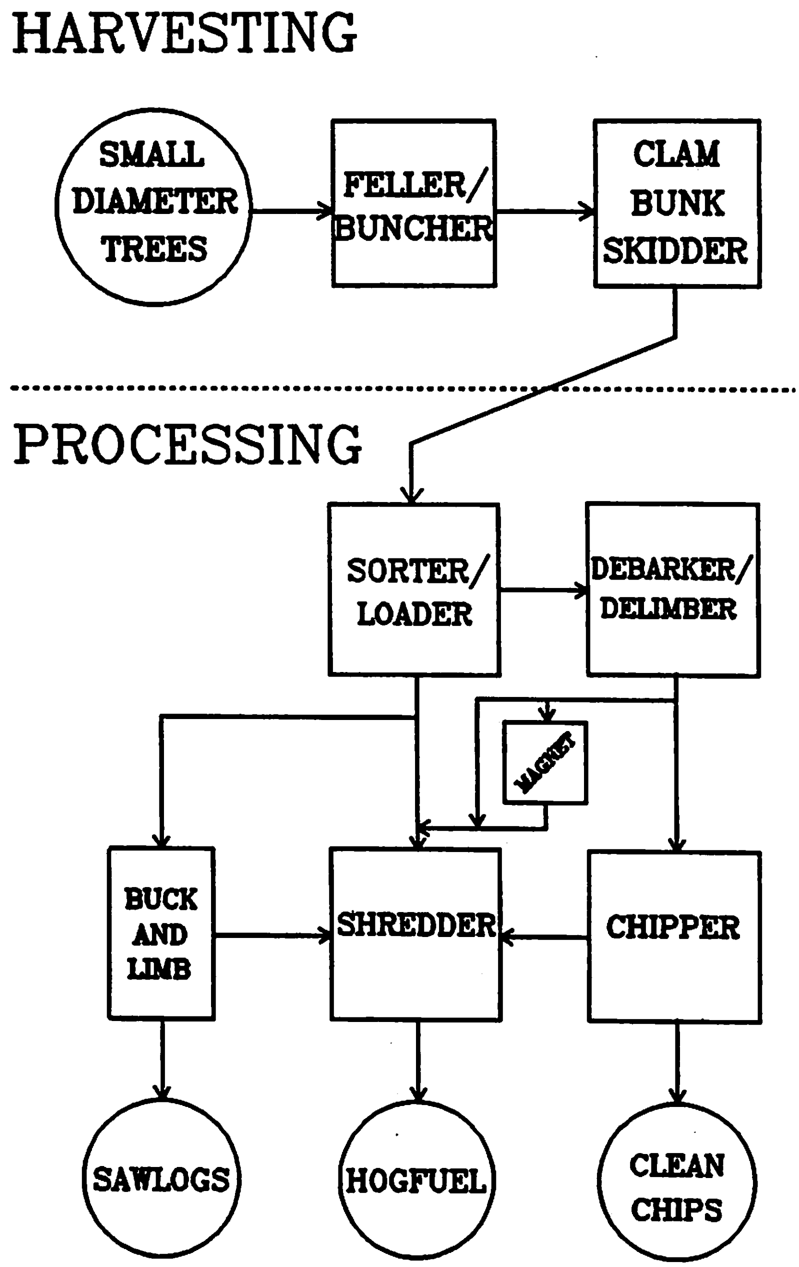

Figure 1. Equipment arrangement and material flows through the in-woods processing system for doghair.

STUDY METHODS

The study was conducted on two blocks of small diameter timber that had been targeted for harvest during the study time frame. For each study block, the harvesting and processing systems were in place and operating before and after the study so that a steady state operation was observed without start-up and clean-up transients. However, in order to track continuity of material flow and material handling procedures, each study block was completely harvested during the respective harvest period. Furthermore, the processing site was purged of all non-study materials before and at the conclusion of each study period so that all of but no more than the trees available on the marked study blocks were processed during the study periods.

STAND INVENTORY

The numbers and sizes of the trees in each study block were recorded by a routine stand exam procedure. On each block, twelve sample plots were systematically laid out. Each plot was a circle covering one fiftieth of an acre. All standing trees in the plots, living and dead, were inventoried by species in one inch diameter classes. Diameters at breast height of all sample trees were recorded, and heights of 3 trees in each diameter class were recorded. The ground slope was measured and the terrain roughness was assessed. An estimate of the total number of trees per acre was then made.

TIME AND PRODUCTION MEASUREMENTS

During actual harvesting and processing of the trees from the study blocks, observations were made and recorded to provide data that could result in measurements of production rate for each piece of equipment in the system. This required a careful distinction in the way each equipment was operated. Time elements and units of production were recorded as described below.

TIME MEASUREMENTS (Hours)

An on-site observer recorded equipment use time in the following categories for each equipment:

Scheduled Time: Total planned work hours that each piece of equipment was assigned to the job.

Productive Time: Actual hours during which the equipment was working at the assigned task(s).

Idle Time: Periods of time during which the subject equipment was ready to be productive but could not process material because none was available from the previous process. (No workload.)

Delay Time: Periods of time during which a machine could not complete material processing because the subsequent process was fully loaded and could not accept new material. (Bottleneck ahead.)

Down Time: Periods of time during which the equipment was unavailable for productive work because of scheduled or non-scheduled interruption of processing due to mechanical or operator inability to proceed.

PRODUCTION MEASUREMENTS (Tons)

Production of the harvesting and processing system was measured in units of green weight (tons). Weight units are preferred over other units such as cords, board feet, or even cubic feet for biomass measurements because all forms and parts of the tree can be consistently accounted for by weight. Very small trees cannot be measured by existing board foot rules, and no other measurement adequately tracks limbs and tops. Also, many wood handling systems are limited in how much weight they can lift, and equipment designers and operators can be more effective, knowing how much actual weight is to be handled. Weight units can readily be converted to other units of measure, when needed to aid communication. Green weight may be adjusted for moisture content to reflect wood weight at a different moisture content, if desired, such as bone dry units.

For this study, all products leaving the processing site at the landing were weighed on portable truck scales. All trucks were weighed loaded and unloaded so that the product net weight could be determined. The portable scale results were corroborated with mill scales where the products were delivered. The net weights of each product were summed to give the individual production of logs, chips, and hogfuel. The weights of all products were then summed to give the aggregated production (multiple-product yield) from the study blocks. Because the landing was cleared before and after each study period, the assumption was made that the total product weight[3] was equivalent to the weight of all trees handled by the feller/buncher and subsequently by the forwarder and also the mobile loader. Similarly, the weight of all chips was the production of the chipper and the debarker/delimber. The total hogfuel weight was the production of the shredder, and the production of sawlogs was equal to the weight of the logs that went out on log trucks.

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[3]The moisture loss was assumed to be negligible during the harvesting and processing activities. This assumption may be weak, because trees felled and left on the ground with their crowns intact continue to transpire moisture. Moisture is also driven off during the chipping and shredding operations (as witnessed in visible evaporation from warm chips in freshly filled vans).

COST METHODS (Dollars)

The cost of harvesting and processing the small diameter stands was an important part of the study because the economics of stand conversion could make the difference between viability or misapplication of the system. Costs of ownership (Mifflin, 1980) were calculated for each equipment, based on the original investment, interest rates, salvage value, depreciation period, taxes, and insurance. Similarly, operating costs, including fuel and oil consumed plus labor and supervision expenses, were also calculated for each equipment. Total costs of owning and operating the system for the entire job of harvesting and processing each of the two study blocks were then calculated. In addition to the total costs, which are of interest when evaluating the overall job, a machine rate was calculated for each piece of equipment. The machine rate is defined to be the hourly cost of ownership and operation for a machine or process, including investment amortization, consumables and labor costs. The machine rate is based on a productive hour. This takes machine reliability (availability) and use rate (ratio of productive time to scheduled time) into account.

COMPUTATIONS

<u>Production Rates</u> for each harvesting and processing operation were calculated by dividing the total production of each operation by the total productive time spent to do that operation during the study.

<u>Machine Rates</u> for each piece of equipment were calculated using the equations below.

<u>The Productive Time Ratio</u> of each machine was calculated by dividing the productive time of each machine by the scheduled time for that machine.

<u>Machine Availability</u> was calculated using the equation below to quantify the reliability of the equipment observed during this study.

<u>The Productive Cost</u> for the total harvesting and processing system was calculated by dividing the total cost of all operations by the total weight of all delivered products.

Computation Equations follow:

$$\text{Productive Time (P-Hrs)} = \text{Scheduled Time} - (\text{Idle, Delay, and Down Times})$$

$$\text{Productive Time Ratio (\%)} = \frac{\text{Productive Time}}{\text{Scheduled Time}} \times 100$$

$$\text{Machine Availability (\%)} = \frac{\text{(Scheduled Time - Down time)}}{\text{Scheduled time}} \times 100$$

$$\text{Production Rate (Tons/P-Hr)} = \frac{\text{Tons of Material Processed}}{\text{Productive Time}}$$

$$\text{Ownership Cost (\$/S-Hr)} = \frac{\text{Total Annual Ownership Costs}}{\text{Scheduled Hours for Job}}$$

$$\text{Operating Cost (\$/P-Hr)} = \text{Hourly Crew Wages} \times (1 + \text{Supervision Rate}) + \text{Hourly Fuel Cost} + \text{Hourly Oil Cost}$$

$$\text{Machine Rate (\$/P-Hr)} = \text{Hourly Ownership Cost} + \text{Hourly Operating Cost}$$

$$\text{Productive Cost (\$/Ton)} = \frac{\text{Machine Rate}}{\text{Production Rate}} = \frac{\text{Total Cost for Job}}{\text{Total Production}}$$

RESULTS AND DISCUSSION

Both study blocks on the Quilcene Ranger District, Olympic National Forest, were harvested and processed during the study. Block A was studied in November 1986 and block B was studied in January 1987. Trees were taken down to a 1 inch diameter and 10 feet long cutting specification. The harvesting and processing operations proceeded relatively smoothly during the study, with only a few interruptions for minor repairs on equipment and occasional system delays. Trees coming into the landing were continuously sorted into the appropriate products and processed accordingly. Before and at the conclusion of the studies, the processing area was cleaned up so that the total time required to process the actual trees from the designated blocks could be observed.

STAND INVENTORY RESULTS (Stems per acre)

Table 1 lists the population of trees on each study block by diameter classes. About half of the trees on each block were dead. The living trees were comprised of western hemlock (33%), douglas-fir (28%), red cedar (22%), true fir (16%), and alder (1%). About 78% of the trees on block A and 85% of the trees on block B had diameters of 6 inches or less. The stand inventory showed block A to contain 1642 stems per acre and 2283 trees per acre on block B.

Table 1--Number of Stems per Acre for Study Blocks A and B by Diameter Class in Inches

Diameter Class	Block A			Block B		
	Live	Dead	Total	Live	Dead	Total
1	25	*271	296	104	*654	758
2	38	*304	342	167	*288	455
3	62	*171	233	179	*100	279
4	121	50	171	129	54	183
5	96	25	121	100	25	125
6	121	4	125	125	12	137
7	42	--	42	58	--	58
8	71	--	71	33	--	33
9	29	--	29	38	--	38
10	62	--	62	38	4	42
11	25	--	25	25	--	25
12	50	--	50	21	4	25
13	17	--	17	8	--	8
14	21	--	21	21	4	25
15	17	--	17	17	--	17
16	--	--	--	29	--	29
17	4	--	4	25	--	25
18	--	--	--	17	--	17
19	--	--	--	--	--	--
20	4	4	8	--	--	--
21	--	--	--	--	--	--
22	4	--	4	4	--	4
23	4	--	4	--	--	--
TOTALS	813	829	1,642	1,138	1,145	2,283

-- = No stems.
* Most dead stems under 4 inches in diameter were left in the woods.

DELIVERED PRODUCTS RESULTS (Tons)

All trees taken from the study blocks were transported to the sorting and processing site at the landing. No materials were permitted to accumulate at the landing. Depending on their size and quality, the trees were processed into three different products. Empty and loaded weight measurements of the trucks and vans leaving the processing site gave the following distribution of products (Table 2):

Table 2--Product Distribution From Study Blocks by Weight and Percent

Product	Block A		Block B	
	Tons/Acre	Percent	Tons/Acre	Percent
Sawlogs	45	16	60	21
Chips	147	53	157	53
Hogfuel	84	31	76	26
Totals	276	100	293	100

PRODUCTION RATES RESULTS (Tons per hour)

HARVESTING

Cutting: Felling and bunching with the steep-slope feller/buncher progressed efficiently and effectively with the machine working both uphill and downhill. Butts of the trees were placed downhill for easy loading by the clam bunk skidder. Because less rotation of the felling boom was required when working uphill, the production rate of the feller/buncher was about 40 percent higher on the uphill passes. The independently pivoting, quad track drive system of the feller/buncher gave it excellent mobility over uneven terrain on all slopes encountered, which ranged between 20-35 percent in the stand and up to about 60 percent in short stretches (leaving the road, etc.). The automatic leveling feature of the feller/buncher boom platform functioned well, freeing the operator from unnatural positions and allowing him and the machine to operate consistently and smoothly. The machine had very high ground clearance (almost 3 feet), which enabled it to pass easily over many ground obstacles that would have impeded travel of most woods machinery. The effective reach of the cutting head was about 60 feet from one side to the other, compared to a cutting path of about 40 feet by the conventional feller/bunchers used in the area. See reference number 1 for more detailed information on the feller/buncher.

<u>Yarding:</u> Forwarding with the clam bunk skidder (forwarder) also progressed smoothly and efficiently. The production rate of the forwarder matched that of the feller/buncher for the yarding distances of this study. A typical turn of about 50-70 trees arrived in about 18 minutes. The forwarder usually climbed to the top of the block and then loaded trees from the prearranged bunches as it headed back downhill towards the landing. The operator swivelled around backwards in his chair to drive the machine uphill in reverse or to operate the loading grapple. Travelling toward the landing, the operator faced forward, stopping occasionally to add logs to the bunk as the load straightened and settled during travel. Yarding with a clam bunk skidder appears to be limited to slopes under about 50%. Cable yarders (also used by Hermann Bros. in doghair stands) could reach trees bunched by the steep slope feller/buncher on slopes greater that 50%. See reference number 1 for more information on the forwarder.

Table 3 presents the production rates of the harvesting equipment on each study block.

PROCESSING

<u>Sorting</u>: As the trees were delivered to the landing for processing by the forwarder, the mobile loader first set the sawlogs aside and then separated the hogfuel material from the trees that could be processed into clean chips. This sorting process progressed rapidly, allowing the loader to attend to its major role of feeding the debarker/delimber.

<u>Clean Chip Process:</u> After clearing the incoming trees from the drop zone used by the forwarder, the loader moved into position next to the debarker/delimber to assist in the clean chip operation. The loader would then typically feed one or two but some times as many as four trees into the debarker/delimber. As the cleaned stems emerged from the double chain flail debarker/delimber, they were grabbed by the loading grapple attached to the chipper. The chipper operator continued to pull the trees through the chain flail at a rate consistent with proper cleaning. The stems were then placed into the feed works of the chipper, which transformed the clean stems into clean chips and blew them into a waiting chip van. The production rate of the chipper is the same as the production rate of the debarker, because both machines process the same trees, and the rate is based on the

weight of the chips in the van. Sometimes during the study, the debarker was bypasssed and the chipper processed whole trees into hogfuel.

Hogfuel Process: The prototype shredder, built by Hermann Bros., normally processed all materials that were not delivered as sawlogs or clean chips into hogfuel. Materials came from several sources:

- Very small or unsound trees
- Limbs and trim ends from sawlogs
- Limbs and broken tops discharged from the debarker/delimber
- Bark and fines discharged from the debarker/delimber
- Bark and other friable particles discharged from the chipper.

A conveyor belt lifted bark and limbs out of the debarker/delimber and discharged them onto another system[4] of two conveyors that continuously separated the materials into three categories. Larger limbs usually overshot the second conveyor and were side cast directly in front of the conveyor that discharged materials from the debarker/delimber. Fine materials, including most of the bark, filtered down through openings in the top bed of the second conveyor and were delivered to a third conveyor along with any metal chain pieces that occasionally became separated during operation. Branches that did not filter down through the top bed of the second conveyor were piled within easy reach of the shredder loading grapple. The third conveyor then lifted the fine materials and any possible chain particles to a chute that passed over a 1000 pound permanent magnet. The magnet was designed to trap chain particles to prevent damage to the sharp knives of the shredder. Fine wood particles that passed over the magnet were collected in a hopper that was regularly emptied by the shredder loading grapple, alternately with branches and other debris as listed above. The shredded hogfuel was then blown into a waiting van.

The shredder operator opened the clam shell doors of the hopper over the shredding drum each time a load was dropped in by the grapple. Materials from the conveyor system and the sawlog operation were small enough to easily fit into the shredder hopper. However, the small trees had to be progressively bucked by a chaser with a chain saw to make hopper length loads (four to five feet long) for the grapple to drop into the hopper. This repeated bucking operation progressed faster than might be expected because the shredder operator used the

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[4]The second and third conveyors were used on block B but not on block A. The added material handling equipment improved production efficiency. Moreover, large quantities of materials did not accumulate during the day on block B. On block A, all three loaders were typically used at the end of each workday to load the shredder until the landing was cleaned up.

loading grapple to move the trees incrementally in bunches over a crosswise cull log. This enabled the chaser to buck many trees at a time without moving wood or binding the saw. The result was a clean landing, with all woody materials leaving in a van or a log truck.

The production rate of the hogfuel process was calculated based on the weight of hogfuel leaving the site. Materials destined for hogfuel were also handled by the sorter/loader and partially by the debarker/delimber, the chipper, the conveyor/magnet system, and the chaser. Therefore, the production rate is most clearly attributed to the shredder itself. The other systems contributed to the production rate but were not specifically characterized by the amount of their contribution. The interrelated functions of the processing equipment make clear assignments of costs equally difficult and arbitrary.

Production rates for the main parts of the processing equipment are listed in table 3. (See reference 2 for more information on the processing system.)

Table 3--Production Rates of Harvesting and Processing Equipment on Each Study Block

Machine	Block A	Block B
	Tons/P-Hr[1]	
Harvesting Equipment:		
Feller/Buncher	55	60
Forwarder	46	65
Processing Equipment:		
Sorter/Loader	30	42
Debarker/Delimber	29	34
Chipper	29	34
Shredder	10	10.5

1 P-Hr = Productive Hour

EQUIPMENT AVAILABILITY RESULTS

The observed results of equipment availability (or reliability) are presented in table 4. The study period was an extremely short time sample for predicting long term reliability. However, the observed availabilities are reported for those who may wish to accumulate the data with other reported data. All machines experienced relatively high availability, especially considering the minor amount of prior operating time on the three new prototype machines.

PRODUCTIVE TIME RATIO RESULTS

The ratios of productive time are also reported in table 4. These ratios were used for calculating costs and production rates on the common basis of productive hours. The ratios may also be used by planners to estimate scheduled hours required to complete a future job.

Table 4--Equipment Availability and Productive Time Ratios

Machine	Equipment Availability		Productive Time Ratio	
	Block A	Block B	Block A	Block B
	Percent		Percent	
Harvesting Equipment:				
Feller/Buncher	95	99	91	99
Forwarder	92	84	75	57
Processing Equipment:				
Sorter/Loader	98	100	93	86
Debarker/Delimber	88	84	55	61
Chipper	90	93	58	60
Shredder	86	99	80	86

COST RESULTS (Dollars per hour, dollars per ton)

Machine rates were calculated for the harvesting (Ref #1) and processing (Ref #2) equipment. The calculations include costs of ownership and costs of operation. They do not include costs associated with equipment move-in, set up, overnight maintenance, nor road and landing construction. Company risk and profit are also excluded. Costs for the conveyor/magnet system[5] were also not included. It should be noted that no interest payments are included for the shredder and the debarker/delimber because funds for these machines were provided by external sources. Machine rates, broken down by ownership and operating costs (with the exclusions noted above), are shown in table 5.

Table 5--Costs and Machine Rates for Harvesting and Processing Equipment

Machine	Block A			Block B		
	Own Cost	Operate Cost	Machine Rate	Own Cost	Operate Cost	Machine Rate
			$/P-Hr[1]			
Harvesting Equipment						
Feller/Buncher	46.86	26.05	72.91	43.07	24.35	67.42
Forwarder	35.71	29.58	65.29	46.98	37.66	84.64
Processing Equipment						
Sorter/Loader	30.83	25.41	56.24	33.34	27.09	60.43
Debarker/Delimber	15.04	2.10	17.14	13.56	2.10	15.66
Chipper	35.74	44.98	84.79	43.48	38.71	82.19
Shredder	44.51	32.06	76.57	41.41	30.38	71.79

[1] P-Hr = Productive Hour

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[5]Conveyors of this type cost about $20,000. They have negligible operating costs, because they are all powered by excess hydraulic power from other machinery and no additional operator is required.

The productive costs of harvesting and processing are shown in table 6. These costs were calculated by combining the production results of table 3 with the cost results of table 5. The total productive cost was $15.79 and $13.59 per ton on blocks A and B, respectively.

The productive costs incurred to process each product (i.e. the clean chip operation) are difficult to calculate without arbitrary assignment of the costs of the multi-purpose machines that operate as an integrated system for the good of the entire system. Therefore, productive costs of each equipment are given (table 6), based on the weight of material actually handled by each equipment. Productive

Table 6--Productive Costs of Harvesting and Processing Equipment

Machine	Block A	Block B
	$/Ton	
<u>Harvesting Equipment:</u>		
Feller/Buncher	1.33	1.13
Forwarder	1.42	1.30
Harvesting Total	2.75	2.43
<u>Processing Equipment:</u>		
Sorter/Loader	1.87	1.44
Debarker/Delimber	0.59	0.46
Chipper	2.92	2.42
Shredder	7.66	6.84
Processing Total	13.04	11.16
Total System Productive Cost	15.79	13.59

costs of the total system are also shown in table 6 as the summation of the harvesting and processing productive costs. Because the different pieces of equipment process different weights of material, and because some materials may be handled by more than one piece of equipment, the productive costs are not truly additive. These costs should be considered along with the percentage breakdown of the products produced (table 2). It would be incorrect to focus on only one product and attempt to isolate the unit cost of that product only. At the study site, all products are delivered by the system. Without all products being delivered, a harvest may not be feasible, because of economics, environmental impacts, or other reasons discussed previously. There could be no clean chips without the debarker; no hogfuel without the collective inputs of materials from the sorting, sawlog, and chipping operations; and no sawlogs from these stands without a way to clean up the harvest site and market the other products.

CONCLUSIONS

The steep slope feller/buncher and clam bunk skidder harvesting system was well adapted to the stand and terrain conditions of this study. The feller/buncher functioned remarkably well, with lift capacity, power, and gradability to spare. The clam bunk skidder kept pace with the felling and the processing production rates, with extra time to do other tasks such as skid road maintenance. Productive costs for harvesting the study blocks were $2.75 and $2.43 per ton on blocks A and B, respectively.

The in-woods, multiple-product processing system demonstrated a consistent ability to sort and process the small diameter trees into a marketable mix of products. All machines had high reliability and high productive time ratios. Average daily production was about 3 truck loads of logs, 8 van loads of clean chips, and 4 vans of hogfuel. Productive costs for processing the material from study blocks A and B were $13.04 and $11.16 per ton, respectively.

The mobile sorter/loader and the chipper appeared to be sized adequately for this application. They are regular, production line equipment items and their reliabilities were very high, even though the chipper had very little operating time on it before this study. The following equipment were designed, fabricated, and used for the first time on this job: the multi-stem debarker/delimber, the shredder, and the magnet/conveyor system. All worked well. Occasional system clogs were encountered, especially with large, unsound cull logs (shredder) or extremely dense crowns (debarker). These clogs were all overcome quickly and the system operated essentially continuously. The added conveyors on block B enhanced the material handling capabilities within the processing system.

The chipping operation could not proceed without the mobile loader, because the loader was needed to insert trees into the debarker. No chips were produced while the loader tended to log trucks, for example. However, log trucks were usually loaded during other slack times for the chipper, such as during knife or van changes. The interruptions were minimal and an additional loader is probably not warranted.

The total system productive costs for harvesting and processing multiple-products from the two study blocks in the doghair stand were $15.79 per ton in block A and $13.59 per ton in block B. The weight ratio of chips to total product weight was 53 percent on both blocks. Sawlogs comprised 16 percent of the product weight on block A and 21 percent on block B. The remaining product was hogfuel: 31 and 26 percent on blocks A and B, respectively.

This system or adaptations of it may be technically and economically suited to harvest and process other stands of small diameter trees, where total marketing is required to justify any harvest, and where it is desirable to collect the energy wood component of the stand.

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ANALYSIS OF FACTORS AFFECTING SOUTHERN PULPWOOD HARVESTING COSTS

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ABSTRACT

Data obtained from a 1979 South-wide pulpwood producers' census were used to assess the importance of various factors in determing average pulpwood logging costs. The harvesting system technology employed was significant in determining costs. Type of cut (clearcut, thinning) had moderate impacts on costs; species cut (pine, mixed) had modest impacts; and topography (coastal plain, piedmont, mountain) very little impact. Neither owner/operator education level or experience seemed to affect average harvest costs.

INTRODUCTION

The forest harvesting and engineering community has always been interested in estimating the costs of different harvesting systems. Harvesting equipment and systems have been studied often to develop production rates. These production studies are usually followed by cost calculations for individual machines or systems. While these production and cost studies are helpful in estimating information for a particular machine, system, or case, they may not be applicable to different harvesting situations. Additionally, they do not measure whether the results found in the case study can be achieved on a broad-scale basis.

We were recently able to perform an aggregate analysis of southern pulpwood harvesting data that enabled us to overcome many of the limitations of individual case studies. Essentially, this method consisted of obtaining and analyzing cross-sectional data from a survey of pulpwood loggers made in 1979 by the American Pulpwood Association (Weaver et al. 1981). This data included information on the equipment, employees, operator education and experience, and production rates for over 3000 pulpwood producers in the South. While it is somewhat dated, it did report on a range of equipment technologies that are similar to those available today. Using this data, we were able to divide the firms into various broad technology classes (harvesting systems) and determine South-wide production and costs for a variety of systems. This information helps provide sound empirical bases for evaluating the

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effects of technology development and adoption and other factors affecting harvesting costs. The results also can be related to the findings from other studies.

METHODS

The data from the 1979 American Pulpwood Association (APA) census were collected originally in order to canvass pulpwood producers; producers who harvested any other products were excluded from that survey. Thus the data for the survey provide a good picture of the effects of different pulpwood systems on production rates and costs. However, most of the firms surveyed were fairly small non-mechanized systems. About 2000 firms out of the 3700 usable responses consisted of bobtail truck systems. But the remaining sample of over 1500 firms still provided an excellent base for analyzing more mechanized harvest systems.

Cost Calculations

Using the data available, each firm was categorized into a harvesting systems (technology class) based on its equipment spread. For each firm, production rates, total equipment assets, equipment operating expenses, estimated payroll costs, and total and average costs were estimated. These calculations for each firm were then aggregated by harvesting system to estimate class averages and variations.

Production rates per week were reported directly on the survey form by each firm. Total assets per firm were computed as the sum of the market value for each piece of equipment reported. Purchase prices in 1980 for each type of equipment were taken from Cubbage (1981). Depreciated values were estimated based on the percentage yearly loss in value as reported for harvesting equipment in the Green Guide (1986). The percentage values were then applied to 1980 cost for equipment. Table 1 summarizes the harvesting system technology classes used, their average production rates, total system assets, number of employees, and the production per amount of input.

Operating costs for individual machines were taken from Cubbage (1981) and wage rates from Cubbage (1982). The operating cost figures used were slightly greater for older equipment and less for newer equipment. Depreciation was calculated based on the yearly loss in market value for each piece of equipment. Interest, taxes, and insurance were calculated as a percentage of the depreciation. These input costs were used to calculate the total costs per week for each firm. Dividing these total costs by production provided an estimate of the average harvesting cost per cord.

Statistical Analyses

Based on the initial data and the cost calculations made above, we have made a variety analyses of the data. The principal results we will

Table 1. Employment, Production, and Assets by Harvesting System Technology Class

Technology Class	Number of Firms	Average Number of Employees Per Crew	Average Assets Per Crew (1980 dollars)	Production Per Week (Cords)		
				Mean	Minimum	Maximum
Shortwood						
A Manual, Hand Load	445	2.6	3,790	21	0	90
B Semi-Manual, Bobtail Truck, Bigstick Loader	1938	3.1	5,721	28	0	140
C Manual/Skidder, Bobtail, Bigstick	360	3.8	29,468	40	0	240
D Forwarder	149	6.3	49,185	73	0	250
E Cable Skidder, Knuckleboom Loader, Trailer Truck	193	5.8	107,844	76	0	400
F Grapple Skidder, Knuckleboom Loader, Trailer Truck	26	6.2	199,479	54	0	390
Longwood						
G Cable Skidder, Knuckleboom, Trailer Truck	382	6.2	150,866	114	0	430
H Grapple Skidder, Knuckleboom, Trailer Truck	166	8.7	254,110	214	0	600
Total	3659					

report on and discuss here relate to the average harvesting costs by technology class; the validity of dividing the systems into the harvesting systems selected; and the effects of harvest type, species, topography, and the manager's experience and education on average harvesting costs.

In order to analyze the usefulness of the harvesting system technology classes, a dummy-variable regression approach was used with the entire data set of over 3700 firms. Average cost per cord served as the dependent variable. Total production per week and/or dummy variables for each harvesting class and harvest type, species, and topography served as the independent variables. A statistically significant coefficient on an independent variable would then indicate that it had a significant impact on average costs. Correlation analysis and regression analysis were also used to determine if employment or education were significant contributors to the average harvesting costs.

RESULTS

Average Production and Costs

The average production per cord was shown in Table 1. Costs per cord by harvesting system technology class are reported in Table 2. Production per system increased with increasing mechanization levels, as one would expect. The bobtail systems averaged less than 30 cords per week. The shortwood forwarder and cable skidder systems averaged about 75 cords per week. The highly mechanized longwood grapple skidder system averaged over 200 cords per week and included some firms that produced 600 cords per week. Few bobtail firms produced more than 100 cords per week.

For shortwood systems, the grapple skidder/hydraulic loader/ tractor-trailer operations (Class F) had the lowest unweighted average logging costs, at $24.46 per cord. They were followed by the manual (A) and semi-manual (B) bobtail truck operations at $27.16 and $28.05 per cord, respectively. Shortwood forwarder systems (D) fell at a medium cost level, followed rather distantly by cable skidder systems C and E, at $36.77 and $36.80 per cord, respectively.

The average costs for longwood systems were generally cheaper than for shortwood systems. The longwood cable skidder technology class (G) had much lower average costs ($28.90 per cord) than the similar shortwood system average. The longwood grapple skidder system (H) had costs ($25.69 per cord) similar to those of the shortwood grapple system.

The variations in average costs were also substantial, especially for the more mechanized harvest systems. The simple manual systems had the least cost variation, as measured by the standard error, but still had some significant outliers. The more mechanized shortwood and longwood cable and grapple skidder systems had large standard errors,

Table 2. Average Costs Per Cord by Harvesting System Technology Class

Technology Class	Harvest Cost Per Cord			
	Mean	Minimum	Maximum	Standard Error
	dollars			
Shortwood				
A Manual	27.16	2.77	70.67	2.36
B Semi-Manual	28.05	11.66	308.34	1.16
C Manual/Skidder	36.77	19.23	113.86	3.59
D Forwarder	31.62	13.03	86.87	6.74
E Cable Skidder	36.80	16.98	186.94	8.68
F Grapple Skidder	24.46	11.82	87.90	28.59
All Shortwood	29.68	2.77	308.34	1.21
Longwood				
G Cable Skidder	28.90	14.63	235.03	7.03
H Grapple Skidder	25.69	10.20	270.09	14.18
All Longwood	26.98	10.20	270.09	5.96
All Classes	27.68	2.77	308.34	1.44

indicating that there were many low-cost and high-cost producers. Each technology class included some firms that had average costs as low as $10 per cord; but most also had some that had costs greater than $200 per cord. Only the completely manual system, the forwarder system, and the shortwood grapple skidder system had no firms with average costs greater than $100 per cord. These wide cost variations presaged the problems we had in developing regression equations with high explanatory power.

Regression Analyses

One analysis of the data involved a dummy variable regression of the factors that might be influential in determining harvesting costs. The regression included a 0/1 variable for each of the types of harvesting systems; for the type of harvest cut (thinning, clearcut, or other); for the species cut (pine, hardwood, or mixed); and for the topographic region (coastal plain, piedmont, or mountains). Use of a 1 in the dummy variable regressions indicated that the firm was operating in that characteristic system, cut, species, or region; a 0 the converse. Production per week was also included in one set of the cost equations, since this was identified as the most significant variable in preliminary correlation analyses.

These regression analyses were performed with the weekly production levels variable for the data consisting of all firms and for separate groups of all shortwood and all longwood firms. Similar analyses were performed without production levels for all, shortwood, and longwood data sets and for each individual technology class. These regressions allowed one to test if differences in harvesting characteristics were statistically significant for the South-wide data set. Table 3 summarizes these analyses.

The results of the regression analyses of the factors that affect costs are revealing. As one might expect, the coefficients of determination are not particularly large. Anyone who has timed an individual logging operation has doubtless encountered large variability in productivity and costs; this is equally true with the South-wide data. However, while not much variation in average costs is explained by the regressions, they are all statistically significant because of the large sample sizes. Many of the factors are also statistically significant.

The regressions which include production per week are much better than those that do not. Both tend to have similar results in terms of the significance of the coefficients for individual parameters, although the comparative magnitudes do differ.

Harvesting System Technology Classes.--All the coefficients for the harvesting system technology classes were statistically significant. This confirms the validity of the classification scheme used to separate out equipment. The coefficients for each of these technology classes

Table 3. Regression Equation Coefficients and Significance Levels for Harvesting Costs Per Cord for Selected Independent Variables

Regression Statistic/ Independent Variable	Data Set Used					
	With Production Per Week			Without Production Per Week		
	All Firm Data	Shortwood Firms	Longwood Firms	All Firm Data	Shortwood Firms	Longwood Firms
Regression:						
R-square	.221	.267	.206	.124	.171	.046
F ratio	59.062	73.674	13.261	31.047	44.324	2.698
Sig. level	.001	.001	.001	.001	.001	.002
Independent Vars:	--- coefficient for average cost per cord in dollars (significance level) ----					
Intercept	18.30 (.016)	7.44 (.415)	27.06 (.040)	9.75 (.227)	-1.34 (.890)	22.81 (.1144)
Cords/Week	-0.11 (.001)	-0.19 (.001)	-0.11 (.001)	NA	NA	NA
Shortwood--						
A Manual	2.61 (.017)	7.84 (.001)	NA	8.62 (.001)	12.60 (.001)	NA
B Semi-Manual	5.01 (.001)	10.74 (.001)	NA	10.34 (.001)	14.26 (.001)	NA
C Manual/Skidder	16.60 (.001)	23.18 (.001)	NA	20.82 (.001)	24.67 (.001)	NA

Table 3. Continued

Regression Statistic/ Independent Variable	Data Set Used: With Production Per Week — All Firm Data			Without Production Per Week — All Firm Data		
	All Firm Data	Shortwood Firms	Longwood Firms	All Firm Data	Shortwood Firms	Longwood Firms
D Forwarder	15.07 (.001)	23.87 (.001)	NA	15.78 (.001)	19.37 (.001)	NA
E Cable Skidder	23.15 (.001)	32.51 (.001)	NA	23.33 (.001)	27.26 (.001)	NA
F Grapple Skidder	19.68 (.001)	34.09 (.001)	NA	12.55 (.001)	15.89 (.001)	NA
Longwood--						
G Cable Skidder	19.00 (.001)	NA	12.55 (.001)	14.86 (.001)	NA	6.96 (.026)
H Grapple Skidder	24.55 (.001)	NA	18.72 (.001)	11.16 (.001)	NA	3.98 (.239)
Harvest Type--						
Clearcut	3.69 (.026)	2.75 (.065)	7.93 (.391)	3.44 (.050)	3.15 (.047)	8.99 (.374)
Thin	3.71 (.027)	3.19 (.034)	9.39 (.323)	4.06 (.022)	3.54 (.027)	13.91 (.181)

Table 3. Continued

Regression Statistic/ Independent Variable	Data Set Used					
	With Production Per Week			Without Production Per Week		
	All Firm Data	Shortwood Firms	Longwood Firms	All Firm Data	Shortwood Firms	Longwood Firms
Other	1.71 (.322)	2.09 (.179)	0.97 (.920)	1.68 (.358)	2.02 (.223)	3.45 (.745)
Species--						
Pine	7.60 (.276)	17.31 (.041)	-4.10 (.344)	6.42 (.386)	15.26 (.091)	-9.11 (.054)
Mixed	7.49 (.283)	16.19 (.056)	-0.46 (.911)	6.54 (.376)	14.58 (.106)	-6.05 (.176)
Hardwood	8.33 (.239)	16.79 (0.50)	NA	9.15 (.223)	16.45 (.071)	NA
Topographic Region--						
Coastal Plain	-1.19 (.669)	-2.56 (.367)	.57 (.942)	-0.11 (.970)	-0.83 (.783)	0.94 (.913)
Piedmont	-1.18 (.674)	-2.84 (.321)	5.73 (.474)	.07 (.980)	-1.56 (.608)	7.58 (.388)
Mountain	2.16 (.488)	2.39 (.453)	-2.11 (.808)	5.63 (0.088)	6.37 (.060)	3.07 (.747)

serve as shifters that move the intercept for the average harvesting cost up or down the vertical axis. For the regression that included production, this shifter increased costs the least for the two small bobtail systems (A and B) and the most for the more mechanized cable and grapple skidder systems (E through G). This seems unreasonable, but can be explained by the fact that the more mechanized systems operated at much larger production levels; thus the negative coefficient on production per week brought the system average costs down more.

The above anomaly makes the costs with production levels harder to interpret than the simple, albeit less significant, regressions that exclude production per week. According to that all firm equation, the bobtail systems A and B were the least cost; moving the line up only \$8.62 and \$10.34 per cord, respectively. The longwood grapple skidder system (H) and the shortwood grapple skidder system (F) were the next least costly, shifting the line upwards \$11.16 and \$12.55 per cord, respectively. The two shortwood cable skidding systems (C and E) had the highest costs, and the longwood cable skidder system (G) and the shortwood forwarder system (D) fell at intermediate price levels.

Cut, Species, Topography.--The results on average costs by type of harvest were moderately significant for the clearcutting and thinning, but not for "other." The regressions with and without production per week as an independent variable both indicated that thinning would increase costs more than clearcutting. These results were significant for the data sets using all the firms and for the shortwood operations, but this was not the case for the longwood systems.

The coefficients for the average costs as a function of species type were not generally significant for the data set of all firms. However, the shortwood regressions including weekly production indicated that harvesting mixed species was slightly cheaper than harvesting all pine. Conversely, the longwood regression without the weekly production variable indicated that harvesting pine was over \$3.00 per cord cheaper than harvesting mixed species.

The regressions equation coefficients for average harvesting costs by topographic region were almost all nonsignificant. Only the shortwood equation without weekly production indicated much significance at all--showing that it was more costly to harvest pulpwood in the mountains. For a bobtail truck, one might expect this.

Education and Experience

Correlation analysis and regression analysis were also performed separately with the data to assess the importance of logger education and experience levels in determining average harvesting costs. Correlations were run between average costs and education and experience for all firms, the sets of shortwood and longwood firms, and for each technology class. These results are summarized in Table 4. In general, they indicate very little statistically significant association between

Table 4. Selected Statistical Analysis Results for Average Harvesting Costs Versus Operator Education and Experience

Harvesting System Technology Classification	Correlation Coefficients Between Average Costs and: Education	
	Education	Experience
	----- R (Significance Level) -----	
All Pulpwood	-.009 (.549)	.023 (.144)
All Shortwood	-.029 (.108)	0.018 (.293)
All Longwood	-.105 (.009)	.054 (.179)
Shortwood--		
A Manual	-.036 (.465)	-.056 (.242)
B Bobtail	-.007 (.776)	-.013 (.545)
C Bobtail Skidder	.012 (.817)	.006 (.909)
D Forwarder	.135 (.103)	-.164 (.044)
E Cable Skidder	-.034 (.642)	.063 (.388)
F Grapple Skidder	-.466 (.016)	-.02 (.921)
Longwood--		
G Cable Skidder	-.185 (.001)	.128 (.013)
H Grapple Skidder	.002 (.980)	-.052 (.506)

average costs and education or experience. One would expect that greater amounts of education or experience would decrease average costs, which would be indicated by a negative sign for the correlation coefficient.

The correlation analyses did little to confirm the importance of either factor. For the aggregate data sets, only that for all longwood firm's costs versus education was significant, and it only had a correlation coefficient of -.105, which obviously did not explain much association. The only individual technology class relationships that were statistically significant were those between shortwood grapple skidder system (F); average costs and education (-.466); longwood cable skidder system (G); average costs and education (-.185); and longwood cable skidder system (G); costs and experience (+.128). At least the two education associations had the correct anticipated sign on the coefficient; the experience coefficient did not. The signs on much of the rest of the associations were also mixed, but none exhibited enough of a relationship to be statistically significant.

As a last hope to find some meaning, we tested the associations among education, experience, and the level of the technology class. Sophistication of technology was ranked from 1 to 8, in order from system A to H. The resulting correlations were:

Technology Class/Education:	R = 0.1977 (.001)
Technology Class/Experience:	R = 0.0811 (.001)
Education/Experience:	R = -0.2675 (.001)

All these correlations were significant, mostly because they used a large number of observations. They did indicate that education increased slightly with greater levels of technology used. Technology levels had little association with years of experience. Educational attainment was inversely related to experience, which does seem reasonable.

A variety of regression equations were also used to try to determine the relationships between average costs and education, employment, or their interaction. None had a level of significance worth reporting.

CONCLUSIONS

This aggregate analysis of South-wide pulpwood harvesting productivity and cost data provides many insights. It helps confirm many widely held beliefs about the effects of various factors on average harvesting costs, but refutes some others. The pulpwood harvesting survey was obviously somewhat dated, and the explanatory power of some of the statistical analyses was not great. But the huge number of responses available from the initial survey and the common equipment types do make the analysis fairly useful today.

If one took the average costs by harvest system findings literally, one might suggest that we encourage low-cost, labor- intensive bobtail truck systems. Then why have these systems provided a dwindling share of the South's mill furnish? Probably because their low average costs, while being accurate, are deceptive. First, bobtail systems could only work on flat, dry tracts that were easily accessible; these should inherently be the easiest and cheapest to log. Second, the bobtail input costs included minimum wage labor, moderate insurance rates, and very limited depreciation and truck expenses. Minimum wage labor for woods work has become more difficult to find. Workers compensation rates for chainsaw operators in the woods have increased greatly. And increasingly strict regulations on log trucks has also increased bobtail system costs.

The other harvest systems with intermediate mechanization levels were essentially attempts to replace labor with machines and to log more difficult sites. They would thus be expected to have somewhat greater costs. Apparently it was the introduction of the tree length systems, particularly using grapple skidders (and probably tree shears and feller bunchers) that were the key breakthrough in low-cost mechanized systems.

Another conclusion from the research is that it is statistically appropriate to divide equipment types into common harvesting system technology classes for further cost analyses. Purists may blanch at the term highly, but average costs were all at least very significant for all the technology classes adopted here.

The findings regarding the relative average cost levels of these harvesting systems--based on actual firm data for production levels and harvesting inputs--are similar to simulation results found by Cubbage (1982). In fact, it is interesting to compare the 1980 average costs (excluding stumpage) found by Cubbage, using the Harvesting System Simulator computer program (Stuart 1981), with those found in this empirical study of 1979-1980 costs. The comparable systems and costs are:

	Average Cost Per Cord	
	Simulation	Empirical
Shortwood--		
B. Semi-Manual Bobtail	$29.67	$28.05
C. Manual/Skidder	35.55	36.77
D. Forwarder	29.60	31.62
E. Cable Skidder	35.22	36.80
F. Grapple Skidder	33.09	24.46
Longwood--		
G. Cable Skidder Longwood	30.18	28.90
H. Grapple Skidder Longwood	25.96	25.69

Both the simulation results and the empirical data found the grapple skidder tree-length systems to have very cheap average costs; in fact they were within $.50 per cord of each other. The empirical results reported here actually showed shortwood grapple skidder systems to have the least costs per cord; this seems unusual and was not the case for the simulation results. However, the empirical results were based on a small sample of only 26 firms. The empirical data indicated that bobtail systems and cable skidder longwood systems were the next cheapest, and forwarder and cable or manual/skidder systems had greater average costs. The simulation results roughly agreed with the empirical costs for the bobtail and manual/skidder system rankings, but indicated that forwarders were more economical. Overall though, the empirical results and the simulation results corresponded fairly well and were usually within $1 to $2 per cord of each other for individual technology classes. This certainly should be comforting to purveyers of harvesting production and cost simulation models in general. These averages did vary immensely from firm to firm for the empirical data, however, and tended to have quite small variations (less than $1 per cord) in the simulation model.

The evidence regarding some other common beliefs was less convincing. The dummy-variable regression coefficients consistently indicated that clearcutting was cheaper than thinning, but not at statistically significant levels for the longwood operations. Cutting mostly pine instead of mixed pine/hardwoods was cheaper for longwood systems, but not for shortwood systems. The topographic region that harvesting occurred in seemed to have very little impact or significance in determining costs, although this may have been partially due to the fact that there were few responses from the mountains. Lastly, the manager's education and experience did not seem to be important in determining average pulpwood harvest costs.

Although these findings are useful, it should be noted that much more variation in average harvesting costs was left unexplained than was explained by the statistical analyses. This suggests that the productivity and management of a particular firm, which we could not measure, are crucial ingredients in determining average logging costs and profits. Other factors such as stand types, volume per acre, tract-specific topography, and tree size probably also explain much of the variation in average logging costs, although they could not be measured in this study. Nevertheless, this research has provided new empirical evidence about the effects of some factors on logging costs.

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SUCCESSFUL SKYLINE LOGGING ON THE ALLEGHENY NATIONAL FOREST: A HARVESTING REPORT ON STEEP/WET SLOPE COSTS AND PRODUCTION

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ABSTRACT

The Allegheny National Forest has begun a skyline logging program to manage the sites too steep and or wet for the traditional rubber tired skidder. In October 1986 a commercial skyline logging demonstration was conducted for evaluation by Forest Service and Forest Industry personnel. The 8 acre demonstration timber sale was successfully operated through the cooperation of a Pennsylvania logging company and a Virginia skyline logging company. The custom built yarder was a 2 drum truck mounted machine with a 40 foot tower, multi-span carriage, spooling 1200 feet of 3/4" skyline and 1200 feet of 1/2" mainline. Detailed records were kept on man hours and production. Based on Forest Service cruise volumes in MBF equivalents International 1/4" the demonstrations costs were : fell, limb, top $15.17; yard $46.62; swing skid, deck, sort $44.95 for a total of $106.74. Production rates for the demonstration were: fell, limb top 5.65 MBF plus 4.44 cords per man day; yard 1.36 MBF plus 1.07 cords per hour scheduled; and swing skidding production matched the yarding production. Projecting the demonstration costs and production to a year round operaton show total annual cost of $161,000 producing 2.3 MMBF equivalents at average unit rate of $71/MBF equivalent.

Introduction

The Allegheny National Forest has identified through the land management planning process a portion of lands needing harvesting by skyline logging systems. An estimated 8-10,000 acres are too steep/wet for conventional rubber tired skidder operations. Skyline logging systems are not currently being used in this area of the country. A demonstration was planned to introduce the system to forest industry and forest managers. Another objective of the demonstration was to learn more about the costs and environmental impacts of the system. The skyline demonstration was successfully conducted during October 1986, in the Sugar Run area on the Bradford Ranger District located approximately 10 miles southwest of Bradford, Pennsylvania.

The demonstration consisted of a Pennsylvania logging contractor (Jayfor Logging Co.) purchasing the demonstration timber and subcontracting with Bess Skyline Logging of Paint Bank, Virginia to move in a yarder, combine crews, and successfully skyline log an approximate 8 acre unit. The logging of the demonstration clearcut unit took two weeks.

The skyline unit contained approximately 136 MBF and 107 cords of hardwood timber. The average sawtimber tree contained 213 board feet (Int. 1/4) and the average pulpwood tree contained .135 cords. Timber characteristics are displayed in Table 1. Ground slopes ranged from 20 to 40% with a high water table and wet soils. The logging plan for the unit contained two yarder sets and eight skyline corridors. Yarding distances varied from 50 to 600 feet with an estimated average of 350 feet. All corridors required tail trees to obtain sufficient deflection. Rigging heights varied from 25 to 40 ft. with one of the trees needing guylines to provide adequate support.

Description of Work

The entire unit was prefelled and the landings were constructed before the yarder was moved in. Felling consisted of dropping the tree, limbing, and topping at a 5" diameter. Sawlog lengths were then measured along the length of the stem and marked with saw cuts in the bark. Logs were bucked out of 20" DBH trees and bigger. The felling did not have a pattern, however a lay on the contour was attempted when practical.

The yarding crew consisted of 5 men experienced in yarding eastern hardoods; a yarder operator, chaser, hooktender, and two chokersetters. Communication from the brush to the yarder was with handheld C.B. walkie talkies. A saw was kept in the woods to lop down brush, cut hang ups free, and buck trees. Once the turn of logs were yarded to the landing the chaser assisted in unhooking the turn and rehooking the turn to the rubber tired skidder for swinging 250 - 700 feet to log piles.

The skidding crew consisted of 3 men; skidder operator, bucker, and side rod. This crew skidded the timber away from the yarder, bucked the trees into merchantable products, and decked the products into separate piles. There were 2 sort piles for pulpwood and 3 sort piles for sawlogs. Decking was accomplished with the blade on the skidder. The skidding crew was experienced in handling this product sort.

All of the loading and trucking was done by independent trucking contractors. The trucks were large tri-axle trucks equipped with small knuckleboom loaders. The trucks would load from roadside piles sorted for a particular market. A limited amount of additional sorting was done during the loading operation.

All of the productivity records analyzed in this report were recorded in a detailed diary kept by Buck Williams of Jayfor Logging. Volume estimates are from two sources.

1. The Forest Service, as cruised in International 1/4".

2. The logging contractor from Doyle scale and tonnage as delivered.

TABLE 1

Cable Logging Demo Diameter Distribution
DBH/MBF (Int. 1/4")

	12"	14"	16"	18"	20"	22"	24"	26"	28"	Total
Hickory										
#Trees	2									2
MBF	.128									.128
Basswood										
#Trees	25	60	31	28	3	2				149
MBF	1.456	7.151	6.002	7.666	.961	.646				23.882
Yellow Birch										
#Trees	1	2		1						4
MBF	.067	.149		.146						.362
Sugar Maple										
#Trees	9	31	12	37	50	13	6	14		172
MBF	.515	3.563	1.719	9.068	14.477	4.777	2.723	7.794		44.636
Red Maple										
#Trees	1		4	1					1	7
MBF	.072		.524	.284					.514	1.394
Black Cherry										
#Trees	15	20	29	30	27	17	8	2		148
MBF	.918	2.555	5.089	7.482	8.194	8.074	4.095	1.049		37.456
White Ash										
#Trees	10	19	28	17	10	2				86
MBF	.609	2.071	4.578	4.044	3.233	.973				15.508
Beech										
#Trees	2	24	17	16	7	3	1			70
MBF	.147	2.389	3.035	3.137	2.082	1.073	.709			12.572
Hdwd. Pulpwood			(6")	(8")	(10")	(12")	(14")	(16")		
(Standing)		#Trees	38	121	158	43	16	5	381	
									(51.37 cords)	
Topwood									(55.2 cords)	

Total MBF = 135.9 (Int. 1/4)	Total Cords = 106.6	Total#Trees = 1019 (SWT = 638 PULP = 381)	Average Tree Size 213.1 bdft/swt tree .135 cds/pulp tree

Marking Specifications

SWT Spec:	Pulpwood Spec:
11" DBH Min.	6" DBH min.
9.6" DIB on small end	5" DIB on small end
8' min. product	8' Min. piece
40% sound	70% sound & reasonably straight

1 MBF equivalent = 2 cords

Demonstration Logging Costs

Felling, Limbing, Topping and Bucking

1. Labor
   8 days with 3 men = 24 man days
   8 hours/day x 11.00/hr. = $88/man day
   24 man days x $88/man day = $2112.00

2. Equipment
   3 chainsaws x 6 hr/day x $4.03/hr[3)] = $72.54/day
   $72.54/day x 8 days = $580.32
   1 truck[3)] x 70 miles/day x .30/mile x 8 days= $168.00
   Total Equipment = $580.32 + $169.00 = $748.32

3. Total Cost = Labor + Equipment = $2112.00 + $748.32 = $2860.32

Yarding

1. Labor
   Crew of 5, 105 crew hours, 11 working days
   105 crew hours x 5 men/crew x $11.00/hr = $5775.00

2. Equipment
   Yarder Hours = 99.75 machine hours[2)]
   99.75 machine hours x $20.21/hour[1)] = $2015.95

   Service Truck[3)]
   11 days x 70 miles/day x .76/mile = $ 585.20

   Pick-up[3)]
   11 days x 70 miles/day x .30/mile = $ 231.00

   Chainsaw[3)]
   11 days x 4 hr/day x $4.03/hour = $ 177.32

   Total Equipment Cost $3009.47

3. Total Yarding Cost = Labor + Equipment
   $5775.00 + $3009.47 = $8784.47

1) Machine Rate Based on 1000 hr/yr Utilization - See Appendix B

2) Includes set-up and road change time, total - 28.5 hr. rigging

3) Machine rates taken from Werblow, D.A.; Cubbage, F.W. 1986 Forest Harvesting Equipment Ownership and Operating Costs in 1984. SJAF 10(1986:pp.10-15.)

Skidding, Sorting and Decking

1.	Labor	Crew of 3, 132 crew hours, 13 working days 132 crew hours x 3 men/crew x $11.00/hr =	$4356.00
2.	Equipment	Skidder - 132 machine hours 132 machine hr x 20.71/hr[1] =	$2733.72
		Chainsaws, 2 ea. 13 days x 4 hr/day x 4.03 x 2 =	$ 419.12
		Service Truck 13 days x 70 miles/day x .76/mile =	$ 691.60
		Pick-up 13 days x 70 miles/day x .30/mile =	$ 273.00
		Total Equipment Cost =	$4117.44
3.	Total Cost = Labor + Equipment	$4356.00 + $4117.44 =	$8473.44

Total Logging Demonstration Cost Summary

1.	Fell, Limb, Top, Buck	$ 2860.32
2.	Yarding	$ 8784.47
3.	Skid, Sort, Deck	$ 8473.44
	Total	$20,118.32

Cost Analysis

1. As Cruised

Unit costs based on Forest Service cruise data. Costs prorated between sawtimber and pulpwood based on total tree count.

1019 Total Trees: 638 Sawtimber Trees
381 Pulpwood Trees

$\frac{638}{1019} \times 100\% = 63\%$ of job cost charged to sawtimber - 135.9 MBF Int. 1/4

$\frac{381}{1019} \times 100\% = 37\%$ of job cost charged to pulpwood - 106.6 Cords

1) Machine Rate Based on 1400 hr/yr Utilization - See Appendix C

	Total	$/MBF	$/Cord	$/MBF Equiv.[1]
Fell, Limb, Top	2,860	13.26	9.93	15.17
Yard	8,784	40.72	30.49	46.62
Skid, Deck, Sort	8,473	39.28	29.41	44.95
Total	$20,117	$93.26/MBF	$69.83/Cord	$106.74/MBF Eq.

2. <u>As Delivered</u>

As delivered unit costs based on volume and weight as delivered to mills. Costs prorated on weight basis.

57 Total Truckloads
28 Sawtimber Truckloads
29 Pulp Truckloads

$\frac{28}{57} \times 100\% = 49\%$ of job cost charged to sawtimber - 100.1 MBF Doyle

$\frac{29}{57} \times 100\% = 51\%$ of job cost charged to pulpwood - 630.94 ton

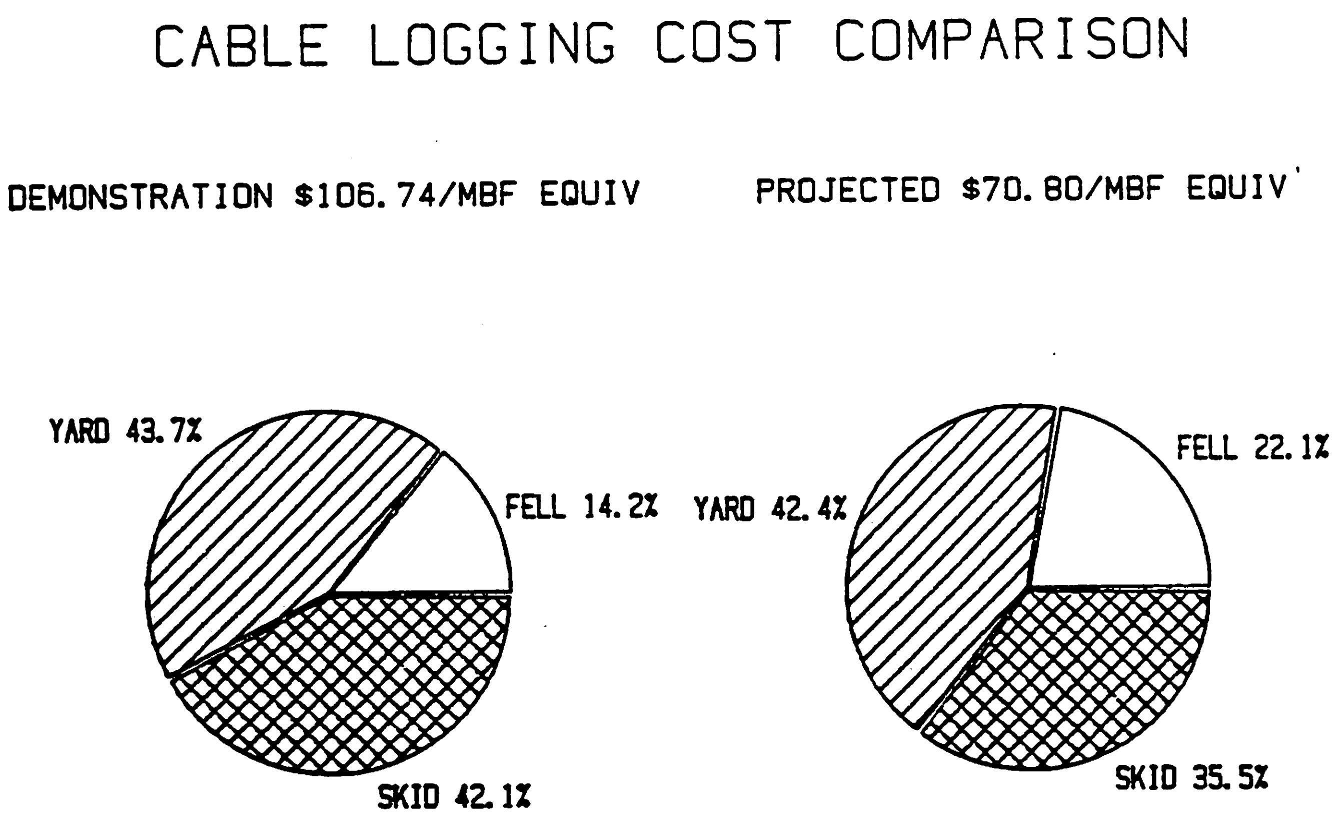
	Total$	$/MBF	$/Ton
Fell, Limb, Top	2,860	14.00	2.31
Yard	8,784	43.00	7.10
Skid, Deck, Sort	8,473	41.48	6.85
Total	$20,117	$98.48/MBF	$16.26/ton

[1] MBF Equivalent is total MBF plus cords/2

Conclusion

One objective of the demonstration was to learn more about the costs and environmental impacts of skyline yarding on the Allegheny National Forest. The soil disturbance aspect of this harvest was clearly very minimal, in relation to the disturbance which conventional wheeled skidding would have caused. Soil disturbance was limited almost exclusively to the construction of landings and roads. How much skyline logging will cost in commercial application can not be answered based on this demonstration alone. However, by using the results of this demonstration and some observations, one can attempt to predict what the long-term productivity and costs could be. The main assumption in using the demonstration data is that the operation would work year around in similar logging chances.

Three observations were made comparing the demonstration to full time operation. 1) The eight man crew was to big. A crew of five would be a better balance. Productivity would go down slightly with this reduction in crew size. 2) The main factor limiting production was the excessive amount of brush. This was due mainly from the felling crew being inexperienced at pre-felling for a yarding side. Directional felling on the contour away from skyline corridors, more complete lopping of limbs and tops, and an understanding of payloads would all increase the productivity of the yarding job. As these measures are incorporated it is expected that felling productivity will remain the same. This increased effectiveness will probably offset the reduction in crew size. 3) Productivity should be lower than that observed for a 6 month to 1 year learning period. The yarding crew was highly experienced and effective at working with one another. Experience has shown that there is a "learning curve" for a new crew learning the basics of skyline yarding.



One of the most difficult jobs in cost effective logging is balancing the productive elements, i.e. keeping it all busy all of the time. An analysis of the felling time, yarding time, and rigging time show the following relationships:

192 man hours of felling required 99.75 yarder hours to yard (including rigging time).

Of the 99.75 yarder hours 28.5 hours were spent rigging, i.e. set-up, road changes landing changes, and tear down and 71.25 hours were spent "pulling".

By assuming that the full time crew of 5 will have 200 scheduled full workdays per year, the following costs and productivity can be derived.

5 man felling crew = 40 man hr./day

192 man hr./40 man hr. = 4.8 felling days to 99.75/8 = 12.5 yarding days

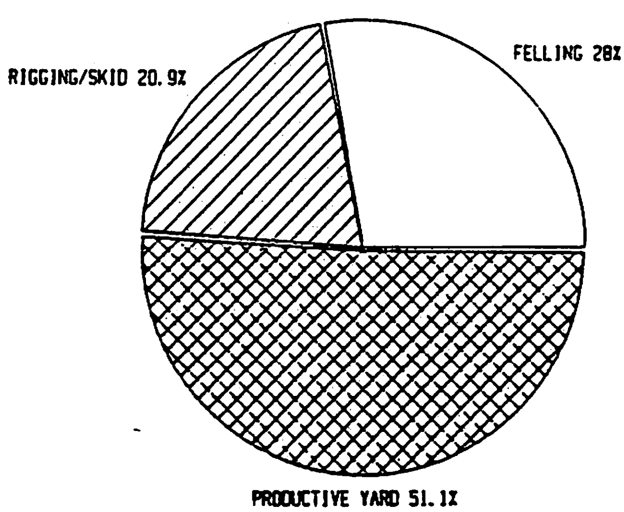
$\frac{4.8}{12.5 + 4.8}(100) = 28\%$ of crew time felling

$\frac{12.5}{12.5 + 4.8}(100) = 72\%$ of crew time yarding

$\frac{28.5}{99.75}$ = 29% of time yarding spent rigging;
71% of time yarding spent pulling

Every 2.5 hr. productive yarding required 1 hr. rigging.

PROJECTED WORK YEAR BY FUNCTION
200 WORKDAYS PER YEAR



Equipment Utilization:

Skidder (200 days/yr)(8 hr/day)(72%) = 1152 hr/yr

Use 1200 hr/yr, assumes skidder and 2 men are productive during time spent rigging by other 3 men.

Yarder (200 day/yr)(8 hr/day)(72%)(71%) = 818 productive hr/yr

Use 800 hr/yr

Annual Costs:

Skidder:	1200 hr/yr x $22.96/hr =	$27,552
Yarder:	800 hr/yr x $24.36/hr =	$19,488
Service Truck:	70 mi. x $ .76/mi. x 200 =	$10,640
Pick-up:	2 ea. x 70 mi. x $ .30/mi. x 200 =	$ 8,400
Saws:	5 ea. x 56 days x 6 hr/day x $4.03/hr. =	$ 6,770
Labor:	5 men x 200 days/yr x 8 hr/day x $11.00/hr =	$88,000
	Total Annual Costs =	$160,850

Annual Productivity:

From the demonstrations productivity it was shown that yarding produced 1.91 MBF/productive hr. and 1.50 cords/productive hr. Therefore annual productivity should be

(MBF eq)
800 hr x (1.91 MBF/hr + 1.50 cord/hr (2 cord)) = 2128 MBF eq/year

In addition to the yarders productivity the two man skidding crew should be productive during rigging time. This skidding productivity is estimated at 18 MBF/40 Hr. week[1]. The annual production should be:

800 hr. productive yarding divided by 2.5 Hour Productive/Hour Rigging = 320 hr/yr rigging.

320 hr. (18 MBF/(40 hr. week)) = 144 MBF yr.

Total annual productivity should be 2272 MBF Eq. per year. This assumes that timber to be skidded only is available during rigging times.

Total annual unit costs should be $160,850 divided by 2272 MBF Eq. = $70.80/MBF Eq. These costs would not include any allowances for risks, profits, general overhead, loading, trucking, road building, or landing construction.

1) Skidding Productivity Estimated by Buck Williams Jayfor Logging Company.

APPENDIX A - PRODUCTIVITY CALCULATIONS

1. Forest Service Cruise

   135.9 MBF International 1/4"
   106.6 Cords

   1. Fell, Limb, Top, Buck

      135.9 MBF divide by 24 man days = 5.65 MBF/man day plus

      106.6 cords divided by 24 man days = 4.44 cords/ man day

   2. Yarding

      135.9 MBF divided by 99.75 = 1.36 MBF/hr. scheduled plus

      106.6 cords divided by 99.75 = 1.07 cords/hr scheduled

      Or

      135.9 MBF divided by 71.25 pulling hr. = 1.91 MBF/productive hour plus

      106.6 cords divided by 71.25 pulling hr. = 1.50 cord/productive hour

2. Delivered Scale

   100.1 MBF Doyle
   630.94 tons

   1. Fell, Limb, Top, Merchandize

      100.1 MBF divided by 24 man days = 4.17 MBF/ man day plus

      630.94 tons divided by 24 man days = 26.29 tons/man day

   2. Yarding

      100.1 MBF divided by 99.75 hours = 1.00 MBF/hr scheduled plus

      630.94 tons divided by 99.75 hours = 6.33 tons/hr scheduled

      Or

      100.1 MBF divided by 71.25 pulling hrs. = 1.40 MBF/productive hr. plus

      630.94 tons divided by 71.25 pulling hrs. = 8.86 tons/productive hr.

APPENDIX B

Machine Rate for Virginia Custom Yarder

5 Year Machine Life

I. Ownership Costs:

1. Equipment Cost Recovery (ECR) = $\frac{\text{Cost}^{1} - \text{Salvage Value}}{\text{Life}}$

$$= \frac{50000 - 15000}{5} = \$7000/\text{Year}$$

2. Interest, Taxes, Insurance = 15% of Average Annaul Investment (AAI).

AAI = ECR ((Life + 1)/Life) + Salvage Value

= 7000 ((5 + 1)/5) + 15000 = $23,400

Interest, Tax, Insurance = .15 (23,400) = $3510/Year

3. Repairs & Maintenance = 50% of ECR
= .50 ($7000) = $3500/Year

4. Line Replacement

Line	Size	Length	$/Ft.	Life	Cost/Year
Skyline	3/4	1200	1.36	2	$ 816
Mainline	5/8	1400	.95	1	$1330
Guylines	3/4	1200	1.36	4	$ 408

Total Line Replacement = $2554/Year

[1] Yarder Cost in this Simplified Machine Rate Includes All Rigging and Equipment (Truck, Carriage, Radio's, etc.) Necessary to Yard.

Total Ownership Costs = $16,564/Year

II. Operating Costs:

1. Gasoline @ 2 Gal./hour x $1.00/Gal. = $2.00/hour

2. Lube @ 1/4 Gal./hour x $5.00/Gal. = $1.25/hour

3. Set of Chokers (9/16" x 8')
4 ea. x $10.00/ea. divided by 100 hours - $ .40/hour

Total Operating Cost = $3.65/hour

III. Ownership and Operating Costs:

Annual Yarding Hours	$/Hour
800	24.36
1000	20.21
1200	17.45
1400	15.48

APPENDIX C

Machine Rate for 100HP Rubber Tired Skidder

I. Ownership Costs:

1. Equipment Cost Recovery (ECR), Straight Line = (Purchase $ - Salvage $)/Life

   ECR = ($60000 - $10000)/5 years = $10000/year

2. Interest, Tax, Insurance = 15% of Average Annual Investment (AAI)

   $$AAI = ECR\ \frac{(Life + 1)}{Life} + Salvage = 10000\ \frac{(5 + 1)}{5} + 10000 = \$22,000$$

   Interest, Tax, Insurance = .15 ($22000) = $3300/Year

3. Repairs and Maintenance = 50% of ECR = .50 ($10000) = $5000/Year

4. Winch Line
   5/8" @ 100 Ft. x $ .95/Ft. x 6 Lines/Year = $570/Year

Total Ownership Costs = $18,870/Year

II. Operating Costs:

1.	Diesel Fuel - 2 1/2 Gal./hour x $1.25/Gal. =	$3.13/hour
2.	Lube - 1/2 Gal./hour x $5.00/Gal. =	$2.50/hour
3.	Chokers - 4 ea. @ $10.00 divided by 100 hr/set =	$ .40/hour
4.	Tires $2400/set divided by 2000 hr/set =	$1.20/hour

Total Operating Costs = $7.23/hour

III. Ownership and Operating Costs:

Annual Machine Hours	$/Hour
800	30.82
1000	26.10
1200	22.96
1400	20.71

HARVEST SCHEDULING

and

TRANSPORTATION ANALYSIS

for an area of the

ALLEGHENY NATIONAL FOREST

using the

INTEGRATED RESOURCES PLANNING MODEL / TRANSHIP

by

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ABSTRACT

A feasible harvest schedule for a 1600 acre area on the Allegheny National Forest (ANF) was determined using the Integrated Resources Planning Model (IRPM). The selected area's proposed management as defined in the Allegheny National Forest Land Management Plan, indicates that spatial constraints are an important consideration in the scheduling of activities in this area. This management is characterized by 10 years of intensive management followed by 30 years of extensive management. This schedule will be followed in further periods. This paper presents the rational for modeling with IRPM, the information used to model the test area and the results of an analysis for maximizing present net value. While the process followed was correct, this was a classroom exercise, and as such, some data development and interpretation was liberalized. It is concluded that the Integrated Resources Planning Model is a powerful tool for resource management planning.

1. INTRODUCTION

This paper documents the analysis that was performed to determine a feasible harvest scheduling and resultant road needs for an area on the Allegheny National Forest in Pennsylvannia (Figure 1). The analysis was performed as a classroom exercise for a course in Transportation Planning. This paper is a summary of the analysis that was completed, with more complete detail available (Salm, et al; 1986).

2. PURPOSE

This analysis had three main purposes. First, to gain a fuller understanding of the models used by the Forest Service for resource allocation and network analysis. Second, to utilize one of those models on an area to see the data and time needed to accomplish an analysis. Third, to document the process used in this analysis.

The results of this analysis should not be construed to reflect the management direction or even an alternative for management direction in this area. While the process followed is correct, some information and data utilized in this analysis may have been interpreted incorrectly. This process should be completed by an interdisciplinary team to ensure that data interpretation errors are minimized. As an academic exercise, the formulation of an ID team for the completion of this project was infeasible.

3. PROBLEM DEVELOPMENT

The first step in any attempt to solve a problem is to define the problem. The definition for our problem is :

> **"Determine a feasible scheduling of timber harvest in the given area, subject to the 40 acre clearcut size limitation, and the management as stated in the Forest Plan for Management area 6.2."**

4. BACKGROUND

This project is located on the Ridgway Ranger District of the Allegheny National Forest in western Pennsylvannia (Figure 2). It consists of 1679 acres located in portions of Highland and Jones Townships, of Elk County. The landform is characterized by broad flat plateaus with steep narrow stream valleys. The following paragraphs are intended to present a quick overview of the area.

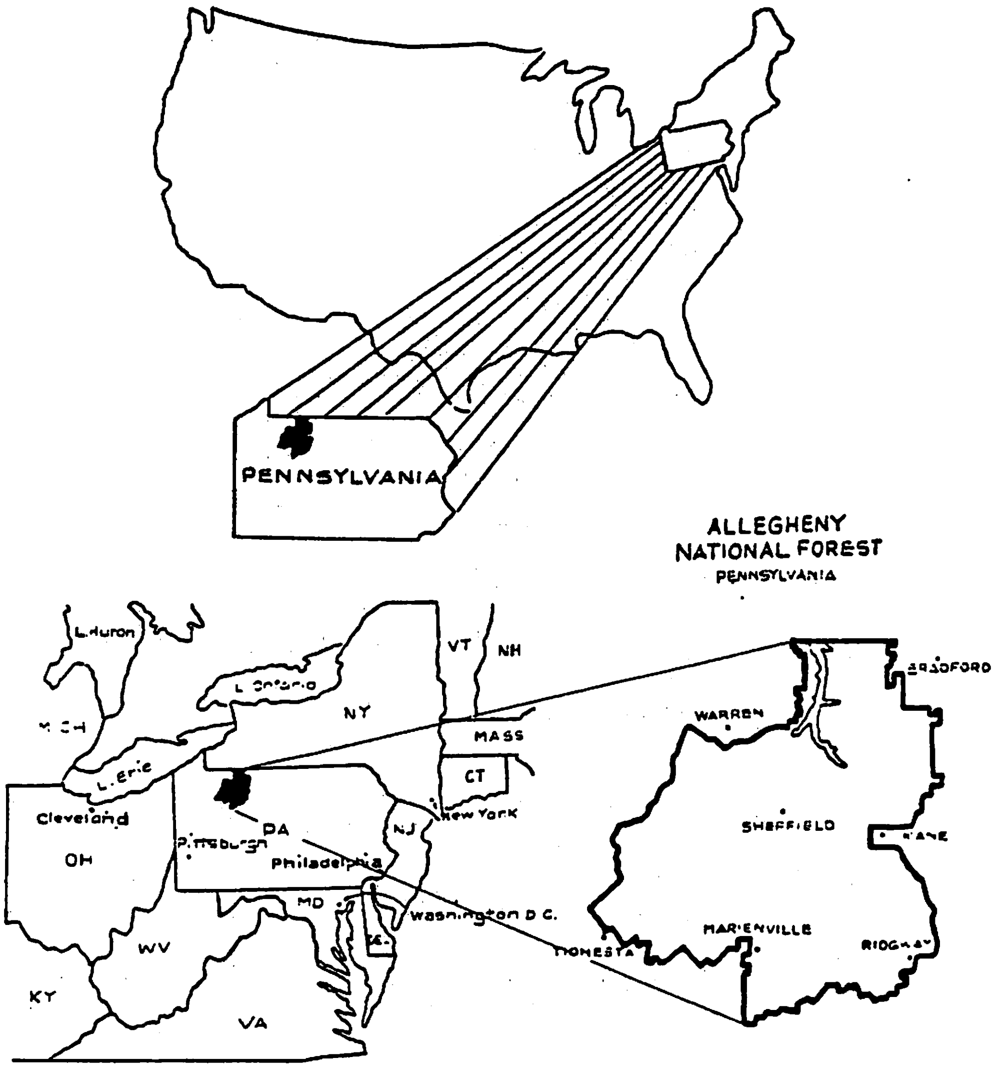

Figure 1 : Allegheny National Forest Vicinity Map

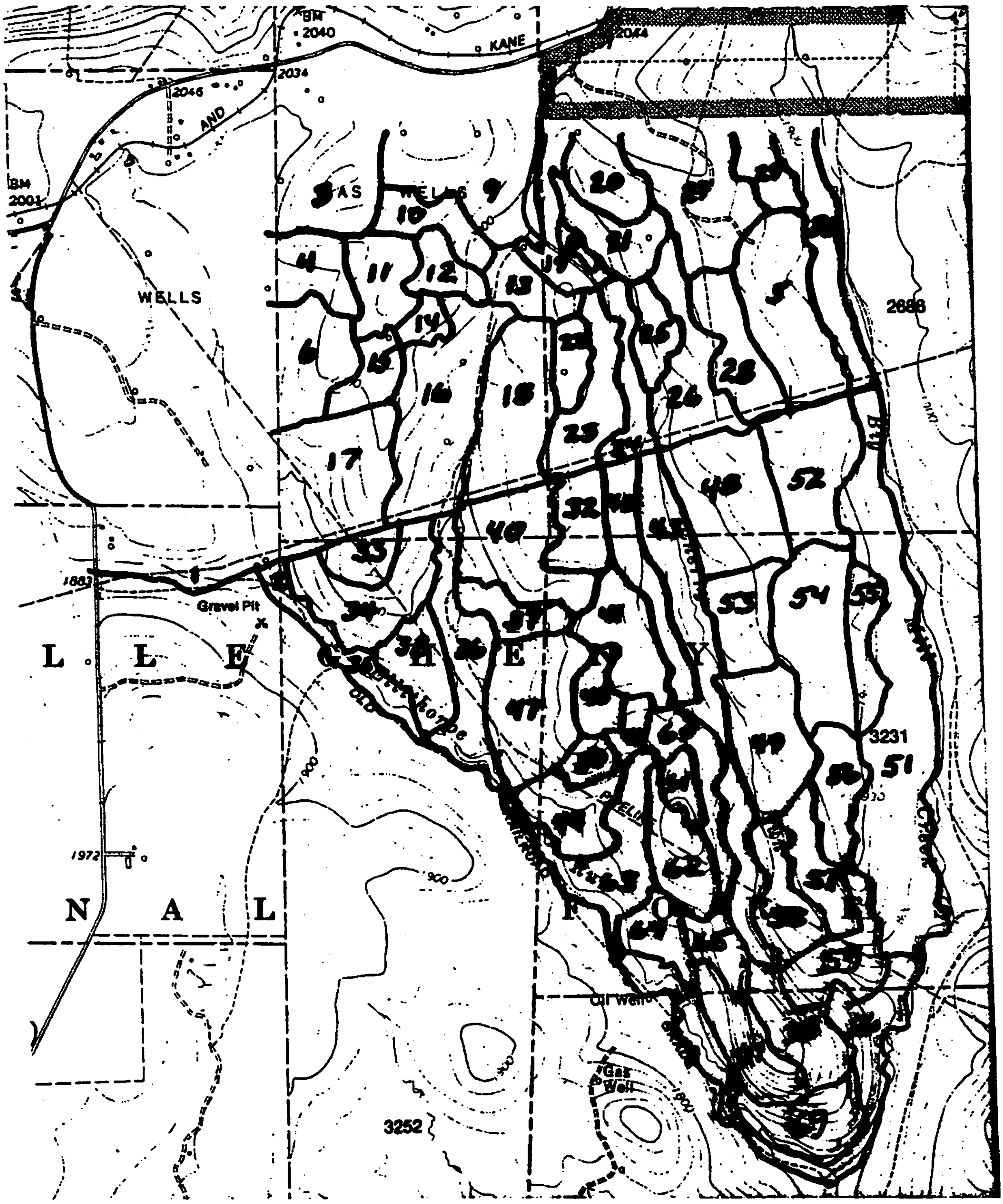

Figure 2 : Stand map

a. Silviculture

The major timber components of the area are Allegheny and Northern Hardwoods, with Black Cherry (Prunus Serrotina) being the most abundant species. Due to past management practices, approximately 56 percent of the timber stands are in the 60 to 80 year age class. The age class distribution is shown in Table 1, and indicated by stand in Table 2. The predominant sivilcultural methods are thinning, shelterwood, and final harvest (clearcut). Stand regeneration is by natural means, with past performance in the area indicating that natural regeneration must be present prior to final harvest. Advanced regeneration is present on 378 acres (23%) of the area. This is partly due to the presence of striped maple on 60 Acres (4%), and fern and grass on 427 Acres (25%). All of these inhibit the promulgation of natural regeneration. Table 2 indicates the locations of areas of natural regeneration, fern and grasses.

b. Soil and Water

Soil types within the project area include: Armagh, Brinkerton, Cavode, Cookport, Ernest, Hartleton, Hazelton, Nolo, Philo, and Wharton. Figure 3 indicates the locations of the soil types based on four levels of operation restrictions.

The project area is located in the headwaters of Big Mill Creek, and includes all or portions of the drainages of Cherry Run and Ellithorpe Run. Big Mill Creek is impounded in the Ridgway Reservoir approximately 8 miles south of the project area. This reservoir serves as the municipal water supply for the Borough of Ridgway, Pennsylvannia (population 9000). The area is typically wet, with many springs, seeps, and rocky areas that impact timber management activities and road location and maintenance. Wet and rocky areas are indicated in Table 2. These areas account for 216 Acres (12%) and 203 Acres (12%), respectively.

c. Recreation and Wildlife

The recreation experience available within the area is in the form of dispersed hunting, fishing, and camping. Mill Creek Trail runs parallel to and 300-1000 feet east of Big Mill Creek. Wildlife found in the area include; deer, turkey, grouse, rabbit, and bear. Deer and bear range over the entire area, while turkey use the drainages. Grouse and rabbit are most likely to be found near grassy areas such as pipeline ROW, clearcuts, and savannah type drainages. The U.S. Fish and Wildlife Service and the Pennsylvannia Fish Commission stock trout in Big Mill Creek approximately 1 mile below the project area.

TABLE 1

AGE CLASS DISTRIBUTION

AGE CLASS	ACRES	% OF AREA
OPEN	16	1
1-10	0	0
11-20	279	17
21-30	0	0
31-40	0	0
41-50	40	2
51-60	190	11
61-70	429	26
71-80	511	30
80 +	214	13
TOTALS	1679	100

Table 2

Stand Information

Proj	age	Acres	LOM	Stock	Repro	Fern	Wet/ Rocky	Maple
1	86	6	Y					
2	0	12	PIPELINE					
3	15	34		0				
4	74	25						
5	15	34						
6	78	34	Y			Y	W	
8	0	4	SAVANNAH					
9	59	36						
10	70	18			Y			
11	70	15			Y			
12	78	13			Y			
13	80	15			Y			
14	74	8			Y			
15	79	17			Y			
16	70	61	Y	58	Y			
17	15	40						
18	15	40						
19	75	20				Y		
20	15	16						
21	69	21					R	
22	79	12			Y			
23	87	31			Y	Y		
24	78	19	Y			Y		
25	88	15				Y	W/R	
26	97	32					R	
27	76	40						
28	81	26			Y			
29	75	11		63		Y		
30	84	15	Y					
32	69	17						
33	64	20						
34	64	25						
35	71	25	Y					

Table 2 con't

Stand Information

Proj	age	Acres	LOM	Stock	Repro	Fern	Wet/ Rocky	Maple
36	50	40	Y	74		Y		
37	60	14					R	
38	78	22						
39	77	16	Y			Y		
40	60	35						
41	60	30						
42	69	27				Y		
43	76	56	Y			Y		
44	68	23						Y
45	60	14			Y			
46	79	7			Y			
47	15	40		71				
48	15	40		71				
49	15	35		45				
50	63	11			Y			
51	75	83	Y	67		Y	W/R	
52	74	35			Y			
53	84	24					R	Y
54	70	30			Y			
55	70	13			Y			
56	85	19						
57	62	23					W	
58	72	27					W	
59	72	20	Y		Y	Y	W	
60	69	23						
61	62	8		54	Y			
62	59	24			Y			
63	63	24						
64	63	15						
65	59	13						Y
66	68	55	Y			Y		
67	84	24						
68	59	24	Y					
69	84	28					R	

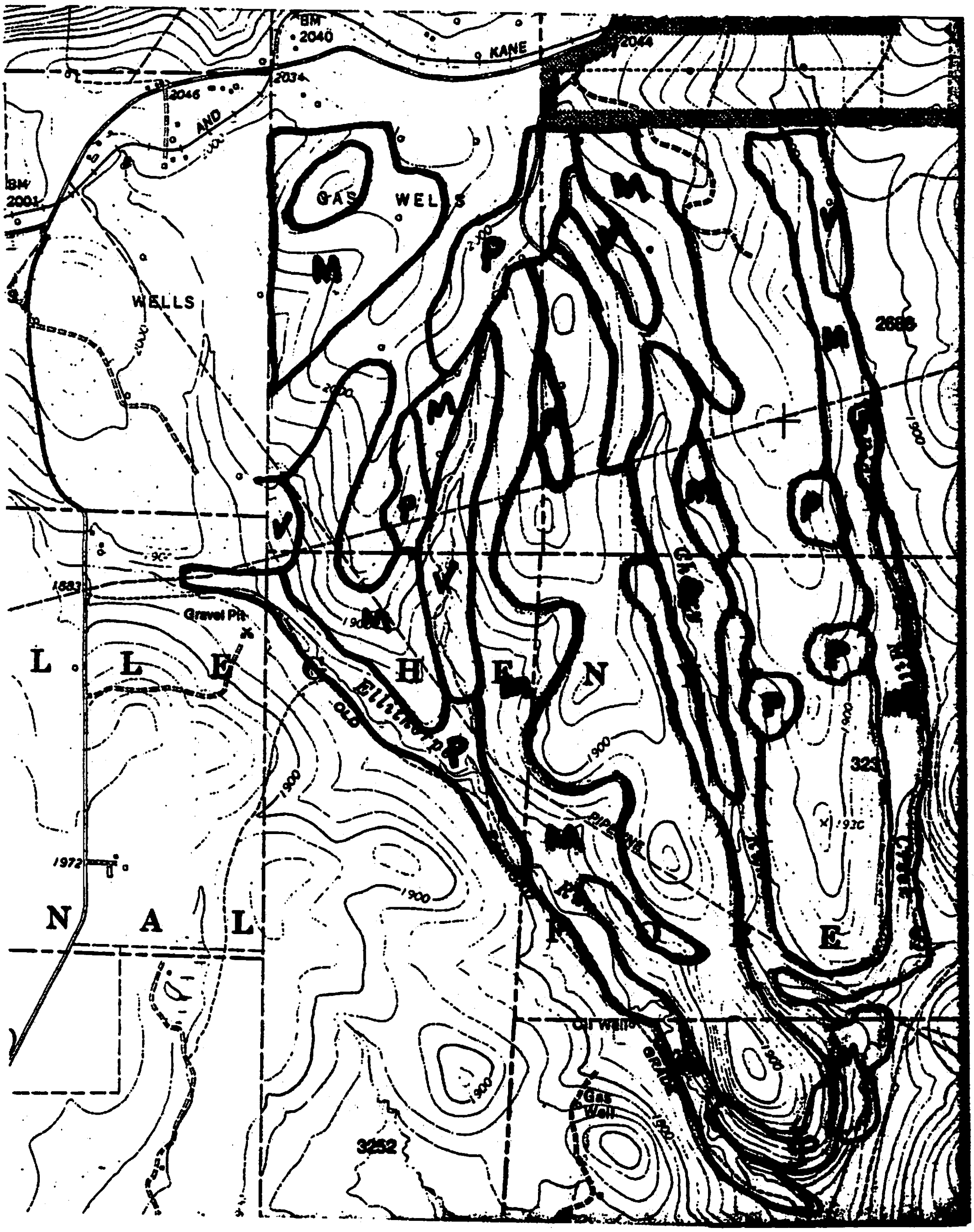

Figure 3 : Soil Types

(V) **Very poor soils**
(P) **Poor soils**
(M) **Moderate soils**

d. Transportation Facilities

The area is considered unroaded, with only one Forest Service administered road into the area. Access is provided by state highways that border the project area on the North and West. Table 3 contains a summary of the features of the roads in this area.

e. Land Management Planning

The project area is a portion of an area selected to recieve management goal 6.2 (USDA Forest Service, 1986). This goal calls for 10 years of intensive management, followed by 30 years of extensive management. This cyle is to be continued ad infinitum. During the 10 year intensive management period, one third of the acreage would be final harvested, and all road construction necessary for accomplishing this would be completed. The public would be allowed within the area on the road system with a roaded natural recreation setting. During the 30 year extensive period, the roads would be seeded and allowed to grass over. No vehicular traffic would be allowed (administrative or public) and the area would revert to a semi-primitive-non-motorized recreation setting.

Of particular interest to this project is the sivilcultural prescription of final harvesting one third of the area every 10 year intensive management period. This area would be subject to the 40 acre maximum clearcut size. It was assumed that final harvests in future intensive management periods would not be limited by past final harvests. While it would be possible to arrive at a solution to this spatial analysis problem by hand, a computer solution would allow for iterative solutions leading to a more optimal solution (lower costs, higher benefits, more even age class distribution). It is obvious that the contigious area subjected to this management must be analized at the same time.

h. Limited Opportunity for Management Areas.(LOM)

After approval of the Allegheny's Land and Resource Management Plan, it was proposed that there were stands within this area where final harvest was not practical. Due to the presence of fern and grass, extreme stocking levels, and the wet and rocky nature of portions of this area, the potential for creating areas with advanced regeneration were minimal. These areas were identified, and for this project, it was assumed that these areas would not be available for final harvest. Those areas are referred to as LOM's (Limited Opportunity for Management), and are indicated in Table 2. These areas amount to 454 Acres or 27% of the project area.

TABLE 3

ROAD LOG

ROAD	FROM	TO	NODES	LENGTH	CHARACTERISTICS
SR 66	Highland	Kane	AZ-AY AY-AW AW-AV AV-AU	7.37	State maintained, 2 lane, asphalt surfaced, gravel shoulders, 24 ft wide, condition- good, alignment- good, grade- fair, haul class High Speed
SR 948	Highland	Montmorenci	AZ-BA AY-AI	7.25	State maintained, 2 lane, asphalt surfaced, gravel shoulders, 22 ft wide, condition-fair to poor, alignment-fair to poor, grade-fair to poor, haul class I.
SR 948	Montmorenci	Ridgway	AZ-BA	4.00	State maintained, 2 lane, asphalt surfaced, gravel shoulders, 24 ft wide, condition-excellent, alignment- excellent, grade- excellent, haul class High Speed.
T326	LR 24006	SR948	AZ-AT AT-BB	2.54	Maintained by Highland Township, pit run surfacing, varies from single to double lane, alignment- good, grade- fair, haul class II.
T319	LR 24006	SR 66	AX-AW	1.14	Township maintained, pit run surfacing, double lane, alignment- good grade- good, haul class III.
LR 24006	SR66	Kane	AT-BB BB-AA AA-AX	4.70	State maintained, 2 lane asphalt, condition- poor, alignment- poor, grade- fair, haul class II.
LR 42001	LR 24006	SR 66	AX-AV	2.99	State maintained, 2 lane asphalt surfaced, 20 foot wide, condition- poor, alignment- fair, grade- fair, haul class III
FR 237.2	LR 24006	Dead end	AA-AB AB-AH AH-AI AI-AJ	.70	Forest Service maintained, L element, single lane with turnouts, open to public, condition- good, alignment- good, haul class III.

6. PROJECT SCHEDULING

This analysis included the scheduling of areas to be harvested, and the scheduling of the road construction necessary to access the area. There are several models available to perform transportation analysis, but only two currently available to schedule resource projects. Each of the model's features are summarized in Table 4.

Of interest to this problem are models that are capable of discounting values (eliminates MINCOST), allows for the minimization of fixed and variable costs for transportation facilities (eliminates TRANS 7), and allows for the scheduling of resource projects (eliminates NETWORK and phase I and II of TTM). This left phase III of TTM and IRPM/TRANSHIP.

In this initial analysis, resource constraints were not utilized, however, if it was deemed desirable to add them at a later date, the IRPM/TRANSHIP model offers the best alternative for their inclusion. Therefore, IRPM/TRANSHIP was choosen as the model for the analysis of this area.

To analize this problem, it was decided the following factors would be considered. First, the timber yields, costs, and benefits for each stand of the area would be used for scheduling. To determine yields, costs, and benefits, the following information was utilized: age,site index, percent stocking, available advanced regeneration, presence of fern and/or grass understory, topography, soils, seeps and time. Table 5 shows the yields, costs, and benefits by time period for several stands analized.

Second, the transportation facilities needed to transport the timber to the mills was considered. This included estimated haul, construction, reconstruction, and maintenance costs for alternative road projects. Table 6 is a link file for the possible roads in this area. Figure 4 indicates the locations of links.

The analysis of impacts on soil and water was not included within this project for several reasons. First, it would require the estimation of sediment production (or some other soil or water output) for each resource and road project. This was beyond the capabilities of this group at this time. Second, with the implementation of LOM's and the requirement of best management practices in the standards and guidelines in the Forest Plan, the impact on soil and water should be reduced. The use of the IRPM model allows for the inclusion of these impacts as well as many others at a later time should the expertise or need become available.

Table 4
A COMPARISON OF EXISTING TRANSPORTATION PLANNING MODELS CURRENTLY BEING USED BY THE U.S.D.A. FOREST SERVICE

	MODEL NAME				
ATTRIBUTE	MINCOST	TRANS 7	NETWORK	TTM	IRPM
Operational mode	network	network	network	net/mip	mip
Discounting	no	yes	yes	Phase 2&3	yes
Fix/Var loading	F	F	F	F	V
Min. Var Costs	yes	yes	yes	yes	yes
Max. PNW	no	no	yes	yes	yes
Optimize PNW	no	no	no	yes	yes
Constraints					
Link Capacity	no	no	no	Phase 2&3	yes
Mill Capacity	no	no	no	Phase 2&3	yes
Budgetary	no	no	no	Phase 2&3	yes
Resource	no	no	no	Phase 2&3	yes
Schedule Proj.	no	no	no	Phase 3	yes
Program Availability	FCCC	HP 9000	PC	FCCC	FCCC
Overhead Cost	mod	low	low	mod	high
Number of					
Time Periods	1	1	unl	7	6
Road Standards	1	1	unl	1	6
Commodities	2	1	unl	2	6
Demand Nodes	10	unl	unl	15	unl
Supply Nodes	100	unl	1000	100	5000
Nodes	1000	1000	3000	1400	5000
Links	1000	1000	5000	2500	5000
Projects	unl	unl	unl	25	500

mip=mixed integer programming

Table 5

YIELDS, BENEFITS, AND COSTS

PROJECT	TIME PERIOD	ACRES	SAW MBF/A	PULP CDS/A	COST /A	SAW BEN/A	PULP BEN/A
pro3	1		0	0	560	0	0
pro3	2	34	.9	10.3	330	110	20
pro3	3		10.7	10.6	330	2985	20
pro5	1		0	0	560	0	0
pro5	2	34	3.0	18.2	330	497	36
pro5	3		13.3	12.9	330	3576	26
pro20	1		0	0	330	0	0
pro20	2	16	3.0	18.2	330	497	36
pro20	3		13.3	12.9	330	3576	26
pro21	1		7.0	11.7	610	1724	24
pro21	2	21	16.5	6.2	360	5133	12
pro21	3		17.6	7.9	360	5520	16
pro25	1		5.5	21.5	430	1040	40
pro25	2	15	13.1	12.5	360	3657	24
pro25	3		15.0	12.1	360	2180	24
pro26	1		5.8	22.4	610	1040	44
pro26	2	32	15.7	12.5	360	4221	24
pro26	3		15.0	12.1	360	2180	24
pro27	1		5.6	19.2	560	1040	40
pro27	2	40	16.9	11.5	330	4700	22
pro27	3		16.0	12.4	330	3581	26
pro28	1		5.6	19.2	330	1040	40
pro28	2	26	16.9	11.5	330	4700	22
pro28	3		16.0	12.4	330	3581	26
pro29	1		5.0	16.4	370	760	32
pro29	2	11	14.8	13.6	330	4072	28
pro29	3		15.0	11.9	330	3213	24
pro30	1						
pro30	2	15	2.0	11.6	50	220	24
pro30	3						

Table 6 : LINK FILE

FROM NODE	TO NODE	LENGTH	STANDARD	HAUL STD	HAUL COST	CONST COST
AB	AA	.11	H	III	.28	-
AC	AB	.45	H	III	1.14	13,400
AC	AH	.57	H	III	1.44	20,000
AC	AH	.57	L	V	3.65	8,600
AD	AH	.27	H	III	.68	12,500
AD	AH	.27	L	V	1.73	6,200
AC	AD	.63	H	III	1.59	22,900
AC	AD	.63	L	V	4.03	10,300
AE	AD	.74	L	V	4.74	11,100
AF	AD	.83	H	III	2.10	24,900
AF	AD	.83	L	V	5.31	8,300
AG	AF	.34	H	III	.86	10,200
AG	AF	.34	L	V	2.18	3,400
AH	AI	.32	H	III	.81	12,500
AH	AI	.32	L	V	2.05	5,000
AI	AN	.17	H	III	.43	-
AJ	AI	.29	H	III	.73	-
AK	AJ	.60	L	V	3.84	9,700
AL	AJ	.55	H	III	1.39	19,250
AL	AJ	.55	L	V	3.52	8,250
AM	AL	.47	H	III	1.19	16,450
AM	AL	.47	L	V	3.02	7,050
AR	AM	.47	L	V	3.01	7,000
AN	AO	.38	H	III	.96	10,000
AN	AO	.38	L	V	2.43	5,000
AP	AO	.34	L	V	2.18	5,100
AO	AQ	.26	H	III	.66	9,100
AO	AQ	.26	L	V	1.66	3,900
AQ	AS	.58	H	III	1.47	25,000
AQ	AS	.58	L	V	3.71	12,000
AS	AT	.86	H	III	2.17	35,000
AS	AT	.86	L	V	5.52	15,400
AV	AU	.49	H	II	.49	-
AW	AV	2.01	H	I	1.41	-
AX	AV	2.99	H	III	4.57	-
AB	AA	.11	H	III	.28	
AC	AB	.45	H	III	1.14	13,400
AC	AH	.57	H	III	1.44	20,000
AX	AW	1.14	H	III	1.74	-
AA	AX	1.52	H	III	2.33	-
AY	AW	2.12	H	HS	1.08	-
AA	BB	1.44	H	II	1.45	-
AY	BB	1.74	H	II	2.66	-
AT	AZ	1.29	H	II	1.30	-
AY	AZ	5.45	H	HS	2.78	-
AZ	BA	8.55	H	I,HS	5.03	-
AT	BB	1.25	H	II	1.26	-

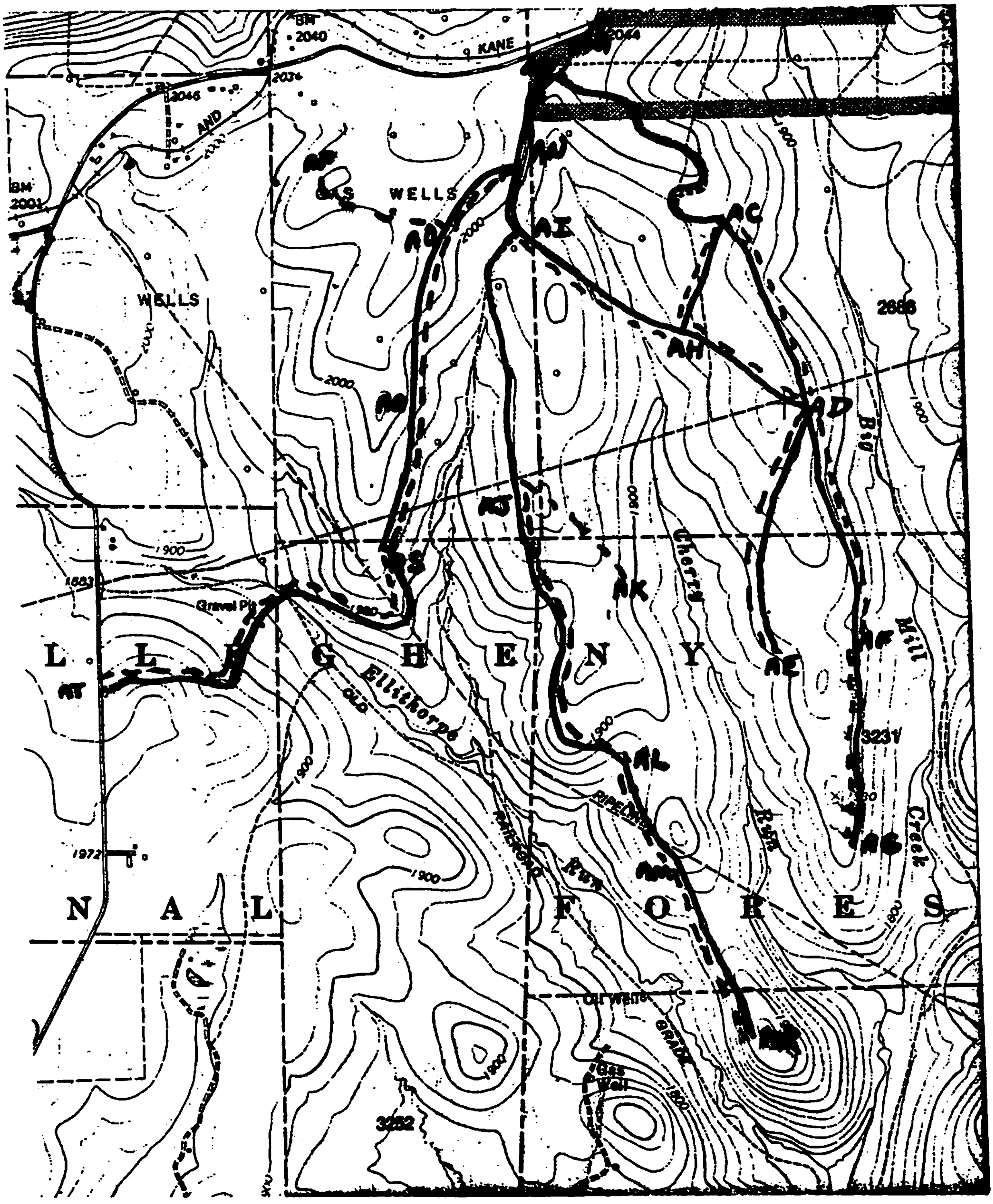

Figure 4 : Alternative road standards and locations

——— Construction/ Reconstruction - high standard
- - - - Construction/ Reconstruction - low standard

7. ANALYSIS

The development of computer input is described in a related report by E. Bergan. The reader is referred to that report, or the IRPM and TRANSHIP users guides.

8. DISCUSSION OF RESULTS

This project meet it's stated purpose. This is shown by the fact that an IRPM run was successfully accomplished. The results of this run are shown on Figures 5 and 6. Shown are the proposed cutting units for intensive management periods 1, 2, and 3, and the proposed road network to access these units, respectively. The present net value of this alternative is $560,000. This alternative allows for the final harvest of 290 Acres in the first period (6845 mbf), 511 Acres in the second period (13,268 mbf), and 263 Acres in the third decade (7612 mbf). These volume figures include any volume associated with the thinnings (393 Acres) and shelterwood cuts in this area in the same period. This volume flow is a non-sustained yield. Whether that would be a concern on this small area is beyond the scope of this project.

The number of acres clearcut varies by period. There are 290 acres in the first period, 511 acres in the second period, and 263 acres in the third decade. It should be noted that the model did not elect to final harvest all areas available (stands 3,4,and portions of stands 23,26,28, 32 and 47). It is believed that this was due to the spacial constraints placed upon the model. It is theorized that forcing the model to harvest all the units would lower the present net value. An alternative formulation of the problem would be to force the harvest of all stands during the planning period. Time did not permit the completion of alternative runs for other considerations than maximizing present net value. Other alternatives that could be run include:

1. minimize costs
2. maximize benefits
3. maximize volume harvested
4. harvest one third of land base every period
5. minimize road construction cost
6. minimize haul cost
7. non-declining yield
8. discount rates other than 4%

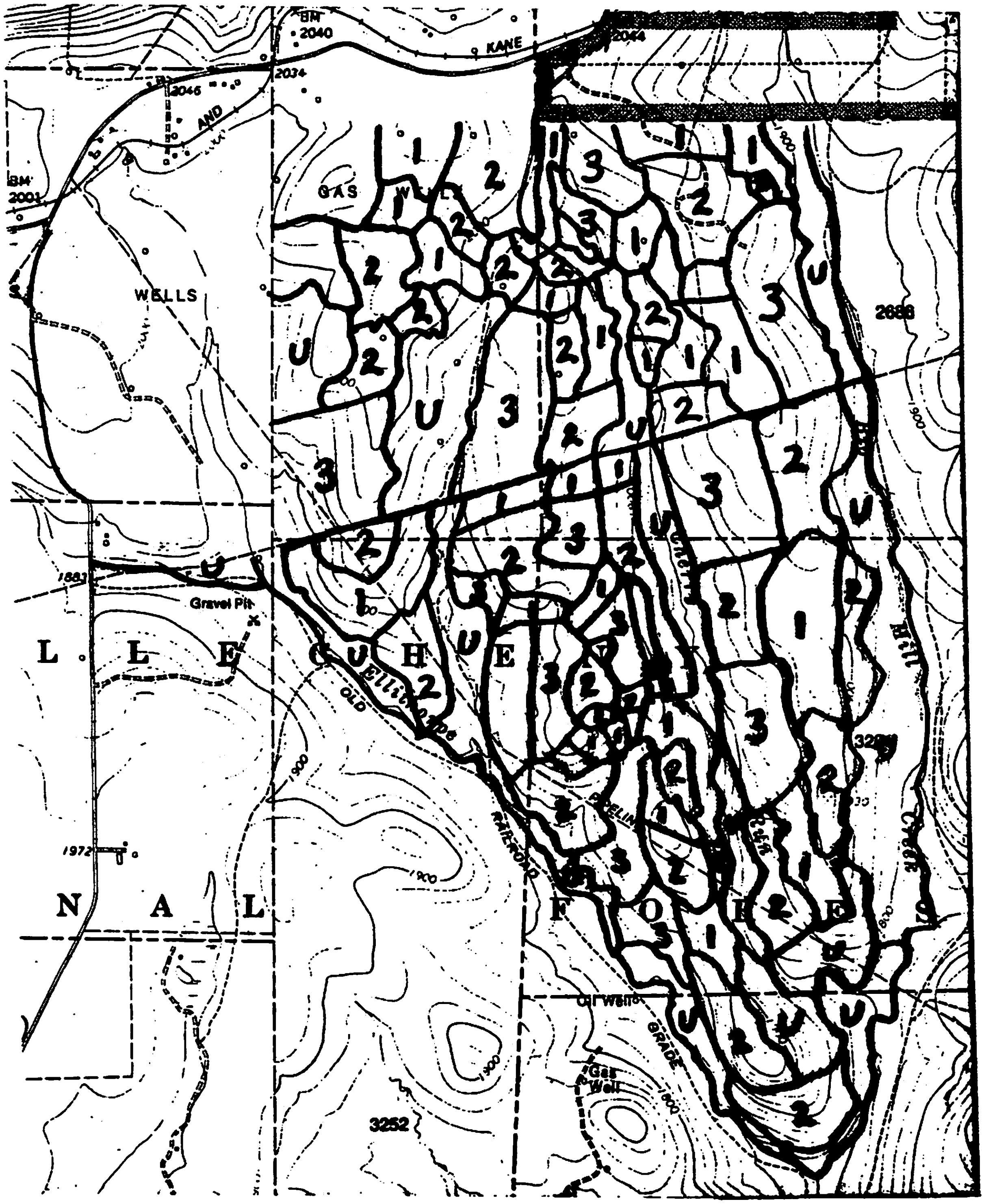

Figure 5 : Analysis results - Potential cutting units

(1) 1st intensive management period
(2) 2nd intensive management period
(3) 3rd intensive management period

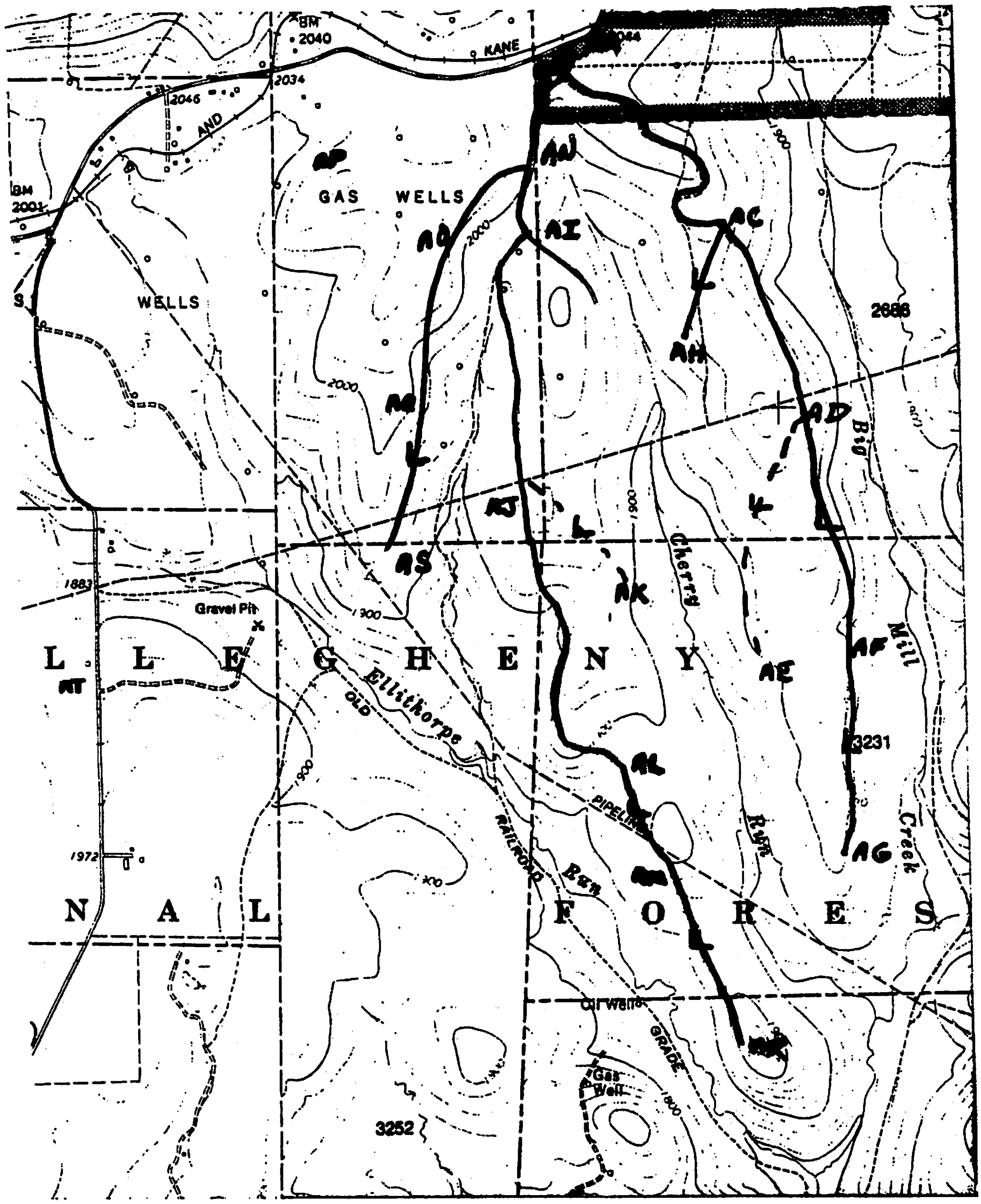

Figure 6 : Analysis results - proposed road network

—— Roads to be constructed - 1st intensive period
- - - Roads to be constructed - 2nd intensive period

9. CONCLUSIONS

IRPM/TRANSHIP is a powerful tool for resource management. This program has utility for all regions of the Forest Service, other government agencies, and private companies interested in spatial feasibility and resource constraint analysis. The use of the preprocessor developed by E. Bergan permits rapid development of project files. A built in growth model in IRPM/TRANSHIP would be a benefit, as would a system for transferring data directly from maps to files.

10. REFERENCES

Salm, D.; E. Bergan, W. Strong, B. Kramer, R. Neilsen, and T. Moore; Harvest Scheduling and Transportation Analysis for an area of the Allegheny National Forest using the Integrated Resources Planning Model - IRPM; Corvallis, Oregon; April, 1986; unpublished.

U.S.D.A. - Forest Service, Allegheny National Forest; Final Environmental Impact Statement and Forest Plan; Warren, Pa. March, 1986

A PREPROCESSOR FOR USE IN THE DEVELOPMENT OF IRPM AND TRANSHIP RUNSTREAMS

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ABSTRACT

A personal computer based software package developed by the author as an aid in using the IRPM (Integrated Resources Planning Model) and TRANSHIP linear programs is demonstrated. The preprocessor allows the IRPM and TRANSHIP users to formulate runstreams in a PC environment for later shipment to a mainframe computer housing the linear programs. The software is developed in a fashion allowing the elimination of much of the previously required repetition in runstream development.

The linear matrices for both the IRPM and TRANSHIP models are defined through the use of more than 15 card types. Problem definitions involving sizeable areas or numerous resource constraints typically require the creation of thousands of individual cards. Information contained in these cards is often repetitive. The former method of card type creation was to fill out paper forms for each card type, and then to create a computer file for use on the mainframe system by traditional keypunch techniques.

The preprocessor eliminates the need for the abovementioned process, allowing the user to concentrate on problem formulation rather than adherence to card format rules. Initial tests of the preprocessor have allowed first- time users to create runstreams with fewer formulation errors in 25% of the time required by traditional methods.

The Integrated Resource Planning Model (IRPM) was developed in the period from 1976 to 1979 by the Management Sciences Staff headed by Malcolm Kirby (Kirby, et. al. 1980). Since IRPM's inception, the program has been used as an area planning tool by seven National Forests in California, Washington, Idaho, Montana, and Oregon. Approximately 150,000 acres of land was analyzed in these studies. IRPM has also been successfully linked to FORPLAN solutions as a test of spatial feasibility and as an estimate of forest plan projected outputs on the Forest road network over time (Cox, 1986).

The Integrated Resource Planning Model is, simply put, a very large set of software modules which assist the analyst in creating a linear programming matrix. The Univac Functional Mathematical Programming System (FMPS) package in place at the Fort Collins Computer Center evaluates the matrix produced by IRPM, and IRPM has a series of report writers which help the analyst to interpret the results of a problem solution.

The IRPM model's diversity and flexibility in handling a wide range of problems is very appealing. However, like most things in life, all the good things IRPM can offer do not come free. The time required to collect the data necessary to model a medium sized problem can entail up to several months of a planning teams time, and the effort required to formulate a problem into the IRPM environment can also be considerable. The Integrated Resource Planning Model is not an analysis tool casually used on day-to-day planning problems. IRPM has been called a `big gun' (or an atomic bomb) by some analysts. However, for tough problems the model's abilities to handle a variety of resource constraints and investment opportunities is entirely appropriate.

IRPM receives a somewhat mixed reaction in Forest Service planning circles. Consider the following two quotes from analysts whose desks reside within a few feet of one another working at the Pacific Northwest Regional Office.

First the glowing report, an abstract from a recent Engineering Field Notes publication (Cox, 1986):

> I Rip 'Em Flexes Its Muscles - Case Studies of IRPM Use in the West ...
>
> Designed as a long-haul, eighteen-wheeler for handling heavy cargo, the Integrated Resources Planning Model (IRPM) is proving its ability to perform like a cross between a sports car and an all-terrain vehicle. Built on an ADVENT chassis, IRPM has a retooled drive train and a beefed up transhipment suspension for handling rough, curvy mountain roads; it is slipped into a classic body and comes complete with a slick, personalized user's guide.

Now a somewhat different quote:

> "No one has ever completed a successful IRPM run and been foolish enough to try it again." (Stapelton, 1987).

While both of the above excerpts obviously contain a humorous bent, let's examine how a software package could earn such diverse reviews. As stated above, IRPM was developed during the late 1970's. Computer technology has dramatically improved since those days... unfortunately some of IRPM's input requirements have not. The input streams for IRPM were first placed on computer punch cards and fed in batch runs to mainframe computer systems. Thus specific card types were developed which aided in defining problems. Twenty-four different card types can be used to define a problem, and much of the information contained in the different card types is repetitive. These punch cards were required to be 'fixed-format' and susceptible to simple key punch errors, thus increasing the difficulty faced by an analyst in accurately defining problems for analysis.

Problem definition in IRPM today still requires many of these fixed format card equivalents, and the number of lines of card statements required to define a real-life problem can be staggering. Problems consisting of several thousand card statements are the rule rather than the norm. Until recently, developing these problem formulations has entailed hand coding every card line on paper forms, followed by key punching of the information into files readable by the mainframe computer system. Besides the tedium of so many card statements, the possibility of error has been increased by the typical transfer from paper coding into a computer file.

Late in 1985 the author and Dr. John Sessions of the Forest Engineering department at Oregon State University developed a preprocessor for IRPM under contract with the U.S.D.A. Forest Service. The goal of the project was to move the input stream development for IRPM into the computer technology of the 1980's. The preprocessor developed for the Forest Service as a result of this request will be summarized here.

The IRPM preprocessor is available in compiled BASIC and runs on MS-DOS or PC-DOS compatible personal computers. With only minor qualifications, all of the paper forms formerly required for problem formulation have been replaced by a series of interactive screen editors. These editors assist the analyst in maintaining some of the mechanics of a successful IRPM formulation such as field lengths and error checking for values that IRPM cannot accept. Much of the preprocessor has the appearance of a spreadsheet, and the analyst is prompted for information as the user proceeds through screen editors.

Attempts have been made to reduce the repetitive nature of several of the IRPM card types, along with the convenience of fast entry, storage, and update of files used to define problems. Problem data screens are stored in an intermediate format suitable to easy editing. After all the necessary intermediate files are created, the preprocessor will create an ASCII file which can be fed directly to the mainframe housing the IRPM software.

Initial tests of the preprocessor have allowed problems to be formulated in as little as 25 percent of the time estimated to be required under the traditional methods.

Layout of the preprocessor might best be explained in brief by first explaining the structure of an IRPM formulation. In IRPM, inputs and/or outputs comprise activities, and an activity or series of activities comprise a project. A problem is comprised of a series of possible projects. For example, logs are an output of a logging activity. A series of activities such as administration, logging, and road construction can be activities in a project defined as a timber sale unit. Different timber sale units might be considered as different projects.

The analyst can constrain or track inputs, outputs, activities, or projects. Aggregates (combinations) of any of the above problem elements may also be constrained or tracked. The analyst has great freedom in defining these elements.

The preprocessor was developed in the same fashion. Each project is defined on a screen, with the inputs and/or outputs for activities comprising a project being listed together. Separate screens assist in developing desired aggregates. Other screens allow the definition of equations to be placed within the linear programming matrix.

The preprocessor has been designed so that a basic set of keystrokes will behave the same throughout the various screens. Prompts appear as the program is being executed to assist the user in correct problem definition.

A complete description of all of the IRPM preprocessor's capabilities is not intended to occur here. The reader is referenced to the IRPM Preprocessor User's Guide. The user's guide is available through Wally Cox, Engineering, USDA Forest Service Pacific Northwest Region (Linares, 1986).

More extensive tests of the IRPM preprocessor as an aid in forest area analyses is scheduled to occur in the near future. It's use as a tool within the Forest Service will hinge upon the degree of continued use of the IRPM model.

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HARVEST PLANNING UTILIZING GIS

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Abstract

Planning timber harvesting activities is a costly and time-consuming process. As tract size and the length of the planning period increase, more site specific information is required to prepare adequate harvest plans. Consequently, harvest planners may not be able to utilize traditional planning techniques when dealing with large tracts due to the increased data demands of the planning process. A potential solution to this problem is to combine the data handling, storage, and retrieval advantages of a geographic information system with the decision modeling capabilities of operations research models. This paper discusses the integration of an existing operational geographic information system (GIS) and a set of operations research models to form a decision support system (DSS) for timber harvest planning. An example of the harvesting system selection component of the DSS for a forested area in Maine is presented.

Introduction

The environment in which harvest planning decisions are made has changed significantly over the past ten years. The increasing use of capital-intensive mechanized harvesting systems and the cloudy financial climate facing the forest products industry have complicated the environment in which this planning occurs. Today's harvest planners must not only evaluate the many diverse site-specific parameters such as topography, soils, timber characteristics, and terrain features, but also must be able to relate them to machine performance. Based on these factors, least cost plans must be formulated that: identify areas to be harvested; estimate harvest and transportation costs; schedule harvest operations; and allocate equipment and crews. Quite often revisions or updates to the plan are required as objectives and budgets change throughout the planning period. As a result, planners are finding it increasingly difficult to keep up with the requests for up-to-date information and analyses required for developing and revising harvest plans, particularly for large forested areas. Consequently, a more structured approach for harvest planning is required. Such an approach would enable the planner to make "better" decisions in a more timely manner.

Operations research techniques have been used extensively in the past to assist in planning. However, Robak and Prasad's (1985) survey of operations managers in the Canadian forest products industry indicated that many of these mathematical programming models were considered to be "operationally unworkable" because of the large amount of data required.

Geographic information systems (GIS) have been used by the forest industry primarily for the storage of inventory and ownership information. As such, they are nothing more than a database system, storing geographically referenced data, that displays information in the form of maps. While GIS systems have the potential to aid in the harvest planning process, very few forest products companies have used GIS systems for purposes other than producing maps and maintaining and/or updating databases.

A logical means of reducing the complexity of the harvest planning process is to devise a method of combining the data storage and retrieval capabilities of the GIS with the efficiencies of mathematical programming models to assist the harvest planner in his complex and changing planning environment. Malac (1985) stated that one of the primary research priorities in the next ten years was to "develop management decision support systems such as fully integrated geo-based inventory models and models for strategic planning."

This paper will describe a DSS that has been developed to integrate operations research models with an existing GIS in an effort to improve the harvest planning process.

Harvesting Decision Support System

The harvest planning DSS (HPDSS) is designed to assist the harvest planner in answering three separate questions:

1) Which stands should be harvested to minimize the risk of fiber loss in order to meet yearly raw material requirements;
2) How can these stands be accessed; and
3) What harvesting system should be used to harvest these stands?

Ideally, these questions should be addressed in a manner that considers the interactions between the three questions. However, this ideal approach may not be possible for actual situations because of the size and complexity of the resultant decision model.

Even if such a model could be formulated, the mathematically optimal solution may not be the "best" solution. The validity of the model is limited by the degree to which "real world" factors may be quantified. Often the harvest planner's experience and/or judgment is required to account for the unquantifiable factors in the decision process.

To allow for this planner-model interaction and to reduce the size of the decision model under consideration, these three harvest planning questions are addressed sequentially. First, a decision is made concerning which stands are to be harvested for each year in the planning period. Then, based on the results of the stand selection process, the stand access question is addressed. Lastly, the choice of harvesting system to be employed is determined. This paper will concentrate primarily on the the harvesting system selection component of HPDSS.

Decision Support System Components

HPDSS consists of four separate, but interrelated, components. As Figure 1 illustrates, these components include: (1) the GIS, (2) a library of mathematical programming models, (3) a graphical interface, and (4) the harvest planner.

The basis of the DSS is an operational GIS maintained by Great Northern Paper Company, a cooperator in this research. The database component of this GIS includes forest cover types, terrain factors (Reisinger and Davis, 1986), site classes, inventory data, and information on past harvesting, silvicultural and protection activities for 2.1 million acres of company-owned forest land in northern Maine. In addition, roads, major rivers and streams, lakes, wetlands, regulatory zones, and corporate and political boundaries are stored in graphical form. Each type of information is stored on separate thematic levels or layers within graphic design files.

The database and the graphic design files are maintained on a generalized interactive computer mapping system developed by Intergraph Corporation. The Intergraph system consists of a VAX 11-750 minicomputer, a dual screen color graphics workstation, a digitizer, a plotter, and Intergraph graphics (Interactive Graphics Design Software) and database (Data Management and Retrieval System) software. One advantage of this system is that graphical elements contained in the design files may be linked to entries in the database. The presence of this linkage means that graphically defined areas may possess attributes that can be used for numerical calculations and reports may be based upon graphically specified areas. Another

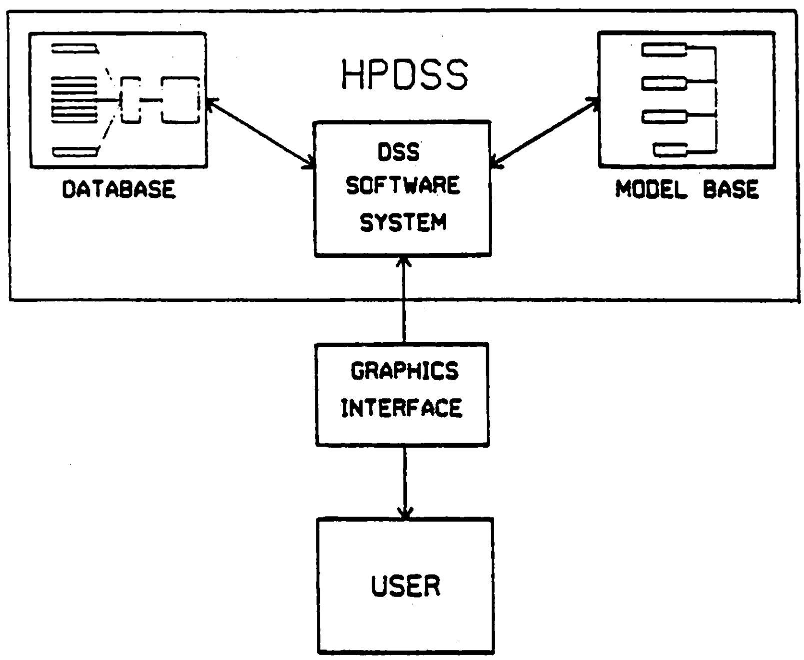

Figure 1. Components of the Harvest Planning Decision Support System (HPDSS).

capability of the system is the ability to perform analytic overlay operations on the contents of two or more different layers to determine complex relationships.

The model library is composed of several mathematical programming models and heuristics that are used to aid the harvest planner in the harvesting decision-making process. The data requirements of the models are determined by the DSS and then the appropriate data is retrieved from the GIS/database.

The graphics interface plays a major role in the harvest planning DSS. Through the use of a series of menus and data prompts issued through the graphics interface, the user determines the type of resource allocation decision being considered and initiates the decision-making process. Having determined the type of decision, the DSS determines which of the models to utilize and then determines what data is required to execute that model. The graphics interface then displays a base map of the land holdings in the GIS and directs the planner to indicate the area that is to be considered in the planning process.

Having determined the model to be used and the data requirements, the graphics interface then acts as a linking device between the other components of the DSS. In this role, it issues database access commands to extract the relevant information about the area under consideration from the database. After accessing the database, the graphics interface initiates execution of the mathematical programming model or heuristic. Once a solution for the model has been determined, the graphics interface extracts the results of the model and displays them for the planner in the form of a map and/or written reports.

The final component of HPDSS is the harvest planner. Since the decisions faced by the planner are semi-structured in nature, his judgement is essential to the decision making process. It is the planner's responsibility to express the constraints imposed upon the decision making process. In addition, the planner must use his judgement to incorporate unquantifiable constraints into the solution proposed by the model base.

Thus, the typical decision making process utilizing the DSS is an iterative procedure:

Step 1). the planner states the problem domain;
Step 2). the DSS displays an initial solution to the problem as stated by the harvest planner;
Step 3). the harvest planner evaluates the DSS's initial solution;
Step 4). the harvest planner revises the problem domain based on his judgement and the initial solution;
Step 5). return to Step 2.

The number of trips through this iterative loop is controlled by the user. When the solution suggested by the DSS meets all of the planner's objectives, the planner may exit the DSS and make the appropriate harvesting decision.

Stand Selection

The objective in the stand selection problem is to determine which stands are to be harvested in order to minimize "risk of fiber loss". The term "risk of fiber loss", utilized by Boss (1985), describes the potential for fiber loss of a stand due to spruce budworm attack. This risk assessment is determined for each stand based on species composition, general stand condition, and degree of current mortality.

In addition to minimizing risk, the set of stands selected for harvest must also satisfy two other constraints. First, for each year in the planning period, there is a minimum volume (for each species) that must be harvested. Secondly, there is normally a maximum yearly volume, for some species, that can be harvested in salvage operations. Additionally, it is assumed that clearcutting is the method of harvest. Finally, because of the method in which the GIS stores information about stands, it is assumed that stands must be considered as integral units. Given these assumptions, the stand selection question may be expressed as a linear program, in which the objective is to minimize the sum of the risk ratings of selected stands while satisfying yearly volume constraints.

Stand Access

The objective in the stand access problem is to determine the minimum cost location of "new" roads that must be constructed to access stands scheduled for harvest. The following assumptions were required to develop a procedure for answering this question: (1) a stand may be represented by the point corresponding to the centroid of the stand; (2) a stand is considered to be accessible if it is within 20-chains (1/4 mile) of an existing road; and (3) the only way to gain access to a currently inaccessible stand is to first gain access to one of its adjacent stands.

Given these assumptions, it is possible to represent the stand access problem in terms of a weighted graph or network. The minimum cost road construction pattern is represented by the minimum spanning tree of the graph.

Equipment Selection

The objective in the equipment selection problem is to determine the lowest cost "assignment" of harvesting systems to stands scheduled for harvest in any particular year. This selection procedure must consider several constraints. First, the number of productive units, i.e. men or pieces of equipment, for each harvesting system is limited. Also, certain harvesting systems may not be able to operate on every stand due to the terrain and timber characteristics unique to that stand. Finally, it is possible that the total number of available productive units for all types harvesting systems may not be sufficient to harvest all stands, so provision must be made to "purchase" additional productive units.

The three types of harvesting systems commonly utilized in northern Maine are the only systems to be considered:

1. a feller-forwarder system that utilizes a single machine to both fell the trees and transport them to roadside,

2. a feller-buncher/grapple skidder system that utilizes two machines: a feller-buncher to fell trees and a grapple skidder to transport the felled trees to roadside,

3. a manual-fell/cable skidder system , in which, trees are felled by chainsaw and a cable skidder transports the felled trees to roadside.

Because of the high unit cost of both the feller-forwarder and the feller-buncher systems, it is further assumed that only additional units of the manual-fell system may be employed if the overall yearly equipment levels are insufficient to harvest all stands scheduled for harvest in any given year. Finally, it is assumed that only one system may be assigned to a stand.

Given these assumptions the equipment selection question may be formulated as an integer program, in which, the objective is to minimize total harvest cost.

Example Harvesting System Selection

To illustrate the use of HPDSS in allocating harvesting systems to stands scheduled for harvest, a harvest plan for a 26,000 acre forested tract in northern

Maine was prepared. The assumptions utilized in the system selection procedure (i.e. data inputs to HPDSS) are listed in Table 1. Included in these data inputs are: the available system resources for each year in the planning period, production rates and operating costs for each system, and the limiting operable terrain for each of the systems.

Based on this information and a list of stands scheduled for harvest (determined by the stand selection component of HPDSS), HPDSS determines the cost minimizing assignment of harvesting systems to stands while satisifying system resource constraints and operability restrictions.

The solution produced by HPDSS is displayed in a graphical form for the harvest planner's review and acceptance. An enlargement of the northern third of the forested tract, with system assignments represented as shaded stands, is illustrated in Figure 2. In addition to the graphical display of the system selection solution, HPDSS provides a detailed printed report of the optimal system selection. A portion of the report for the 26,000 acre area is shown in Table 2. The report states the system assignment for each stand, including the cost and number of system resources required to harvest that stand. The report also displays a summary of the acreages cut and costs incurred by each system during the planning period.

Summary

The DSS approach applied to harvest planning provides several benefits to the harvest planner. First, it provides a mechanism for incorporating mathematical programming models in the harvest planning process. In the past, the use of these models has been limited because of the amount of work required to assemble the data required for the models. However, by combining the data storage capabilities of a GIS with the graphical input/output system of the DSS, this data handling problem is reduced to manageable proportions.

Additionally, the DSS approach allows the harvest planner to incorporate his experience into the planning process. Through this planner-computer interaction, unquantifiable constraints to the planning process may be expressed, resulting in a more realistic description of the harvesting problem.

Finally, the DSS utilizes graphics displays to present the results of the mathematical programming models for the harvest planner's acceptance. Since harvest planning problems are essentially spatial in nature, graphic displays of the planning area facilitate the planner's understanding and interpretation of the proposed solutions.

Table 1. Equipment selection data for the example harvest planning problem.

System	Available Production Units				
	Year 1	Year 2	Year 3	Year 4	Year 5
Manual Fell (2-man crew days)	1200	1200	1200	1200	1200
Feller-Buncher (machine days)	125	125	125	125	125
Feller-Forwarder (machine days)	125	125	125	125	125

System	Prod. Rate (cd/day)	Limiting Terrain		Costs	
		Gd. St.	Slope	Oper. ($/cd)	Extra Units
Manual Fell	20	-	-	12.80	300
Feller-Buncher	60	5	5	10.50	---
Feller-Forwarder	65	4	4	10.24	---

Percentage Reductions in Productivity Caused by Terrain

System	Slope				
	2-8%	8-15%	15-25%	25-45%	>45%
Manual Fell	5	15	35	55	75
Feller-Buncher	5	25	55	--	--
Feller-Forwarder	10	40	--	--	--

System	Ground Strength			
	Good	Moderate	Poor	Very Poor
Manual Fell	5	15	30	60
Feller-Buncher	5	15	40	--
Feller-Forwarder	10	25	--	--

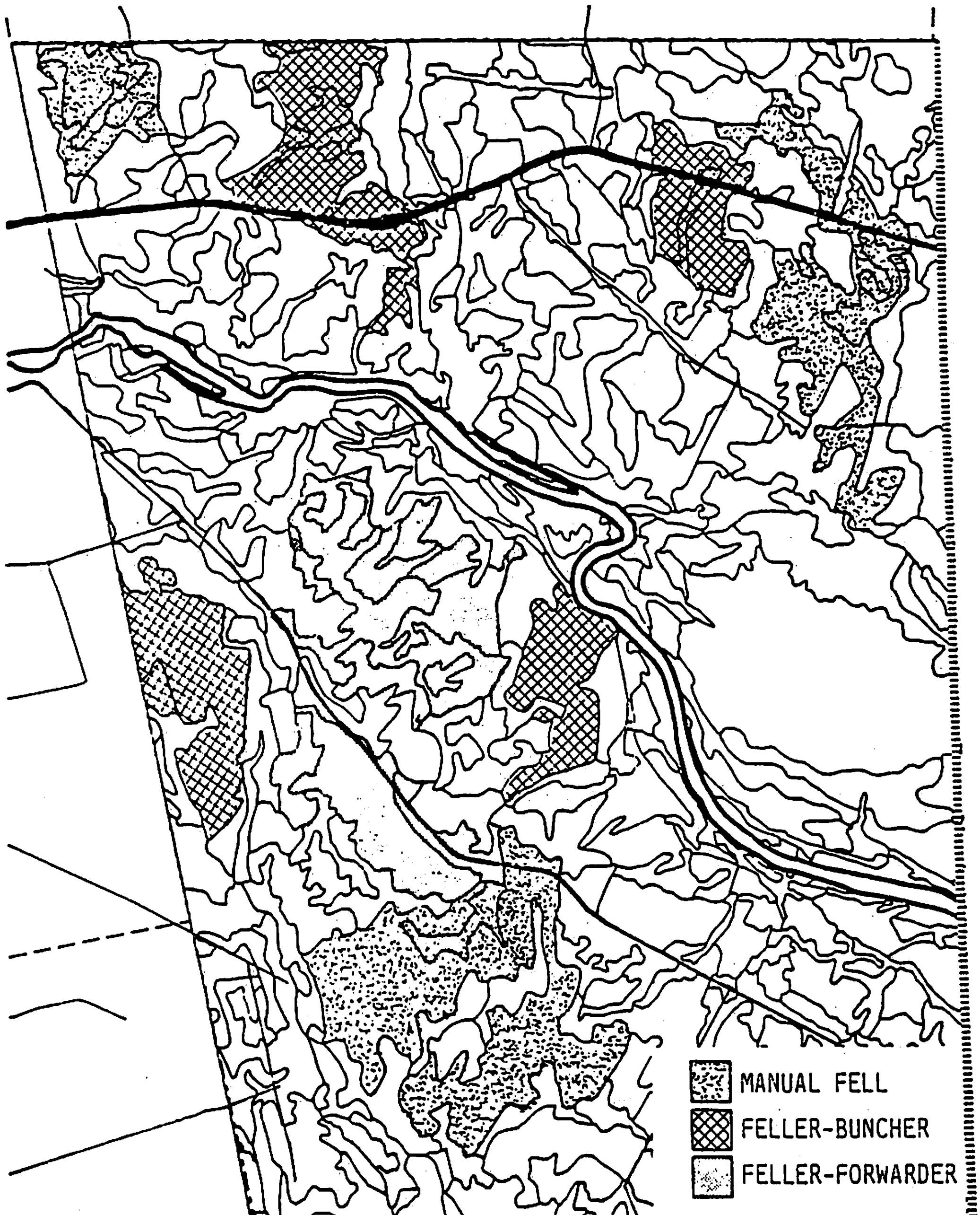

Figure 2. Portion of the equipment selection solution display for the 26,000 acre tract in northern Maine.

Table 2. Portion of the report produced by HPDSS for equipment selection decisions.

HARVESTING SYSTEM ALLOCATIONS IN YEAR 1

Stand ID	Area (ac)	System Type	System Resources Required *	Cost ($)
113	64.8	FELLER FORWARDER	24	18565
114	39.4	FELLER BUNCHER	20	13955
410	484.9	MANUAL FELL	717	183782
433	67.5	FELLER FORWARDER	28	22047
438	24.5	FELLER FORWARDER	10	7987
655	139.1	FELLER FORWARDER	60	46346

HARVESTING SYSTEM ALLOCATIONS FOR 5-YEAR PLANNING PERIOD

Stands	Area (ac)	System Type	System Resources Required	Cost ($)
17	1797.8	MANUAL FELL	2672	686233
13	929.2	FELLER BUNCHER	440	305616
15	1224.5	FELLER FORWARDER	586	455005

* system days

While the DSS approach has many advantages, a major problem has been identified. Solutions proposed by the DSS are limited by the type and quality of information stored in the GIS. Ideally, harvest scheduling (i.e. stand selection) should consider financial criteria. However, since no financial information was contained in the GIS that was used in this research, the stand selection problem had to be approached from a purely biological viewpoint.

Additionally, several of the assumptions incorporated in the formulation of the harvesting problems addressed by the DSS were a direct result of the type of information stored in the GIS. Since the Great Northern Paper's GIS is essentially a stand based system, stands had to be considered as integral units. However in actual practice, stand boundaries are rarely adhered to in harvest scheduling even though they are quite often considered to be an "input" to the harvest scheduling problem.

Through the use of DSS techniques similar to those used in HPDSS, forest products companies may find that their GIS can become a valuable component in the harvest planning process.

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AN EVALUATION OF THE PULPWOOD PROCUREMENT ENVIRONMENT OF NORTHWEST LOUISIANA WITH A GEOGRAPHIC INFORMATION SYSTEM[1]

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ABSTRACT: An approach to wood procurement analysis based on a GIS is developed. A data base is developed from wood usage requirements, pulpmill and wood concentration yard locations, location of forested areas and timber volumes. The thirteen parishes of the Northwest Louisiana region comprise the study area. Areas of potential sources of pine pulpwood stumpage are developed via various forms of procurement zones around each of the 3 pulpmills in this region.

Three major problems addressed are the effects of zone overlap and wood supply to various delivery points on the drain of pulpwood from each parish, locations of low areas of competition that would support future wood yards and expansion of manufacturing facilities, and identification of wood concentration yards which could be closed. Output for the analysis is in the form of maps and descriptive statistics from the GIS database. Various scenarios can be modeled by manipulating new locations, relocations, and price structures.

INTRODUCTION

Wood procurement is a specialization in forestry that has received minimal research attention in the past. Probably one-half of all industrial forestry graduates are employed in wood procurement, yet little effort is expended in research to analyze and improve wood

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procurement techniques. Probably no other specialization within forestry has such an immediate financial impact as wood procurement. Effects of decisions by the wood procurement forester today are revealed in days and weeks, and not in the years and decades imposed by biological and sivicultural decisions.

Forestry students generally receive little, if any, formal training to prepare them for wood procurement problems. There are no wood procurement handbooks, or Principles of Wood Procurement textbooks. University level training in wood procurement is seldom offered, and if offered, a wide response from the student population is not always received. Past wood procurement research has been minimal, but in a recent survey (Jackson and Brinker 1986) industrial foresters expressed a need for more research in the area of wood procurement.

Wood procurement encompasses a broad area for which there is no succinct definition. Generally, it is the art and science of accomplishing all activities related to the purchase and securing of wood fiber resources for resale or remanufacture. The procurement forester's main objective is to minimize the delivered cost of wood to a mill or concentration yard. To attain this objective, the wood procurement forester must be aware of the 3 major components that comprise the delivered wood cost:

1) stumpage price,
2) harvesting cost, and
3) transportation cost.

The wood procurement task is complicated by the fact that competition for stumpage dictates the timber selling price, and transportation costs are impacted by the distance from woods to delivery point and by the quality of the existing road network over which the wood is transported.

TRADITIONAL WOOD PROCUREMENT APPROACH

One of the basic problems confronting the wood procurement forester is where to begin the search for wood fiber. On a micro-scale the forester on the ground usually approaches this problem by applying the "art" portion of the definition above. The development of this approach involves the time consuming task of acquiring wood procurement knowledge through experience, because the wood procurement forester has to learn the geographic area, who has timber for sale or might be convinced to sell, what the costs are to harvest and transport the timber, types and lengths of contracts to negotiate, and maximum affordable delivered price. The wood procurement forester must also be able to visualize and react to any unforeseen event that may impact the ability to purchase a tract of timber. This information is acquired through personal contacts with landowners, loggers, and consulting foresters and is based on the credibility established over time of the individual and wood procurement organization.

On a larger scale, the macro approach to the search for wood fiber is centered around determining the availability of wood fiber on a regional basis and evaluating the effects of competition within a proposed procurement region. Data for this approach are usually obtained from USDA Forest Service Resource Bulletins, wood-using industry directories, and independent marketing surveys of wood availability. The macro approach usually involves interviews with pulpwood dealers, pulpmill procurement personnel, consulting foresters, state forestry personnel, etc. The competition for the resource is usually described in terms of average procurement radii and estimated wood requirements of competitors; the wood fiber resource itself is usually described in terms of volumes of growing stock available and annual harvest volumes tabulated on as small a geographic unit as possible. Output from this approach is normally in the form of a compilation of statistical tables and thematic maps to portray the information spatially.

Historically, foresters are trained to handle tables of statistics, and the use of maps to process spatial information has been in the forester's toolbox for many years. Basic wood procurement decision-making requires knowing the location of specific quantities of timber by specific categories; this requires a database and the production and use of maps. When the database and maps are stored, updated, and manipulated within a computerized system, the essentials of a geographic information system (GIS) are present. With GIS, the technology is available to efficiently present this wealth of information in a convenient manner. A GIS can allow selective information retrieval, ease of editing and updating the database, and output of combinations of database entities in tabular and spatially referenced map form.

BACKGROUND

This study originated in part as a result of a 1984 regional survey which revealed a need perceived by industrial foresters for a greater research effort in the area of wood procurement (Jackson and Brinker 1986). In the fall of 1986, the effort was undertaken at the Louisiana State University School of Forestry, Wildlife, and Fisheries to develop a method of using a GIS to evaluate wood procurement problems. The area selected for the study was northwest Louisiana. This is Region 5 of the state as classified by the USDA Forest Service, Southern Forest Experiment Station. The region consists of the 13 parishes depicted in Fig. 1 (Rossen and Bertelson 1985). This region includes a land area of 2.4 million hectares (6,010,700 acres), of which 1.8 million hectares (4,400,900 acres) are classified as forest land. The 13 parishes range from 50-94% timberland, and they average 73% timberland. There are 3 pulpmills in the region that require 2,395,000 cords of pine and hardwood pulpwood annually; this is 36% of the total state annual requirements (King and Nachod 1981). The region supports approximately 40 wood concentration yards, which is approximately one-half of the total in the state. These yards account for the purchase of over 750,000 cords of pine pulpwood and 360,000 cords of hardwood pulpwood annually. The forests of this region are composed of 42% pine, 38% hardwood, and 20% mixed pine-hardwood.

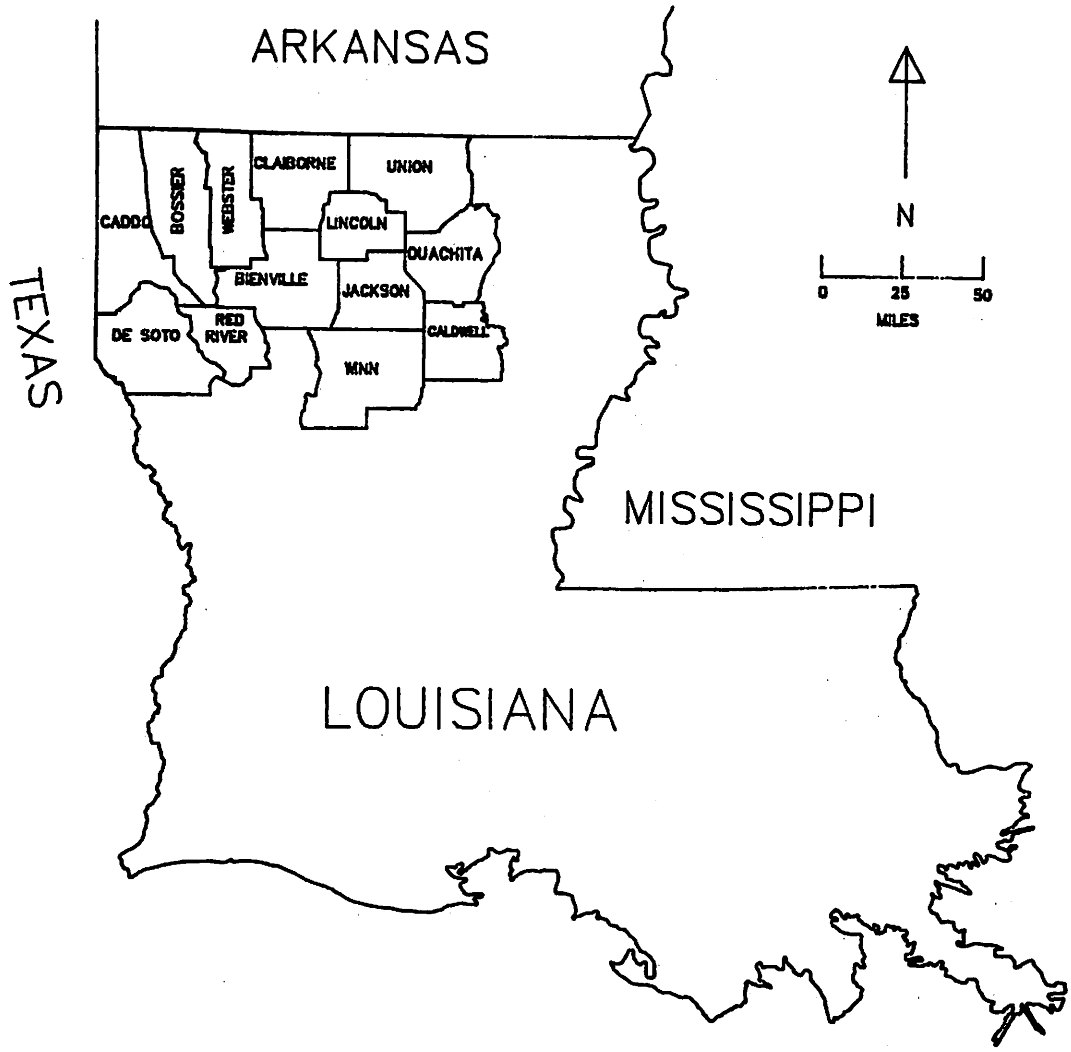

Fig. 1. – Location of wood procurement GIS study area.

GEOGRAPHIC INFORMATION SYSTEM

The wood procurement GIS consists of 3 subsystems (See Fig.2). The data processing subsystem is comprised of the acquisition and input of information to the database. This is the most time-consuming portion of any GIS project, often requiring as much as 80% of the time required to build the GIS (Devine and Field 1986). The data analysis subsystem is the main component used upon completion of the database. Data analysis is the "brain" of the GIS and information output must be designed to be readily utilized and clearly understood by the users, who comprise the information use subsystem. The GIS must be designed to be usable by the specific user group requiring access to the GIS. Governmental planners, resource managers, or institutional researchers usually have different problems and questions; therefore, the designer of the GIS must be aware of all potential user needs.

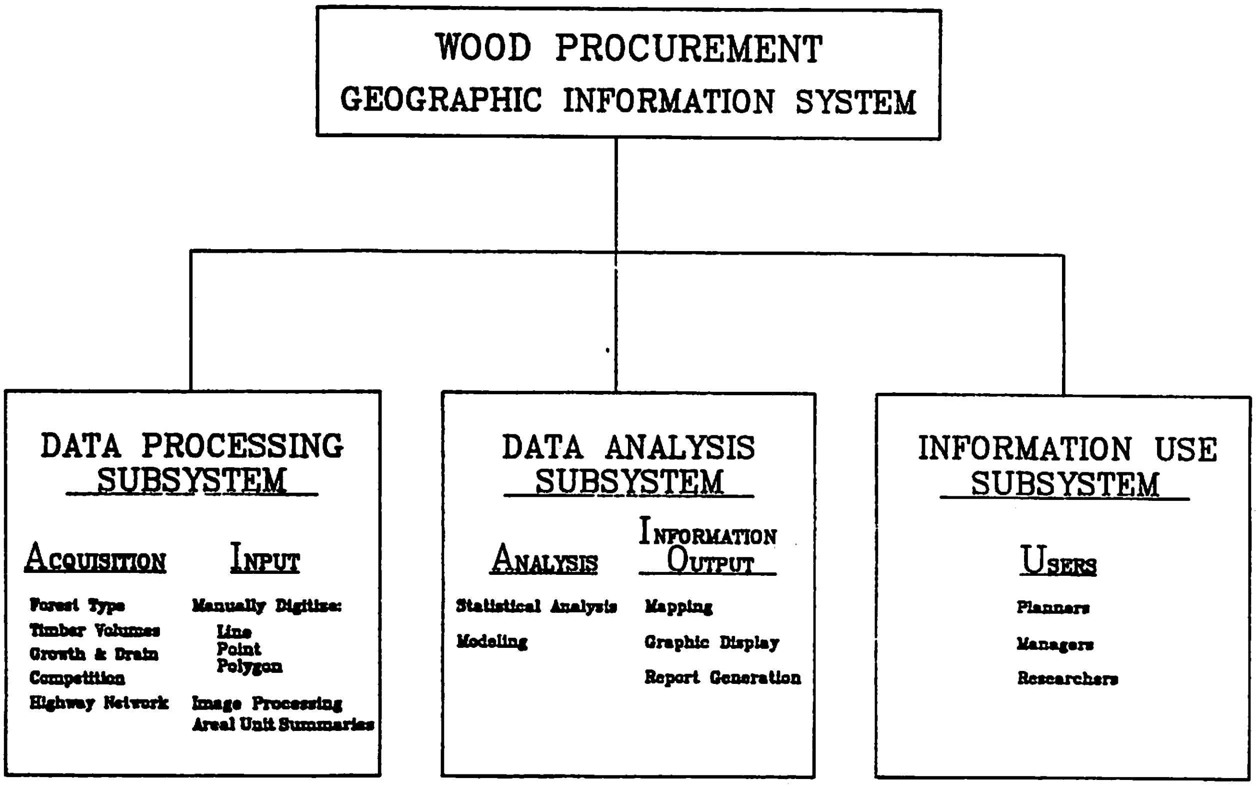

Fig. 2. — System development chart of a wood procurement GIS.

Hardware [2]

One of the important facets of the wood procurement GIS is that it is structured on a micro-computer system, with standard, readily available peripherals. Thus, it is an affordable system for those who cannot invest the capital dollars required for a mini-computer system. The system is centered around an IBM PC/AT with 640K RAM. Data storage is accommodated by a 20-megabyte hard disk, a 20-megabyte external disk drive with removable cartridges, and a 60-megabyte tape backup. This allows for the storage of as many map and data files as required.

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[2] Mention of brand names in no way represents an endorsement of the manufacturer's products by the authors.

Two monitors are used in the system. A IBM 13-inch monochromatic monitor displays system commands and menus. Color display for images and drawings is accommodated on an Aydin 8811 Slow Scan Analog Monitor. It is a 13-inch monitor with a resolution of 800 pixels per line by 512 lines. Color input is provided from lookup tables composed of 256 hues for each of the 3 primary colors.

Data input is provided by one of two primary methods. Manual digitizing is done on a Summagraphics, 11 x 11-inch digitizing tablet, or on a Hitachi 36 x 48-inch digitizer. The Hitachi tablet is the primary data input work station and is linked to a second IBM PC/AT equipped with the AutoCad software package for the input of point and line (map) data. Automated data capture of raster data can be accomplished through the use of an RCA, TC2000 Videcon camera in conjunction with a frame-grabber board in the IBM PC/AT.

Software

The software for this system is called RESOURCE. It was written by Decision Images, Inc., of Princeton, New Jersey. This package is versatile in that it provides both an image processing and a geographic information system. One of the appealing facets of this system is the capability of the user to access the source code to allow software modification as required, and the provision of continuous software updates included in the original purchase price. The GIS software utilizes vector operations for digital cartography and spatial data analysis and raster operations for image storage and overlay functions. It can utilize a virtual coordinate system which can be in any Cartesian system desired or a screen coordinate system of 512 x 512 pixels. Polygon identification is accomplished with character data, with one ID per polygon allowed.

Image manipulations can be performed with an overlay function that allows the performance of image arithmetic, buffer, and map overlay operations. Image files can be added, subtracted, or replaced by other selected files. This function is used to find the intersections of different map categories. Any overlay of significant interest can then be saved as a separate image file.

Within the image processing capability, the software is functionally designed to accept U.S. Geologic Survey (USGS) vector and raster digital maps and Landsat and SPOT imagery. It has the capability to perform many widely used statistical analyses and image transformations commonly used in remote sensing applications.

One of the main drawbacks in the system is an inadequate interactive editing capability. It is difficult to remove or change line data once it is put into the system. We have overcome this problem by incorporating the AutoCad software package, which has excellent editing and georeferencing capabilities for input of vector data; the data files in the AutoCad format are then exchanged into the required GIS format of the RESOURCE software.

Database

The primary database was obtained from a questionnaire mailed to the wood procurement manager at each wood purchasing facility in the study region. We received a 70% response rate from this survey. The primary purpose of this questionnaire was to determine raw material volume requirements by:

1. type (pine or hardwood and percentage of each),
2. raw material classification (roundwood or chips),
3. transportation mode (types of delivery systems),
4. perceived procurement radius, and
5. price structure allowed for "gate wood".

In addition, the respondents were asked to: 1) identify the percentage of annual pulpwood purchases that come from within a 25, 50, 75, and 100-mile procurement radius; and 2) divide a 360° procurement circle into 8 - 45° corridors, and identify the percentage of annual pulpwood purchases from each corridor. Thus, a 100-mile procurement radius could be divided into 32 segments, and approximate pulpwood volume requirements from each segment to each facility calculated. An example of an overlay of multiple procurement segments is shown in Fig. 3.

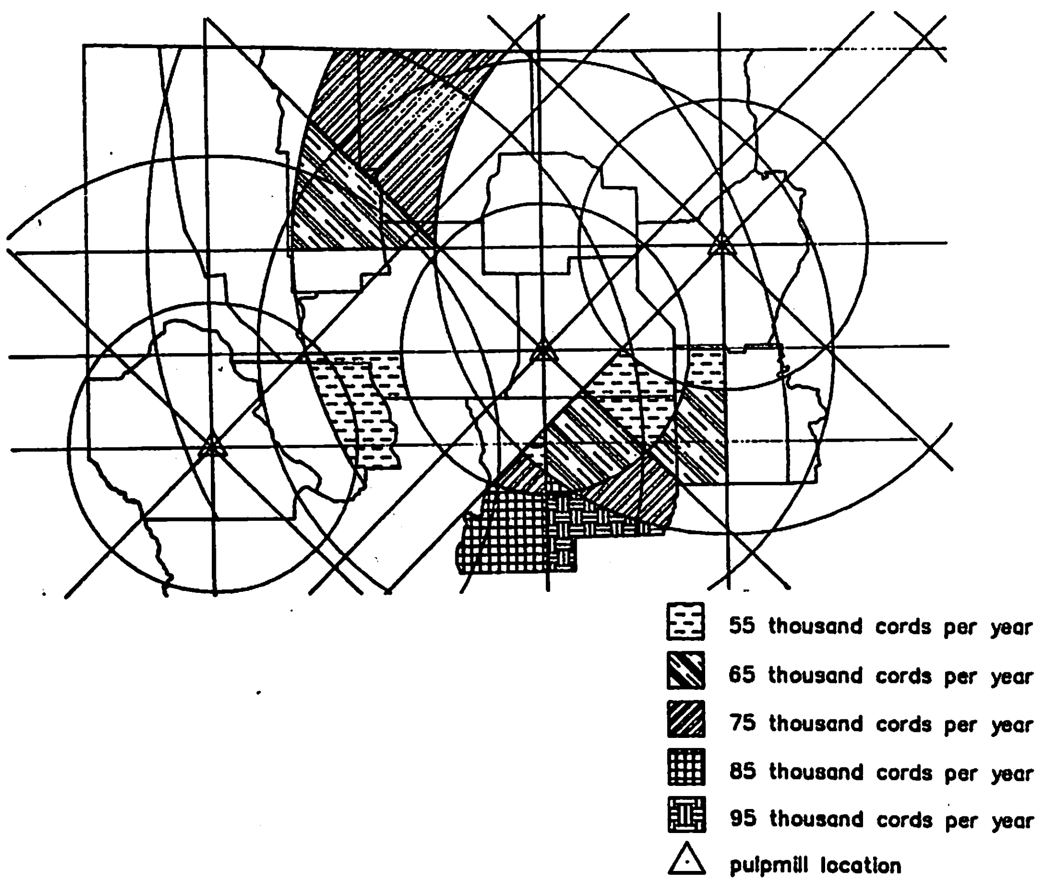

Fig. 3. — Example output of the interaction of procurement segments which reveal areas of high demand.

The secondary database is being compiled from publicly available sources. The transportation network has been digitized from the most recent 15-minute USGS topographic map sheets. This includes railroad lines and the highway system categorized by: interstate, primary-arterial, minor-arterial, hard-surface, and gravel collector roads. This is the classification system used by the Louisiana Department of Highways (La. Dept. of Highways 1974). Each of these highway types is maintained as a separate data layer within the database.

Forest types are from USGS Land Use/Land Cover digital map data. This information will be utilized in a raster format, with a 16-hectare (40-acre) cell size on a scale of 1:250,000. This digital map contains a number of non-forest land use/land cover categories, but for simplicity, the only classifications being retained in this GIS are the forest type delineations of coniferous, deciduous, or mixed forest type.

A variety of data is being accumulated from detailed 1984 Forest Survey data provided by the Southern Forest Experiment Station, Forest Survey Unit located in Starkville, Mississippi. Timberland area, ownership class, growing stock volumes, species composition, and stand age classes are being obtained. The shortcoming to using these data is that a parish is the smallest discernible unit; thus homogeneity within the parish boundary must be assumed.

PULPWOOD PROCUREMENT ANALYSIS SYSTEM

Three major problems concerning wood procurement are being addressed in this project: evaluation of the effect of zone overlap and wood supply percentage to various delivery points on the drain of pulpwood from each parish, determination of locations of competitively void areas that would support future wood yards and manufacturing facilities expansion, and identification of wood concentration yards that might be closed or moved.

Within the database, the transportation network, forest type, growing stock volumes, procurement segments, and pulpwood requirements are stored as separate thematic map layers. These layers can be merged by the use of image arithmetic to create new thematic maps. Locations and areas of intersected polygons of interest can then be calculated and evaluated.

Each woodyard and pulpmill procurement area requirement is stored as a separate map file. Pulpwood volume requirements are categorized and assigned to numeric classes. To exhibit areas of relative demand, procurement segment files can be added, and areas, by pulpwood volume required, can be calculated, with locations graphically displayed in map form (See Fig. 3) and in tabulated form (See Fig. 4). With this map overlay approach, the area of overlapping zones can be clearly seen. In making decisions concerning wood concentration yard expansion or relocation, areas of excess competition can be avoided, and void or low-demand areas explored further for future expansion.

THE AREA FOR ALL CLASS VALUES IS GIVEN

SQUARE MILES	CLASS NUMBER	
51219.57703	0	
9135.751418	1	ONE MILL PROCUREMENT AREA
12554.34783	2	TWO MILL PROCUREMENT AREA
4518.549149	3	THREE MILL PROCUREMENT AREA

Fig. 4. Tabular output of a simple area intersection of the 75-mile procurement circles of 3 pulpmills.

Another approach being taken in this wood procurement GIS is the analysis of the effect of the creation of isodopanes or isolines of equal highway travel cost to reflect more realistic procurement zones. Because approximately 90 percent of the wood in this region is transported by truck, procurement zones are being depicted as isodopanes to offer a more realistic perception of the impact of procurement zone interaction.

SUMMARY

The study of wood procurement has been very limited, but the GIS technology holds the potential for assimilating and structuring large amounts of geographical and descriptive data. This is a microcomputer based GIS with a total equipment cost of less than $35,000, thus allowing a broad user market. The application to wood procurement is currently being developed. The capability to overlay procurement zones of varying distances around wood-using facilities would be an asset to procurement foresters in determining areas of low competition for the wood resource; these areas could then be considered for the emphasis of wood procurement efforts.

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THE USE OF A GEOGRAPHIC INFORMATION SYSTEM IN COMPUTER-ASSISTED FOREST ROAD NETWORK ANALYSIS

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Abstract. The use of computerized geographic information systems (GIS) for forest management has increased rapidly during the last decade. The capability of these systems to facilitate the accessibility of diverse data allows for the inclusion of all essential information in management planning procedures. The increasing costs of road construction, maintenance, and timber transportation warrant extensive planning of forest road network layout and transportation scheduling. The integration of these efforts in the overall management decision-making process will result in more efficient timber harvesting operations. A forest road network location procedure was developed using both the spatial and descriptive data bases of an existing GIS, including a road network inventory and analysis module. The objective was the optimal location of a road network in areas not yet serviced by existing roads, constrained by a user-defined maximal service zone width. A local search algorithm was designed, producing optimal or near-optimal solutions in all cases examined. The location procedure gives the user flexibility in defining the area under investigation and the access road configuration. The influence of physical and operational restrictions on the optimal spacing of parallel roads is examined, and a modification of the classical road spacing model is discussed.

Introduction

Computerized geographic information systems (GIS) provide the decision maker with complete and up-to-date information, required for the effective and efficient management of large timberlands. The introduction of these systems enables the user to have all data readily accessible in the form of maps and reports. The capability to combine the different data sets, such as cover type, timber volumes, soil types, cut areas, topographical features, and other management information, allows for the inclusion of as many factors as appropriate in the decision-making process.

One aspect of the forest operations which is often not included as an integral part of the present information systems is the harvesting and transportation of timber. It has been claimed that the most valuable real estate in many operational forests, on a per unit area basis, are the road networks. Because of this high value, combined with the high transportation and road maintenance costs, it is essential to ascertain the right combination of road quality and quantity for successful forest management. Special harvesting decision-making support systems exist, but are uniquely designed for this purpose and do not allow for complete integration into a GIS.

An important part of road network analysis is the problem of locating new roads within an existing network. Because of the growing need to control logging and transportation costs, road networks should be optimized with respect to the costs of road construction, maintenance, skidding, and trucking. In many cases this will mean network expansion. New roads are also required in areas not previously subjected to intensive operations (Corcoran and Nieuwenhuis, 1983). Other reasons for new road construction include changes in transportation systems, upgrading of existing network segments, environmental policies, fire control, and recreation. In addition, the possibility exist that, because of vehicle size and weight restrictions for public roads, it becomes economically attractive to link forests and processing locations by private road networks.

The Existing Road Network

Part of the developed GIS is a road network inventory module (Nieuwenhuis, 1983). The system is currently used by a large paper company in Maine for the management of almost 1,000,000 hectares of forest land and 3,500 miles of forest roads. Because of the fast-growing complexity and size of the in-place road network, it became necessary to automate the inventory procedures used for transportation and road maintenance management. Making the inventory module part of the overall GIS has the further advantage that the information can be used to enhance the usefulness of the system for other procedures, such as accessibility studies or environmental impact analyses. At the same time, the road inventory module can use all capabilities and data of the overall system, which increases its flexibility and accuracy. The developed road inventory module is also the basis from which a road location procedure has grown.

The permanent road network is classified into three functional categories, class I, II, and III. For each of these categories minimal and/or maximal structural requirements are defined (by company policy). These requirements include maximal up-hill and down-hill grades, minimal widths, maximal curvature, and required surface material for roads; minimal diameters, material, and slopes for culverts; and minimal load capacities, minimal widths, and required materials for bridges. The ability to identify roads, road segments, and structures which do not satisfy their required structural specifications is necessary to efficiently bring all roads up to their functional specifications. The capability to do this in the form of maps and/or reports facilitates the upgrading and maintenance scheduling process.

The GIS is a combination of the Data-base Management and Retrieval System (DMRS) and the Interactive Graphics Design System (IGDS). A special feature of the DMRS is the possibility to use coded information to represent attribute values. The use of the code lists serves three purposes: storage space reduction, ease of handling, and error detection. The code lists are also an efficient way to assign values to graphic parameters, such as color, line code, and line width. For the mapping of elements with discrepancies between structural specifications and functional requirements, extensive use is made of code lists to assign color and line code values to the graphic elements, enabling the plotting of road segments and structures according to their structural-functional relationship. Other applications which were taken into consideration are network analysis procedures. In order to use the road inventory module for these purposes, a number of changes must be made in the way the roads and road segments are stored in the data base. These modifications make it possible to use the inventory module for network analysis algorithms, such as travel time estimation and route selection, including both simple shortest route determination and more complex tour optimization procedures.

The road inventory module in its present form is sufficient to be used as a basis for the road location procedure. If the serviced area of roads of a given class has to be found, the data base and the graphics can be used to find the roads of that class in the area of interest. With this information the road location procedure starts by constructing service zones along these roads.

New Road Location

The problem of road location consists of the optimal location of roads in forest areas not yet served by an existing road network. Each existing road serves a zone at both sides of the road, restricted by physical obstacles such as rivers, lakes, and bogs. The constant service zone width used is established by company policy. The goal of this policy is to create an equally-spaced, minimal-cost network throughout the company's forest lands. The problem can be stated in the following manner: locate a minimal-cost road network in areas which are not served by existing roads, using a constant service zone width to determine the served areas. In order to allow the use of combinatorial optimization techniques in the algorithm, a grid representation of the areas involved must be established. The roads to be located consist of a selection of the links of the grid. The developed road location procedure integrates road network analysis techniques with overall forest management decision-making processes, by utilizing the data base and graphic design files of an operational GIS. The procedure is designed to locate non-served land areas by constructing service zones along existing roads. In the non-served areas new roads are located to serve the area at a minimum road construction cost. The selection of the service zone width used for a particular problem depends on several factors. First, it is possible to apply certain rules, as defined by company policy. In this case, service zone widths are predetermined for each of the possible road classes. Second, for small areas, it will be possible to use a service zone width directly related to the optimal yarding distance associated with the local situation and selected harvesting system.

The developed algorithm is based on a local search principle, using shortest distance and minimal cost matrices. The algorithm does not guarantee an absolute optimal solution in all cases. Because of the complexity of this type of network location problems, a proven optimal algorithm would be extremely time consuming (Tansel, Françis, and Lowe, 1983). From extensive testing of the developed procedure, it can be concluded that the solutions are optimal or very close to optimal. For small scale problems optimality can be verified. For larger problems it rapidly becomes impossible, and surely impractical, to determine if solutions are optimal. In these cases, only local network cost minimization can be evaluated easily.

The integration of the developed location procedure with the existing GIS is a rather complicated process. The reason is that the GIS is not designed to be used for network analysis purposes. The data transformation from polygon format to grid format is necessary to perform spatial analysis, and requires a complex series of scanning and overlay procedures (Boss, 1985). The representation of roads and streams as linear elements further complicates the process, because only complex shapes are recognized by the scanning software. The integration of the location procedure output with existing design files is relatively simple. The output consists of a report file and a road segment coordinates file. This is in accordance with the principles of the GIS, which allows for output in both report and map form. The coordinates file only has to be transformed into design file format to display the solution in graphic form, on the screen or as a map, if desired as an overlay on other GIS graphic files. The problem of cost determination, based on a series of color codes relating to different types of information, has been explored, but not fully resolved. A weighting procedure, which evaluates new combinations of, and interactions between, the individual data layers has been conceptualized.

The location procedure is developed to be used as a tool, not as a decision maker. In most cases, several runs of the program, using various entry cell configurations, should be made. The results then serve as an aid in the actual road network layout planning. Especially in cases where dividing rivers or streams are present, possible bridge location and access combinations should be carefully examined. The options for area access selection provided in the program, give it the necessary flexibility to deal with special conditions. Selection of only the non-served area gives the user full control over possible access. In the case that existing roads are included in the data set, the user still has a choice between access from all existing roads, or selection of only part of this network for access. In this case, the total existing network is still used for coverage of the associated service zones. In all of the above cases, the user has the additional option to include required but non-existing roads in the solution network. This allows for the access of selected grid cells, such as future gravel pits, by the resulting road network.

Parallel Road Spacing

During the development of the road location algorithm special attention was being paid to its behaviour in situations close to the boundaries of the areas to be roaded. Using the classical logging road spacing model for ground skidding operations under flatland conditions (Matthews, 1942), and assuming that the roadsides are used as storage areas, parallel roads will be located at the optimal spacing

$$S = \frac{2\ R}{M\ V\ F}$$

where S = optimal parallel road spacing in 100 meter units,
R = road construction cost in dollars per 100 meter,
M = skidding cost in dollars per cubic meter per 100 meter roundtrip,
V = volume to be harvested in cubic meters per hectare, and
F = sinuosity or indirectness factor (>=1), equal to the ratio of the actual over the straight-line skidding distance.

In other situations, the service zone width will be directly related to the physical properties of the logging equipment, such as the maximal yarding distance for cable systems, or the maximal reach of forwarder cranes. In all cases mentioned, a special situation arises if the area to be roaded has a limited depth. This depth could be restricted by a wide range of factors, including physical and property boundaries, stand characteristics, logging system limitations, and the existing road locations. Given the selected constant service zone width S and the restrictions on the depth of the area to be roaded, it is possible to reduce the total length of new roads, as compared with the length needed if the optimal classical spacing is used.

Consider the situation in Figure 1a. An existing or planned haul road and the boundary of the forest area define a zone that requires roading for timber extraction. The use of the classical road spacing model will result in a optimal parallel road spacing or service zone width (S) (Figure 1b). In this case the roads have to run up to the boundary to ensure that the complete area is served. If, however, the roads are spaced closer together, it becomes possible to make use of the circular service areas at the end of the roads (Figure 1c).

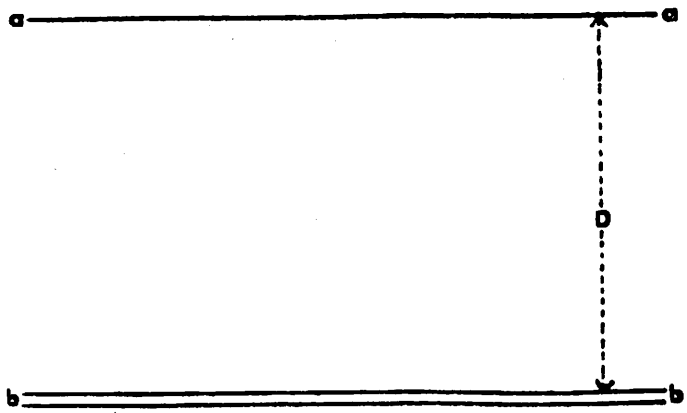

Figure 1a. A forest area with depth D defined by forest boundary (a-a) and existing or planned haul road (b-b).

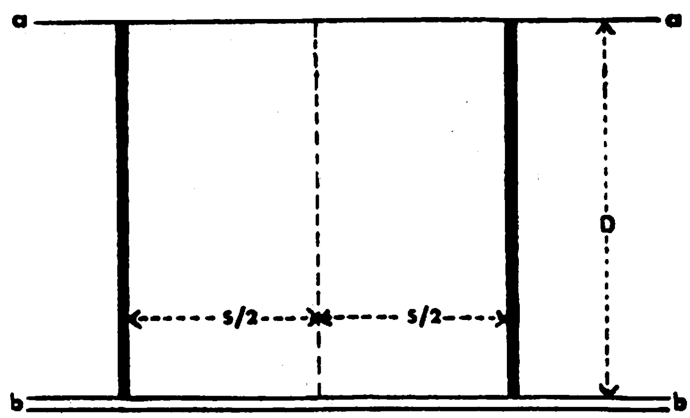

Figure 1b. Parallel roads spaced at distance S as obtained with classical model.

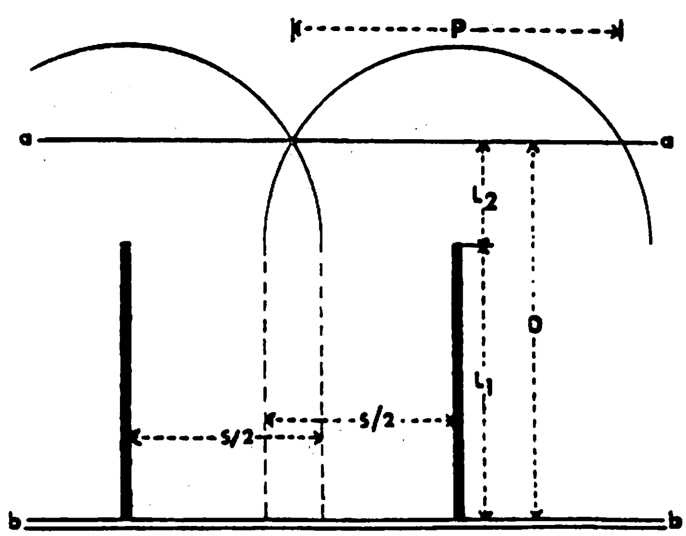

Figure 1c. Parallel roads spaced at distance less than S. minimizing the total road length per area served.

By decreasing the spacing (P) between the roads, the length of the individual roads (L_1) can be reduced. The optimal spacing (P_{opt}) is determined by minimizing the total length of parallel roads, while maintaining a maximal service distance of S/2. The derivation of the optimal spacing formula starts out with the fact that the area served per unit road length is A square units, where:

$$A = \frac{(D)(P)}{L_1}, \quad L_1 = D - L_2 \quad \text{and} \quad L_2 = (0.5)(S^2 - P^2)^{1/2}$$

$$\text{Therefore } A = \frac{(D)(P)}{D - (0.5)(S^2 - P^2)^{1/2}}$$

To maximize A, the first derivative of A with respect to P is set equal to zero. This gives the value of P for which A is maximal as:

$$P_{opt} = \frac{(S)(D^2 - (S/2)^2)^{1/2}}{D}$$

The road length L_1 associated with P_{opt} is:

$$L_1 = D - \frac{S^2}{4D}$$

Using these formulas, optimal road spacing (P_{opt}) and associated road length (L_1) can be calculated for any combination of service zone width (S) and depth of area to be roaded (D) (Table 1). The area served per unit of road length (A) and the percent improvement in A (IMP) can also be computed. With S = 1, and D ranging from (0.6)S to (3.6)S P_{opt} varias from 0.5528 to 0.9903. The improvement in A (IMP) then ranges from 80 percent to less than 1 percent. This illustrates the influence of the circular service areas at the end of the roads on the optimal road spacing if the depth of the area to be roaded is small in comparison with the service zone width. It has to be kept in mind that the theoretical models are constructed using assumptions such as uniform terrain and stand characteristics. In practice it will be necessary to adjust the road spacing to local conditions (Ashley et al., 1973). In addition, it may be necessary to construct landing sites at the ends of the parallel roads because of the large areas served form these points. The cost of these landings has to be taken into account during the calculation of the associated total variable cost.

Table 1. Optimal spacing (P_{opt}), associated road length (L_1), area served per unit road length (A), and percent improvement in area served per unit road length (IMP) as compared with the classical spacing (S). S = 1, and depth of area to be roaded (D) ranges from (0.6)S to (3.6)S.

D	P_{opt}	L_1	A	IMP
0.6	0.5528	0.18	1.809	80.91
0.8	0.7806	0.49	1.281	28.10
1.0	0.8660	0.75	1.155	15.47
1.2	0.9091	0.99	1.100	10.00
1.4	0.9340	1.22	1.071	7.06
1.6	0.9499	1.44	1.053	5.27
1.8	0.9606	1.66	1.041	4.10
2.0	0.9682	1.87	1.033	3.28
2.2	0.9738	2.09	1.027	2.69
2.4	0.9781	2.30	1.022	2.24
2.6	0.9813	2.50	1.019	1.90
2.8	0.9839	2.71	1.016	1.63
3.0	0.9860	2.92	1.014	1.42
3.2	0.9877	3.12	1.012	1.24
3.4	0.9891	3.33	1.011	1.10
3.6	0.9903	3.53	1.010	0.98

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A RATIONAL FRAMEWORK FOR FOREST ROAD / FOREST TRUCK SYSTEM DESIGN

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A B S T R A C T

The requirement for a transportation system design methodology, useful in day-to-day practice, which takes into account the relationships between forest roads and the trucks which run on them, is first identified. It is shown that overall transportation system costs, including the cost of road construction and maintenance, plus vehicle operating costs, should be minimized. However, the greatest impediment to implementing such an approach is the absence of a method of predicting the performance of a logging truck travelling on arbitrary road alignments, before the roads are committed to construction. Consequently, current research underway at the University of New Brunswick is aimed at producing interactive microcomputer software which will simulate the performance of logging trucks. A review of the research programme, and the progress made to date, is given.

KEYWORDS: logging trucks, performance simulation, forest roads, geometric design, gradients, horsepower, road costs, truck operating costs, minimization

Introduction

The estimated cost of wood delivered to Canadian mills can be broken down as follows (Edwards, 1983):

- forest management operations, and administration and planning — 35 %
- logging — 35 %
- transportation, and road construction and maintenance costs — 30 %

These represent roughly equal thirds as cost components. However, the attention each receives from forest engineers as a group is far from evenly divided. In particular, transportation and road costs appear to be the neglected child in this cost family.

Nevertheless, this third of the cost -- approximately $1.8 billion annually in Canada (Edwards, 1983) -- should be looked at much more carefully. If significant cost reductions in the roads and transportation sector can be achieved, they will be reflected in significant reductions in the cost of wood at the mill. It is worthwhile to go back to first principles, and examine the situation rationally.

Since at least 75 percent of all raw wood transported in Canada goes by truck (anon., undated), this points to an examination of truck transportation. It makes sense to begin by focussing on one of the largest cost components of trucking.

Fuel in Trucking

One of the most significant costs arises in fuel for haul trucks. Fuel is used to produce power: knowing how power is consumed implies knowing how the fuel is used. Savings in power requirements imply reduced operating costs.

Essentially, the power produced by the truck is used in five ways, as shown by Figure 1. If there is residual power left after meeting these five needs, the vehicle will accelerate: if there is a deficiency, it will decelerate.

Road/Truck System Design

A closer look at Figure 1 indicates that the power requirements can be divided into two groups:

Vehicle Alone	Vehicle/Road Interaction
•power for accessories •power to overcome chassis friction (bearings, oil churning etc.) •power to overcome air resistance	•power to overcome grade resistance •power to overcome rolling resistance

It is apparent that reducing the power requirements and thus the fuel consumption cannot necessarily be accomplished by tinkering with the truck alone. There is an interaction between the truck and the road on which it runs which can be manipulated in order to decrease the fuel consumption.

The power required to overcome grade and rolling resistances can obviously be reduced by flattening the road alignment and improving the road surface (Figure 2). However, both measures, aimed at reducing vehicle operating costs, result in increased road construction costs.

The Basic Premise

In Canadian forestry, road construction and hauling are usually handled by two separate bodies: either two different contractors, or two different branches of the forest operating company. Each attempts to minimize its costs.

The basic premise put forward here is that the road and truck costs should be examined together, and the minimum total cost of the two should be sought, by recognizing the interaction between truck and road (Douglas, 1986).

With improved road alignment and structural design, road construction and maintenance costs go up. However, this results in the reduction of haul costs. Fuel consumption decreases. Horsepower requirements are less, making the selection of smaller engines possible. Smaller engines mean less torque, and therefore down-rated components can be selected. Smaller components mean greater payloads for the same gross weight.

The trade off is shown schematically in Figure 3 (Douglas, 1986). At some point, improvements in road quality, as reflected by the surface quality and alignment severity, result in the minimum overall transportation system cost. Improvements beyond this point will not result in a further decrease in the overall system cost.

The difficulty at this time is that two of the three cost curves cannot yet be quantified. By searching records of past construction projects, a forest operating company could conceivably plot a curve of road construction costs as a function of some measure of road quality (road classification, say). However, it is not yet possible to plot vehicle operating costs as a function of road quality. As a result, the total curve cannot be plotted, and most importantly, the minimum cost point cannot be determined.

In order to resolve the problem, a vehicle performance simulation package is needed, to allow forest engineers to predict vehicle performance over various trial alignments and proposed road surfaces, before the project is committed to construction.

Work Done by Others to Date

To date, it appears that interest in the problem has been centred in two institutions.

The Forest Engineering Research Institute of Canada (FERIC) has had an ongoing program of research into the problem. Essentially, a precise breakdown of the power sinks has been accomplished, and an instrumented truck has been developed, in order to measure the actual power consumption under typical conditions. The results have been reported in three FERIC Technical Reports, and at a Canadian Pulp and Paper Association (CPPA) National Convention (Ljubic, 1982, 1984, 1985, and Ljubic and Michaelsen, 1986). The work continues as a major project in connection with Transport Canada. (FERIC, 1987).

The FERIC work is so far directed at measuring the various performance parameters, rather than modelling them. However, the data collected will be of great use in calibrating any models produced.

The Commonwealth Scientific and Industrial Research Organization of Australia (CSIRO) has undertaken the development of a computer program called TRUCKSIM (McCormack, 1985). In order to use the program, the user enters the road profile and truck characteristics, and the receives plots of road speed, fuel consumption, and gear selection.

The difficulties with the program, from the point of view of Canadian woodlands managers, are that it is not available in Canada and apparently requires the use of a mainframe computer.

In addition to these two current centres of research, there is one other source of some help available, in the old ICES[1] ROADS package, now somewhat difficult to gain access to, and its descendants. ROADS requires access to a mainframe computer. It's use in forest haul cases is questionable because it was specifically designed for lighter, standard trucks, travelling on paved provincial highways. There is a facility to add new trucks to the program's library of vehicles, but the modelling of the truck characteristics is limited to such things as gross combination weight and net horsepower.

Access to mainframe-based ICES ROADS derivatives can be obtained through a number of engine manufacturers. With such an arrangement, an interactive testing of the response of vehicles to trial alignments is not possible: problem data is packaged and sent to the program operator for analysis. In addition, the fees charged for the service are apparently thought to be prohibitive for most cases arising in forest engineering.

Work to Date at the University of New Brunswick

Bearing these problems in mind, research into the development of a microcomputer-based program designed to simulate the performance of forest haul trucks on proposed haul roads has been started at UNB. At present, a spreadsheet analysis has been developed. It predicts the change in speed of any arbitrarily selected truck (in terms of power, gross weight, frontal area, and driveline efficiency) as it climbs an infinitely long grade of a given gradient and surface roughness, starting with a known entry speed. An example of the tabular and graphical output is shown in Figure 4.

Essentially, the spreadsheet is set up to calculate the power required to satisfy each of the power sinks shown in Figure 1, using simple equations suggested by McNally (1975), and to compare their total to the net power supplied by the engine. Acceleration or deceleration over a short time interval, together with the distance covered during that increment of time, is then calculated. The final speed

[1]ICES: Integrated Civil Engineering System, a collection of computer programs initially devised by the Massachusetts Institute of Technology, and now maintained by McDonnell-Douglas.

for that time interval becomes the initial speed for the succeeding time interval. The power sinks are recalculated and the algorithm continues to loop in this way for a specified number of iterations.

Verification of the Spreadsheet Program

The cooperation of Great Northern Paper Company, Millinocket, Maine, was obtained to carry out a pilot study in the field, to gather the data necessary for a verification of the spreadsheet.

A stretch of haul road for which the truck speeds were not controlled by horizontal alignment was sought. In addition, it was thought that the clearest verification could be obtained on a section of roadway where long adverse gradients would establish a "terminal speed" for the trucks -- the steady state speed where total power requirement is just balanced by the net power output by the engine.

The adopted road section is shown in plan in Figure 5. It is part of the Golden Road, a main logging road, unpaved but surfaced with compacted gravel at this location. The gentle horizontal alignment does not control vehicle speeds. In the loaded direction, the road rises fairly steadily from a bridge crossing the West Branch of the Penobscot River, to a height of some 280 feet above the river, along the 16,000 foot stretch selected.

A level survey was performed to establish the vertical alignment (Figure 6(a)). Chainage flags were placed at 500 foot intervals along the road shoulder. Vehicle speeds were observed from truck speedometers at the chainage flags and recorded on audio tape during two loaded production runs each along the test section.

The characteristics of the two trucks used in the study are shown in Table 1.

Table 1
TRUCK CHARACTERISTICS

	Truck 29	Truck 32
configuration	3-S3-F5 A-train	3-S3-F5 A-train
gross power (HP)	400	400
power plant	Cat 3406	Cat 3406
transmission	Fuller RTO F14608LL 8 speed	Fuller RT 15615 Spicer Aux 1241D
rear axle	Rockwell? 9:1	Clark BD7100 9:1
gross weight (lb) (average, 2 runs)	323,900	322,220

Field Study Observations

The steepest adverse gradient observed along the test section was +4.7 percent, leading to the peak at approximately sta 130+00. A favourable gradient of -3.4 percent was noted just beyond the peak of the hill.

The average observed speeds for two runs by the two trucks are shown as light lines in Figures 6(b) (Truck No. 29) and (c) (Truck No. 32). Because of distortions in photocopying the spliced together spreadsheet graph output, it should be noted that the distance scale in Figures 6(b) and (c) is only approximate. The distances have been estimated on the basis of peaks and break points in the predicted speed curves (heavy lines).

Speeds were very difficult to estimate from the speedometers at low speeds. The pilot study did not allow for calibration of the speedometers, and it is doubtful that they were accurate to much better than about ±5 miles/hour. The lowest speeds observed were around 5 or 6 miles/hour, on the climb from sta 120+00 to sta 130+00. The highest speeds were observed to be approximately 35 to 40 miles/hour at the bottom of the dip at approximately sta 145+00.

Generally, the alignment required the driver to endure long periods of slow, steady state driving, interspersed with occasional short periods of almost feverish gear shifting and double-clutching.

The compacted, unpaved road surface, along with the paved sections closer to the mill, appeared to be in very good condition. The road surface was dry during the tests.

Discussion

This inexpensive pilot study was intended to provide initial data for the verification of the spreadsheet analysis. The alignment was broken into identifiable segments, each with a constant gradient, and the spreadsheet analysis applied piecewise. Predicted speed curves for an "average" truck of 400 HP and 323,060 lb GVW are shown as heavy lines in Figures 6(b) and (c).

As shown by the plots, the agreement between the predicted and observed speeds is generally good. The maximum difference appears to be approximately 15 miles/hour, occurring at sta 140+00 to sta 150+00. Some of this difference must lie in the poor precision of the speedometer readings. Prediction of the terminal speeds (sta 30+00 and 125+00) was particularly good.

Closer scrutiny reveals that there appears to be a consistent lag between the predicted speed curve, and the observed speed curve. When climbing, observed truck speeds remained high longer than predicted. When running downhill, observed truck speeds did not pick up as quickly as predicted.

It is postulated here that although the spreadsheet model accounts for the inertia of the mass of the vehicle, it does not account for the rotational inertia of the driveline components. As an example, it would not be able to faithfully model the "engine braking" technique sometimes called for in travelling down steep roads. By the same token, it is postulated that the model does not account for driveline inertia tending to pull the truck up a recently entered adverse grade.

The Next Steps

The development of the simple spreadsheet analysis has had a number of beneficial results.

In itself, it is a useful tool for quickly determining what the effect of proposed vertical road alignments will be on the speed of a vehicle. In addition, sensitivity analyses can be quickly and easily carried out, by operators with little training in computer applications. With the spreadsheet presentation, there are few programming demands to distract woodlands personnel from the problem they really want to address.

Road/Truck System Design

The simple spreadsheet analysis of the field results has pointed out a phenomenon which other, larger models may have missed. It would be worthwhile to thoroughly check the algorithm coding of programs such as ICES-ROADS to determine if the rotational inertia effect is faithfully modelled. If not, this could be a serious problem for the very heavy drivelines associated with forest transportation.

Finally, it was always borne in mind that the spreadsheet analysis was essentially a step to a more comprehensive model. The real question centres on what the rate of fuel consumption will be as the truck travels along the prototype road alignment. Spreadsheet analyses cannot handle this much more complex problem. Resort will have to be made to a computer program written in a lower level language, to accomplish a complete modelling of the problem. The rotational inertia question will have to be resolved.

Measurements made by FERIC and others will be invaluable in calibrating and verifying the model. In addition, a much more sophisticated field investigation than the one associated with the pilot study will be needed. In particular, speeds should be determined with the use of radar. In addition, other mainframe models such as ICES-ROADS and CSIRO's TRUKSIM are under investigation.

Conclusions

Work has been completed on the simple spreadsheet approach to the the truck performance simulation problem, pointing out what will be needed in the development of a more comprehensive interactive simulation program.

Once a reliable, microcomputer based package has been developed, woodlands personnel will be able to carry out the design of forest truck transportation systems in the context of global systems, including consideration of both trucks and roads simultaneously. The two will be tuned one to the other, using construction records to model the response of road construction costs to improvements in road quality, and using the new truck performance simulation package to model the response of truck operating costs to improvements in road quality. Road construction costs and truck operating costs will be balanced, to achieve a minimum overall transportation system cost.

Development of this new global context of forest truck transportation systems should result in significant savings on what amounts to fully one third of the cost of wood as it arrives at the mill.

ACKNOWLEDGEMENTS

The kind assistance and provision of fine field accommodations during the field work for the study, by Great Northern Paper Company, through Mr. J. Perz, Roads Engineer, is gratefully acknowledged. Enthusiastic support, and tolerance, during a day of "joyriding" by the field personnel was provided by Gardner Trucking, Millinocket. Thanks go to Mr. Douglass, and "Puffwheat".

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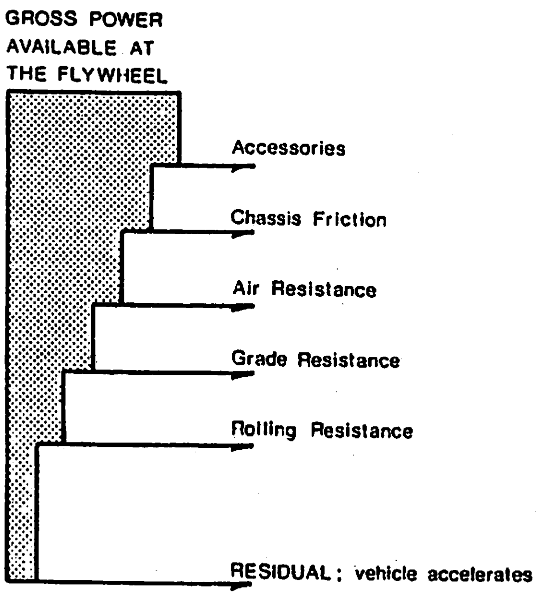

Figure 1. Power breakdown.

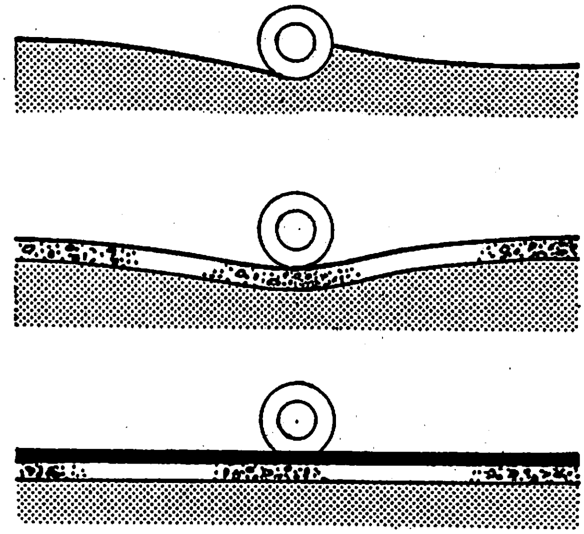

Figure 2. Improved road structure decreases rolling resistance.

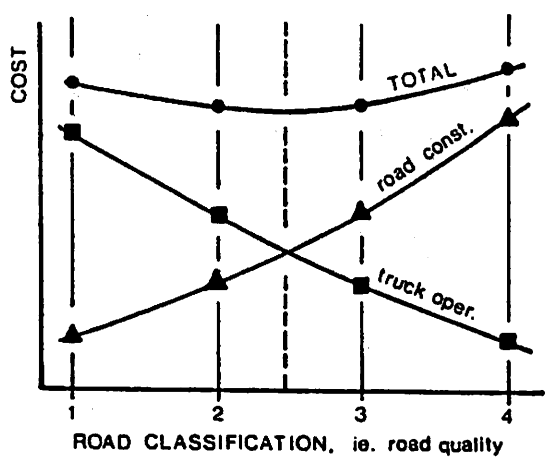

Figure 3. Conceptual cost models.

University of New Brunswick
DEPARTMENT OF FOREST ENGINEERING

VEHICLE PERFORMANCE SIMULATION

Job Description   Example Problem

Date   July 2, 1987

TRUCK GROSS HP	450 [HP]		
Truck Width	12.0 [ft]	Frontal Area	180 [ft2]
Height	15.0 [ft]	Efficiency	100 [%]
Gross Comb Weight	323000 [lb]		
Accessories HP	25 [HP]	Time Interval	1.0 [sec]
Segment Descript.		Gradient	3 [%]
Surface		URR	5 [lb/1000lb]

S I M U L A T I O N   C A L C U L A T I O N S

Initial Speed [mph]	RRHP [HP]	GRHP [HP]	ARHP [HP]	Req'd Gross HP [HP]	FINAL SPEED [mph]	Distance [ft]
30	207	775	32	1039	29	44
29	202	762	31	1020	29	87
29	197	750	29	1001	29	129
29	193	737	28	983	28	170
28	189	725	26	965	28	[illegible]
28	184	713	25	[illegible]		
27	[illegible]					

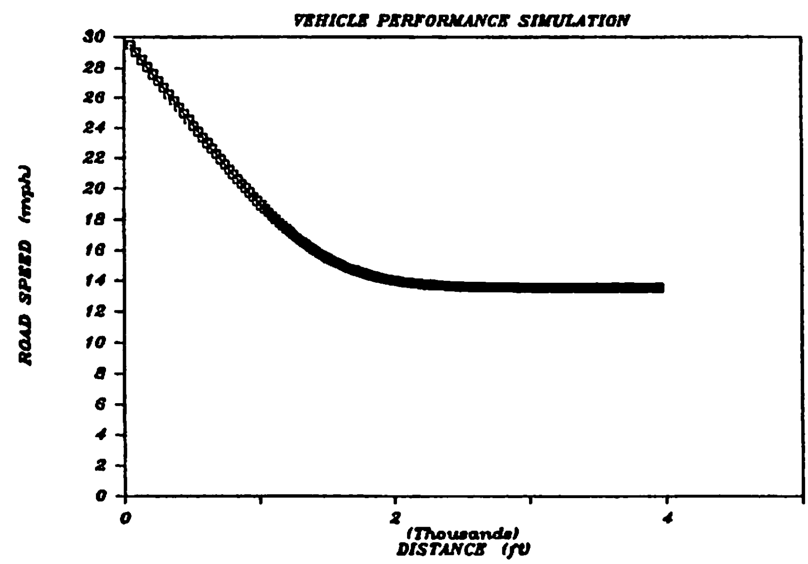

Figure 4. Example spreadsheet output.

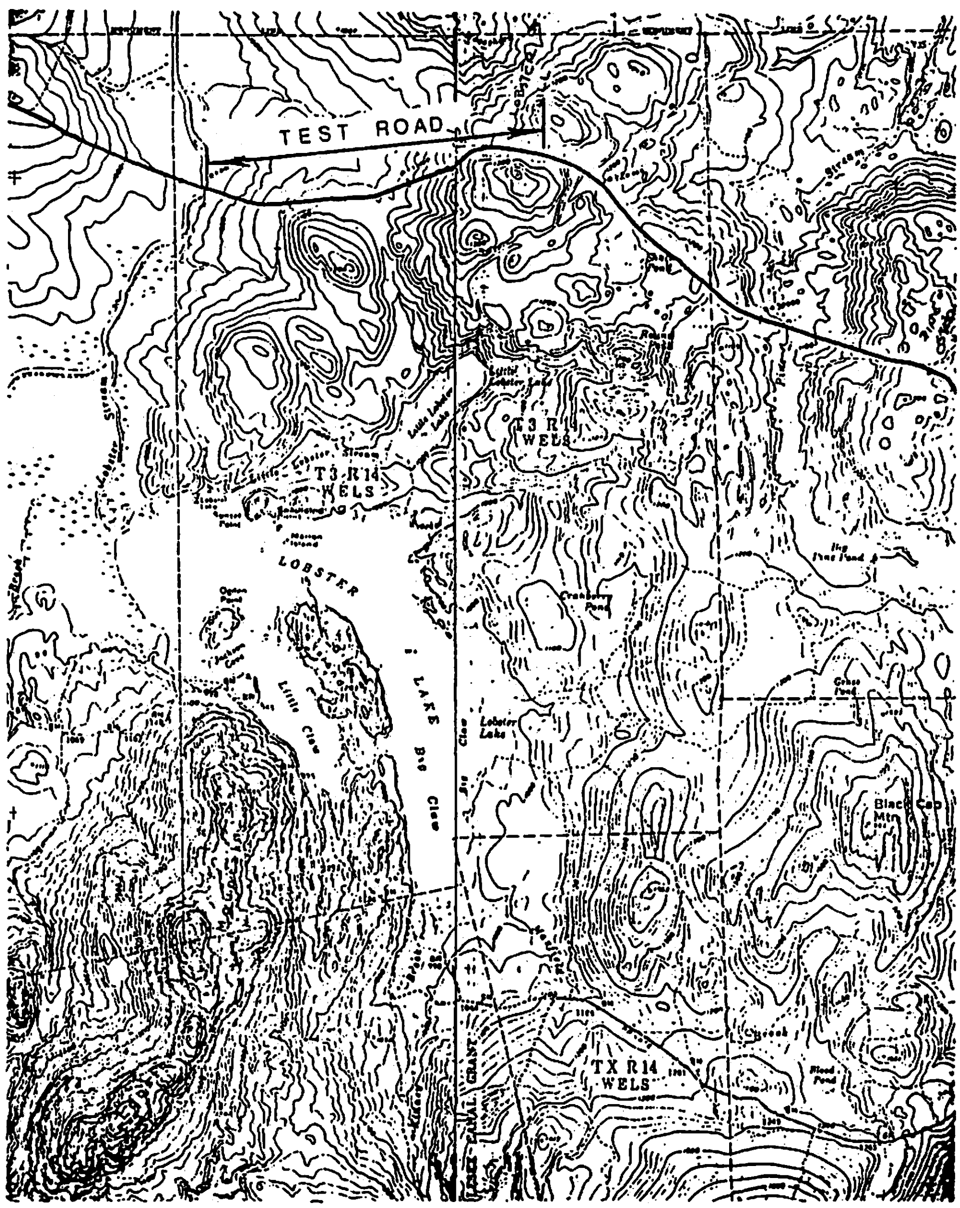

Figure 5. Plan of study site.

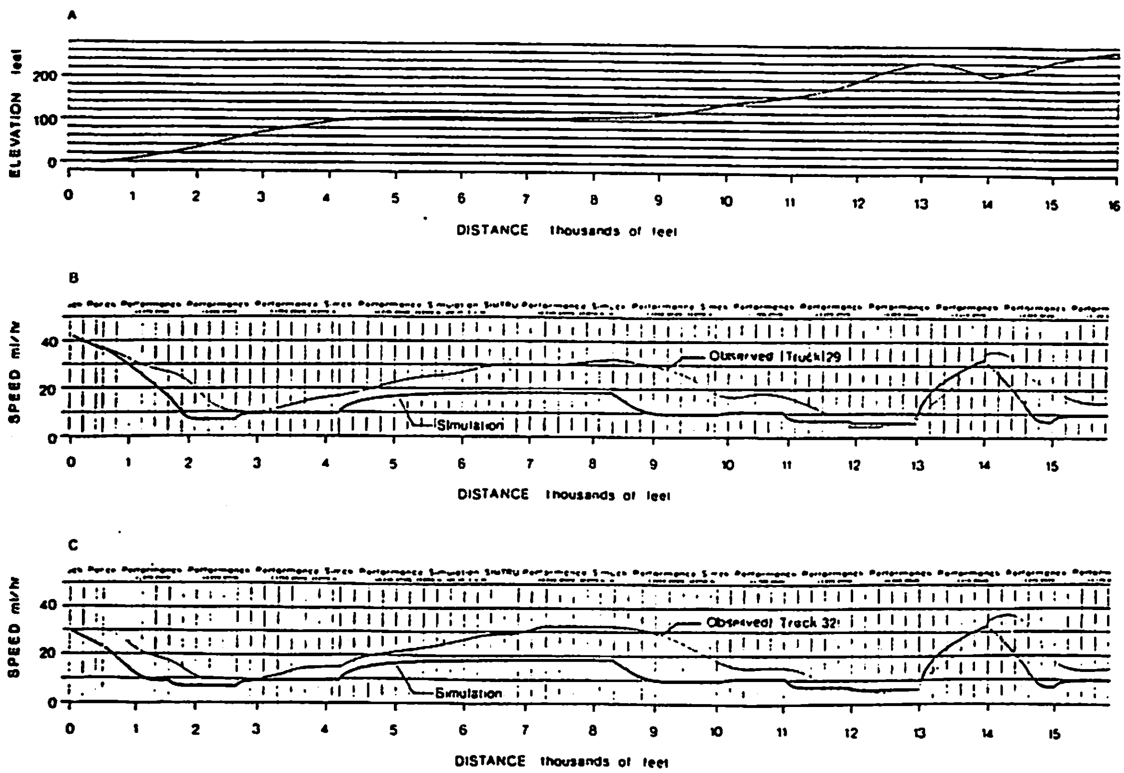

Figure 6. Study results: (a) vertical profile of test section, (b) speeds of Truck No. 29, (c) speeds of Truck No. 32.

COMPUTER ASSISTED FOREST ROAD ROUTE LOCATION

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A B S T R A C T

The development of forest access road route location methods is outlined. It is found that there is a need for a forest road route location system which uses an overall optimization scheme, facilitates sensitivity analyses, can be implemented on widely available micro computers, and can be easily integrated into geographic information systems. The algorithm for a micro computer program which is designed to fit this specification is presented, and tested with a typical route location problem.

KEYWORDS: access roads, forest roads, route location, dynamic programming, micro computers, optimization

Introduction

It has been estimated that the annual cost of forest road construction and maintenance in Canada amounts to approximately $0.6 billion (Edwards, 1983). Despite the fact that harvesting and on-road transportation (trucks and roads) represent roughly equal components of the cost of wood arriving at the mill, the design of forest road transportation systems receives much less attention than harvesting systems. One aspect of the transportation problem is the layout of road networks -- route location. The route locator is faced with the prospect of enormous economic impact due to poor location of haul roads, yet has very little help in the exercise.

What is needed is a route location scheme for access roads in previously unserviced areas, which will use an optimization routine, and will preferably run on micro computers available in field offices. To date, no such system is available.

This paper examines traditional methods and the application of new computer approaches, to arrive at a micro computer based system of route location. The system can be used as it stands now by field personnel, and with modification, by managers employing geographic information systems.

Available Approaches

In general, the approaches used in forestry have stemmed from traditional methods used in the layout of conventional highways. In a full-blown study, the route locator goes through a number of steps (Douglas, 1986), including:

- **an office study** of maps, photos, and topographic sheets
- **a reconnaissance** of selected corridors in the field
- **a route survey** of the features of the selected route, and
- **a location survey** of the final alignment in the field

During this process, the route locator has a number of schemes in mind for dealing with the topography, such as the consequences of building across drainage patterns, in valleys, or across ridges. Other, harvesting-related matters, such as tree species, wood volume, distribution, and quality, and the planned harvesting system, must be recognized. The process is a complicated one and should not be left to inexperienced personnel.

Turner and Miles (1971) characterized the process in three steps: data collection, generation of alternatives, and selection of the optimum route. The literature often blurs the distinction between the last two steps.

In a discussion of route location, Roberts and Suhbier (1964) use a link analysis procedure. Their procedure starts with preselected alternatives, and evaluates each with respect to capital cost, user cost, and maintenance cost. The procedure results in a rational selection of the best alternative of the preselected alternatives. The greatest difficulty encountered by woodlands personnel, however, is first arriving at these preselected alternatives themselves.

More recently, Jordan (1984) described the use of geographic information systems (GIS) for transportation system planning in the forest setting. Again this is a matter of evaluating **existing** road networks, in this case, using the capabilities of GIS. This represents a powerful tool, but to date the GIS approach is limited to work downstream of the more important problem: **what route alternatives should be selected for evaluation in the first place?**

Recent attempts at solving the primary problem have been published. Minamikata (1984) constructed a computer algorithm which works its way across a topographic map of the area which has been divided into grid cells. The cells are each assigned a rating for such characteristics as wood supply, topographic features, construction difficulty, and aesthetics. The algorithm moves along the route, cell by cell, from start to finish, searching for the best adjacent grid cell.

The weakness of this scheme is that it may not necessarily generate the optimum location. Tradeoffs involving the crossing of poorly rated areas in order to reach more desirable areas are not possible, because the algorithm always turns away from the poorly rated cells.

A Method Using Optimization

A computerized method of optimization of the layout of low class roads within an area has recently been reported by Nieuwenhuis (1986). An area not previously serviced by roads is divided into grid cells, and the sides of the cells (links) are evaluated for road construction costs through the use of GIS operations. Then the optimum road network is set up, given the entry points specified by the user, subject to minimizing the overall road construction costs, while simultaneously ensuring that no point within the area is beyond a specified maximum distance from any road.

The object of the program is to fill in an area with low class roads efficiently. It does not deal with the problem of locating main roads.

In addition, although "road costs" can be defined in such a way as to reflect attributes of the area other than just road construction costs, such as stand data, this scheme does not allow the user to see the effect of these additional factors explicitly. In addition, alternatives cannot be generated: the scheme outputs only "the best" road network. Thus sensitivity analyses are not facilitated.

In the light of the shortcomings of these methods, at least from the viewpoint of the locator of main forest roads, it is well to return to first principles in the route location problem.

Specific Inputs to the Location of Main Roads

As is the case in forest road location, conventional highway location must consider a multiplicity of factors. Turner and Miles (1971) classed these as:

- **route independent factors:** topography, soils, geology, land use, population
- **route dependent factors:** user costs, maintenance, cost of structures, aesthetics, disruption of existing communities and facilities

The first set of factors may be associated with the generation of alternatives, while the second set may be associated with the evaluation of the alternatives to find the optimum route. It is desirable to take both sets of factors into account, while at the same time allowing an interaction between the user and the computer program running the scheme, to examine the sensitivity of the optimum route location to factors under the control of the user.

In the GCARS scheme (Turner and Miles, 1971), individual "cost models" are set up for each factor to be considered. These represent the way in which costs vary over the area of interest. They may be visualized as three dimensional surfaces, much like topographic data, with "elevation" representing cost (Figure 1).

A minimum path analysis is applied to the data, to find the optimum route across the area. Generally, this can be visualized as a matter of following the valleys in the cost model. The importance of the method is that it allows users complete flexibility: cost models for various factors (e.g. topography and population distribution in highway design - topography and wood volume per hectare in forest road design) can be superimposed in any combination, and weighting factors accounting for the relative importance can be applied before superposition. Sensitivity analyses can be carried out with complete flexibility.

In addition, by reassigning very high costs to the path the first selected route takes, routes of successively lower ranking can be determined, leading to the recognition of families of alternatives close to the optimum route.

An Approach to the Problem in the Forest Setting

It is clear that the solution to the problem should embody the following:

- use of an overall optimization scheme, such as that used by Nieuwenhuis (1986) in the area network problem
- the ability to facilitate sensitivity analyses of the various factors considered in forest road route location, as would be the case with GCARS (Turner and Miles, 1971)
- the implementation of the solution routine on micro computers, so that it may be made available to woodlands staff in the field
- the possibility of integrating the route location routine with geographic information systems, so that the analyses of rationally preselected routes such as those illustrated by Jordan (1986) can be carried out

A system designed along these lines is discussed in the following paragraphs.

A Micro Computer Based Route Location Scheme

The attributes of the schemes found in the literature have been combined into a micro computer program called BRUCE (Best Roads Under Conditions Existing). It uses a minimum path analysis scheme found in classical dynamic programming to determine the optimum corridor.

As a first step, a map of the region of interest is divided into grid cells. For work in maritime Canada it has been found convenient in many cases to use topographic sheets at 1:50,000 scale, which have a 1 km grid ruled on them. Whatever the grid spacing selected, it must be chosen so as to achieve a high level of precision while at the same time not requiring excessive data entry effort. The grid is oriented so that the start and end of the proposed road are placed in the upper left corner and the lower right corner of the grid respectively. A given grid cell is referred to by its column and row numbers.

Each of the grid cells is then rated for the criteria of importance to the route locator. In almost all cases these criteria will include topography. Although a number of schemes can be envisaged for dealing with topography, the one so far found most effective and convenient is simply to count the number of contour lines encountered within the cell, from its lowest point to its highest point. As the program treats the ratings of the grid cells as costs, it can be seen that simply counting contour lines gives the correct representation of how steep the terrain is within the cell, to the program.

Other criteria of importance - tree species, wood volume per hectare, or land ownership, for example - can be rated in the same way. If a rating scale of 0 to 10 for each criterion were adopted, land ownership might be reflected by rating a company's own land as "0", and land owned by others as "10" (recalling that these ratings are treated as if they were costs, and the minimum cost route is sought).

The program is designed so that the ratings for each of the criteria can be superimposed in any combination. In addition, they may be weighted. For example, aesthetics might be half as important as topography to the route locator, and thus the ratings for aesthetics would be halved before being superimposed on those for topography.

After the rating of each of the grid cells, the optimum route is determined.

The algorithm determines the optimum route by progressing backwards across the map, from the end cell to the beginning cell. Map grid cells are represented by nodes in a network. Stages are defined as all the nodes a given number of steps away from the end node (Figure 2).

At each stage, the algorithm searches for the optimum path from each of the nodes at that stage, along to the end node. The paths are judged by totalling the ratings of all cells along the path, with the lowest total rating indicating the optimum path. An optimum path for each node at the current stage, from that node along to the end node, is retained in memory. Thus all possible routes are considered, but only the best for each node is stored, saving on required computer storage space.

Finally, the highest stage is reached. It consists only of the node for the beginning cell. There is only one optimum path from it to the end node, and this path is the optimum route for which the program has been searching.

The core of the program is the equation:

$$f(s,n) = C_{min}(s-1,n_a) + f(s-1,n_a)$$

where:

$f(s,n)$ = total rating for the optimum path from the current node, at the current stage, along to the end cell

$C_{min}(s-1,n_a)$ = minimum rating for the step from a node at the current stage to an adjoining node at the previous stage

$f(s-1,n_a)$ = total rating for the optimum path from the adjoining node on the previous stage, along to the end cell

The sequence of nodes corresponding to the optimum path as defined by Equation 1 for the path from the highest stage, the beginning cell, to the end cell, is the optimum route sought by the algorithm.

Example of the Program's Use

A double blind test of the program was carried out. The route of an existing main haul road for a forest operation in southwestern New Brunswick was predicted by working from an old topographical sheet of the area, Figure 3 (Department of Mines and Technical Surveys, 1950), published before the haul road had been constructed.

The road's end points were found on the <u>current</u> topographic sheet, Figure 4 (Department of Energy, Mines and Resources, 1981), and transferred to the corresponding old topographic sheet, Figure 3, upon which the road did not appear. Working from the old topographic sheet, BRUCE was then used, to locate a 1 km wide corridor for the road, to be compared to the route established by conventional methods for the existing road (Figure 4). The criteria for route location were:

- **topography:** number of contour lines from the highest point to the lowest point within a given grid cell.
- **land ownership:** rated as 0 if shown as uncleared land (ie. assumed to be available for road construction), or 10 if cleared (ie. assumed to be owned by others).
- **hazards:** rated as {0, 5, 10} corresponding to none, about half, or essentially all of the cell being occupied by some terrain "hazard" such as marshes, or bogs.

Under normal circumstances, other criteria, especially those concerning stand data, would be considered. However, it is understood (Chisholm, personal communication) that this particular haul road was constructed to access harvest areas beyond its end, rather than around it. Therefore, omitting details having to do with servicing the area through which the road passes should not, in this case, contribute to any differences between the actual route and the projected route.

Figure 4 demonstrates how closely the route corridor generated by BRUCE corresponds to the actual route of the road. It should be noted that the complete route location process took approximately 3 man•hours, considerably less than would have been the case if done manually.

Comparison

As shown by Figure 4, the selected corridor follows the existing road fairly closely, with no more than 3000 m distance between the road and the corridor.

Without more specific information, it is not possible to determine if the differences in location are significant. The selected corridor has been optimized for the criteria given above. However, other unknown criteria may have been used at the time by the route locator, and it may have been that construction details (e.g. use of the railway or existing trails), additional land ownership factors, the locations of sand and gravel deposits, or specific road, water, and railway crossing requirements, influenced the actual route location.

If judged solely according to the criteria used in the selection by the program, the existing road follows a less satisfactory route.

In summary, the selected corridor is within 3000 m of the existing road's centreline, took very much less time to be determined, and may well be a better choice. An experienced locator would **begin** with the selected corridor, and improve upon it after examining the area in detail.

Strengths and Limitations of the Program

It is not suggested here that the program be used to displace the work of experienced route locators. Rather, the intention is to speed up the process, and make experienced locators more efficient. It is expected that the efficiency of route locators will increase dramatically for cases with more challenging topography. In addition, the program can serve as an educational tool for those with little experience in route location, facilitating the acquisition of experience by allowing them to test themselves at very low cost on hypothetical problems.

Sensitivity analyses are facilitated by the program in two ways. First, the route locator can iterate over successive locations for the same input data, checking families of optimized routes, with successively poorer overall ranking. Secondly, the sets of rankings (topography, stand data, etc.) can be superimposed arbitrarily, allowing the route locator to determine optimum routes for each set independently, or in combination, and with various weighting factors applied. Thus a much more flexible approach is facilitated, catering to the specific questions the locator must answer for each particular problem.

It is acknowledged that resource operations in areas where work has been carried out for some time, may already have the bulk of their road networks in place, and may do little route location any more. However, these old roads may have been poorly located. It would be worthwhile to examine these roads objectively, to determine if they are so poorly located as to make it economically worthwhile to abandon them in favour of new, well located roads.

The chief limitation of this route location scheme is the requirement for manual entry of grid cell ratings. As the computer program is currently configured, data entry is simple and easily carried out. However, it can be tedious, and it represents the most time consuming part of the process. As the use of geographic information systems becomes more widespread, it should be a simple matter to implement schemes for the automatic rating of grid cells, thus eliminating the requirement for manual data entry.

The algorithm employed by the program will not "allow" certain moves from one cell to another. Because complications in the programming of stages would arise, diagonal moves across the grid are not allowed. For similar reasons, it is not possible to accommodate routes which loop back on themselves.

However, these limitations have not proven to be restrictive, and the requirement for a simple route location tool, easily accessible to those who need it most, has been respected.

Conclusions

A simple computerized method of route location has been presented. The algorithm searches for the optimum overall route, across a grid of cells ruled on a map of the area of interest. By rating each cell and searching for the optimum route, it is possible to determine the best route for the access road with respect to any criteria. The ratings can also be weighted, reflecting the relative importance of each criterion, and superimposed.

The system is readily implemented on micro computers. In addition, it appears that it could be easily integrated into geographic information systems resident on mainframe computers, tying into powerful GIS operations.

Acknowledgements

The kind assistance of Mr. Bruce Chisholm, PEng., Logging Development Engineer at Valley Forest Products, Nackawic, New Brunswick, in commenting on the use of the program, and in supplying the information for the haul road route location example, is greatly appreciated.

In addition, thanks go to Dr. T.D. Needham, Department of Forest Engineering, University of New Brunswick, who reviewed the manuscript primarily for forestry content. If I have still violated the terms and concepts foresters hold dear, please blame me, not him!

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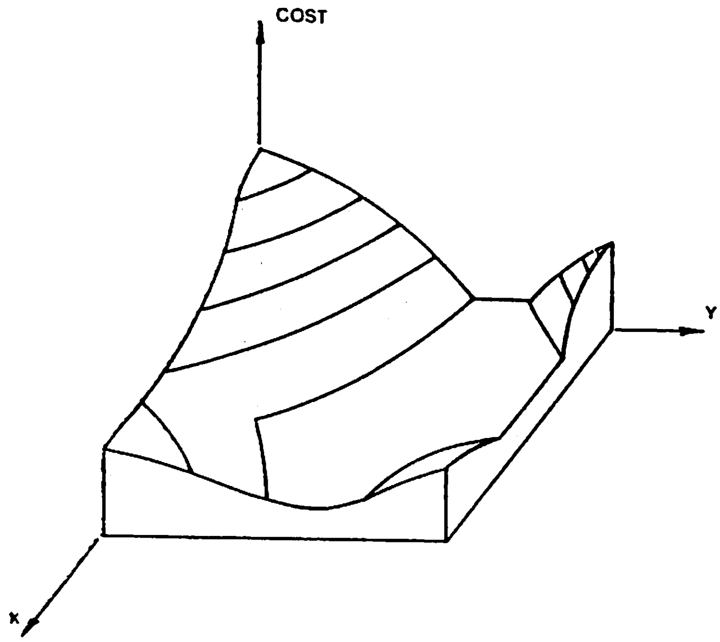

Figure 1. Cost models (after Turner and Miles, 1971).

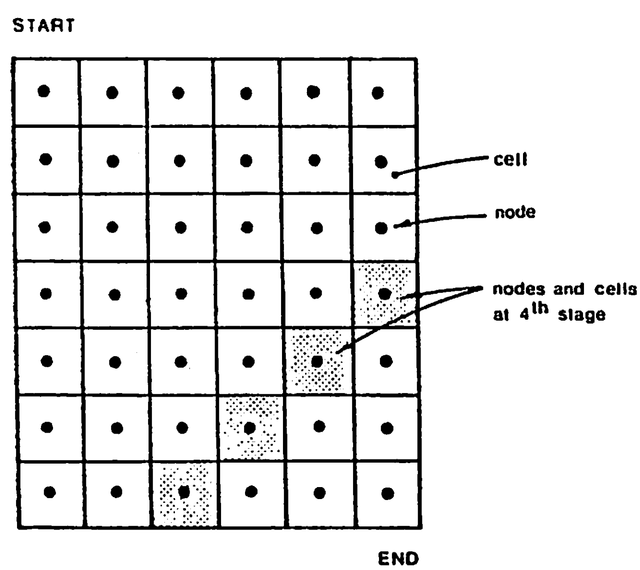

Figure 2. Definition of cells, nodes, and stages.

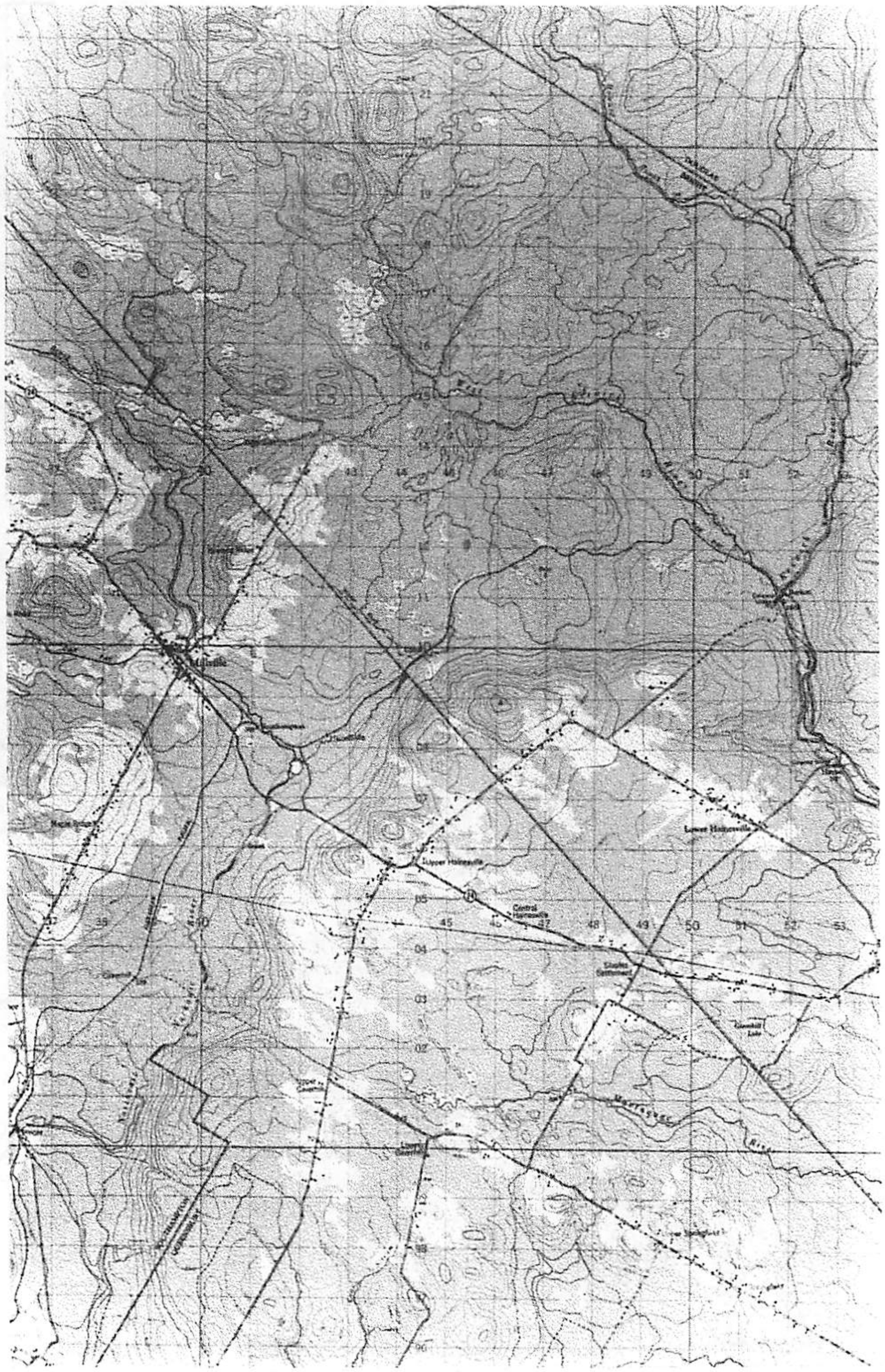

Figure 3. Old topographic map (after Department of Mines and Technical Surveys, 1950).

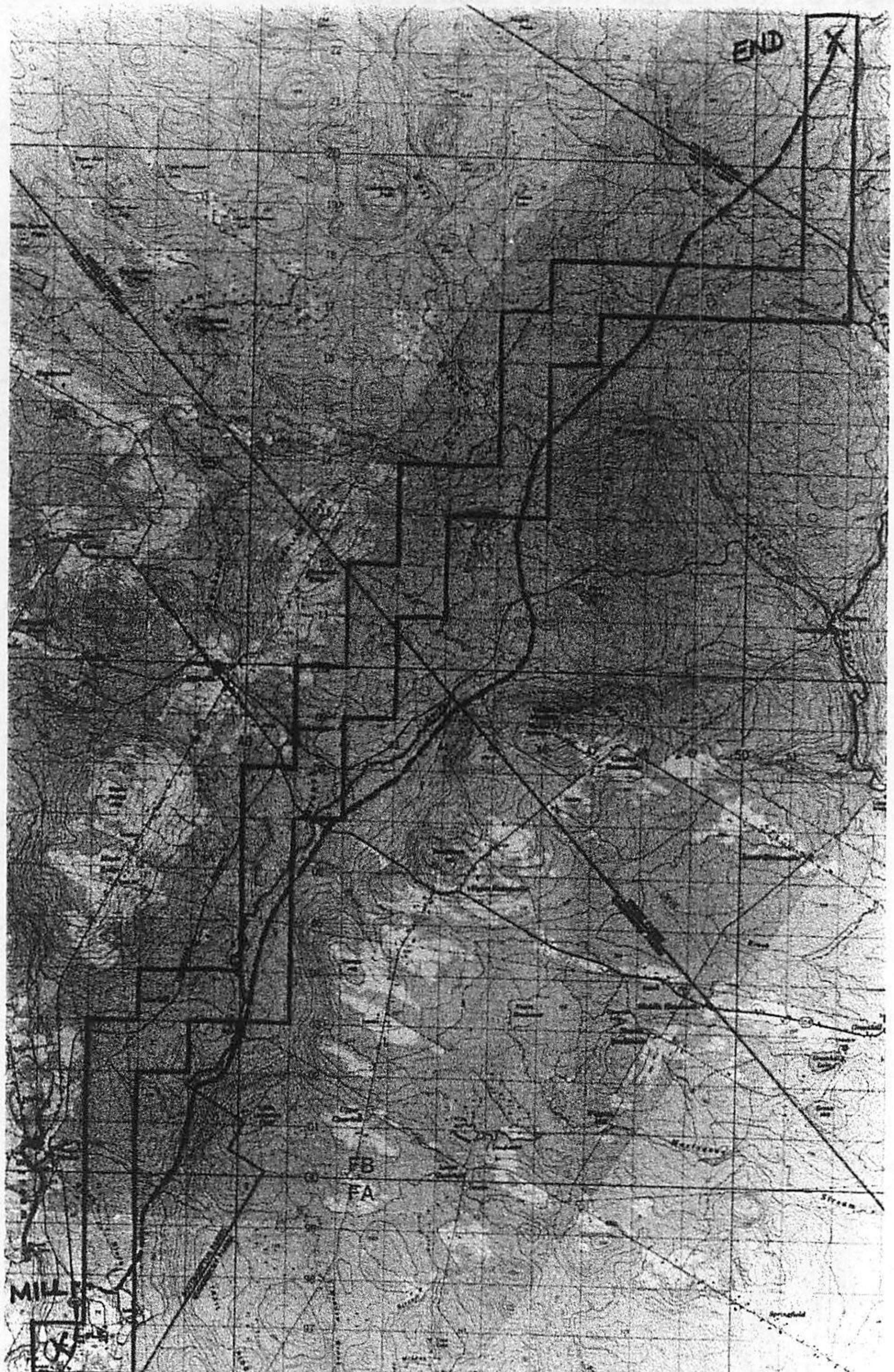

Figure 4. Present topographic map, showing existing road (dashed lines), and selected corridor (after Department of Energy, Mines and Resources, 1981).

PHOTOMAP - Data Input from a Photographic Image into a Geographic Information System Utilizing Photogrammetric Condition Equations and USGS Digital Elevation Models

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Abstract

PHOTOMAP is a digitizing system for data collection from a photographic image for input into a geographic information system. The package is currently being implemented with the Resource Information Management and Spatial Analysis Laboratory geographic information system, MeGIS.

The PHOTOMAP package consists of four principal parts: Photograph registration, photo coordinate refinement, space resection, and space intersection. Photograph registration and image coordinate measurement are conducted on a digitizer tablet, or in photogrammetric terms, a monocomparator. All photographic measurements are monoscopic in nature. A space resection, the determination of the six parameters of the camera from the positions of three or more objects and the positions of their corresponding images on the photograph, based on the collinearity principle, is calculated. Finally, a space intersection is performed to determine the ground position of any other image point. Least squares adjustment techniques are utilized in all cases where redundant observations exist.

User/System Interaction Characteristics:

- The system operates in a systematic, consistent, and orderly manner, thereby facilitating user trainability and utility.

- The system provides clear, coherent, and useful instructions, prompts, and error messages.

- The system provides the user with feedback on the effectiveness of orientations and transformations.

- The system provides project management (archival) and verification information.

- The system provides a means for saving and recording orientation and transformation parameters throughout the user session.

- The system enables a one-phase process, photo information to GIS, rather than employing photo information transfer to a base map, then information input into a GIS.

- The system provides for user verification, by actually having photography in hand during the information input process, rather than input from an intermediate transfer source (i.e. a base map, without having the actual photography in hand for verification and blunder detection purposes).

System component design specifications utilized include:

- FORTRAN 77 source code, designed to be easily modified, appendable, and well documented. An Assembly Language library significantly enhances program input/output, error-checking, and overall capabilities.

- All measurements are performed monoscopically. Stereoscopic measurements are not required, thereby reducing cost, time, and complication.

- Calibrated camera parameters (calibrated focal length, principal point location, fiducial mark coordinates, and lens distortion values) are utilized by all coordinate refinement and transformation routines. A utility program allows for the creation of a camera calibration file, in a standard and specified format.

- The package provides for correction and removal of distortions, inherent to photographic images, utilizing photogrammetric principles. Coordinate refinement is performed to correct for: shrinkage/expansion of the photographic material differentially in the photographic x and y directions, non-orthogonality of the principal axes, principal point offset, and symmetrical lens distortion.

- Photograph registration on a digitizer tablet (used in photogrammetric terms as a monocomparator), is conducted employing known camera calibration fiducial point coordinates. A six-parameter non-conformal affine transformation is used to transform tablet coordinates into the photo coordinate system. Transformation parameters and standard deviations are output to the terminal for user acceptance/rejection.

- A space resection, based on the collinearity condition, is performed to determine the elements of exterior orientation of the photograph, (Three camera orientation angles about the three principal axes, and the perspective center coordinates in the ground space). Three horizontal and vertical control points are required for the resection parameter determination. Least squares adjustment techniques are utilized with redundant observations (i.e., when more than three ground control points are used).

- A project control file can be created and used to store and retrieve control point information. This file, essentially a listing of point names with associated horizontal control coordinates and vertical control values, decreases the probability of errors in keyboard coordinate entry, as well as the ability to store control information for use in resection parameter determination of other project photos.

- Horizontal photo control can be established via keyboard entry, transfer from a registered control map, or from a project control file created during a previous user session. Latitude-Longitude, State Plane, and UTM (Universal Transverse Mercator) coordinate systems are supported.

- Vertical photo control can be established via keyboard entry, from a project control file, or interpolation from a USGS digital elevation model, knowing the horizontal coordinates of the control point. English and metric vertical control units are supported.

- A space intersection, utilizing the collinearity conditions and elevation data from either ground control information or digital elevation model interpolation, is performed to determine the position of any point on the photograph in the ground space.

- After photograph registration and resection parameter determination, photo information is collected, refined, and processed using calculated corrections, transformations, and the intersection principle.

- Bridging of control from an area with adequate control to an area of inadequate control is accomplished by locating and determining the horizontal and vertical position of project control points, utilizing the intersection principle. This information is output to a project control file to be used later in the project (i.e. by adjacent photograph resection parameter determination).

- Known elements of exterior orientation of a given photograph can be input from a photo orientation file for resection parameter determination, thereby enabling the parameter determination by other sources to be input into the PHOTOMAP package, i.e. from a stereo plotting device.

- A digital elevation model utility routine allows for enhanced utilization of the elevation data by performing data conversion to reduce disk storage requirements, memory requirements, and to significantly enhance elevation interpolation functions.

Applications:

- Direct land cover information collection without intermediate transfer of polygons and polygon information to a base map, with inherent distortions accounted for.

- Road and trail location and layout directly from photos without intermediate transfer of locations to a base map.

- Compilation of a network of photography, for a given purpose, without the time and cost of utilizing stereoplotting equipment.

- Map updating and revision directly from photography. The user can see the photography and the changes between database information and current information.

Council on Forest Engineering

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August, 1987

SUNY College of Environmental Science and Forestry

Background Information for

Demonstration/Discussion Session on Power Production from Biomass

The purpose of this session is to demonstrate and to provoke discussion concerning the conversion of woody and other biomass materials to useful synthetic gas. Two types of gasifier systems are demonstrated. One is of an air-blown downdraft design, while the other is an airless, pyrolysis unit that makes use of the heat of combustion from sawdust fuel to gasify a variety of other, separate fuels. Both systems are connected to internal combustion engines driving electric generators.

The larger trailer-mounted downdraft gasifier subjects fuel to high temperatures in a closed vessel in the presence of air or pure oxygen to engender a change of state from solid to gas. The product gas is of low energy density--about 140 Btu/scf LHV (people in the "real U.S." use English units)--when made with air, or about 300 Btu/scf LHV when made with oxygen. This particular system has a capacity of about 450,000 Btu/hr, enough to produce 30 kW_e with the 330 cubic inch Waukesha engine driving a synchronous generator at 1800 rpm.

Beneath the gasifier vessel's automatically controlled fuel zone, gas produced by rapid pyrolysis is cracked as it is drawn down through a bed of char and routed at 1250°F to a particulate cyclone and scrubber unit. Gas enters the engine mainfold at around 110°F. Activated char suitable for water treatment is a significant byproduct of the process. This proprietary system operates reliably over a range of fuel feed rates and moisture contents (≤30%), producing a gas substantially clean of tars and oils, a major problem with past gasifier designs.

The smaller pyrolysis unit, also trailer-mounted, produces a gas of higher energy density--about 600 Btu/scf LHV on biomass fuel--due to the absence of pass-through nitrogen. Process heat is generated by a 40,000 Btu/hr sawdust burner. Product gas is cooled, separated from oil and water condensate, and either run directly into a much-modified 107 cubic inch Wisconsin engine connected to a10 kW induction generator or compressed to 120 psi in a pair of propane storage cylinders. Net latent output is around 125,000 Btu/hr, depending on feedstock. Heavy oils condensed from the gas can be used for a variety of purposes, including engine fuel. Char must be manually augered from this particular batch-fed system. The fractions of gas, oil, and char can be regulated by pyrolysis reactor temperature and other parameters. This very crude system provided a research basis for a subsequent proprietarty design under final stages of development by Forest Engineering Prof. Dave Palmer.

All equipment shown is owned by Atlantic Energy Systems, Inc. (AES), an alternative energy and waste management company founded by Palmer and headquartered currently in Utica, NY. AES also owns and has performed extensive testing on a prototype 5 million Btu/hr gasifier and 300 kW_e Caterpillar engine-generator system.

The Company has filed permits for and is planning to build two 5-MW biomass power plants in central New York during 1988. One of these two plants will incorporate a European-design furnace, boiler, and conventional steam turbine, while the other has been planned as a computer-controlled, advanced gasification technology application featuring lean-burn, spark-ignition engines recently developed by the Auburn, NY firm Alco Power, Inc. (formerly American Locomotive), site of AES gasifier performance testing in 1986. AES has selected a gasifier design originally developed at the Solar Energy Research Institute and recently offered commercially by SynGas, Inc., of Golden, CO, under a joint technology development agreement with Ebasco Services, Inc., a major engineering firm. The plantwould be the first installation of its kind in the United States. However, as of 1 August AES is reevaluating the trade offs between being innovative with relying on proven track records, and could well end up opting for a second steam plant because of the greater ease of financing a plant based on familiar technology.

Whatever result obtains in the present case, the recent technical advances made possible by improved understanding of gasification chemistry, improved control technology, and new reactor designs assure that gasification will play an increasingly important role in small biomass power plant expansion prior to 1990.

There are two primary advantages of gasification over direct combustion: they allow direct conversion of gaseous or liquid fuel burners to burn solid fuels; and they allow cost-effective, environmentally benign power production below 10 MW through use of advance-design internal combustion engines. It now appears that the combination of gasifier and IC engine will allow the effective, low-cost destruction of a variety of toxic waste materials. The two trailer units being demonstrated for COFE visitors represent two alternative approaches to gasification, both of which can be upscaled for commercial application.

Forest engineers at ESF are introduced to gasification, steam plants, biomass fuels, and power production as part of a senior course in alternate power systems. This year, there will be an opportunity for a graduate student to become involved in a mass & energy balance analysis of gasification-cogeneration systems through use of digital instrumentation, gas chromatography, and other laboratory equipment loaned by AES.

The energy crisis may be dozing, but political instability in the middle east could bring on a rude awakening at any time. Regardless, there is a need for developing viable uses for the thousands of annual tons of forest, mill, and municipal wastes which currently represent a significant disposal problem in the U.S. The efficient identification, collection, transport, and utilization of biomass waste materials is seen as a challenge worthy of forest engineering attention for the remainder of the Century.

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DATA ACQUISITION SYSTEMS FOR FOREST ENGINEERING RESEARCH

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ABSTRACT

Data acquisition systems for forest harvesting research must be rugged, reliable, and meet a wide variety of sampling requirements. New solid-state digital data acquisition systems have proven effective during recent forest harvesting studies. Three of these systems are described. Cost, limitations, and capabilities are discussed and examples of applications in research projects are presented.

INTRODUCTION

Data acquisition is a critical part of any research project. A data acquisistion system (DAS) samples variables of interest at certain times, accurately measures and records the data values, and stores them on a stable medium for data analysis after the testing is completed. Constraints imposed in typical forest harvesting studies dictate that a DAS for forest harvesting research must be relatively immune to environmental conditions (i.e. heat, electrical noise, vibration, dust), compact, and cost efficient. In addition, a DAS must meet the criteria of sampling frequency, data storage capacity, and signal conditioning that are unique to the individual project. The selection of a DAS for a research project will directly affect the accuracy, resolution, and reliability of the data and may affect the statistical outcome of the study.

Timber harvesting studies span a wide range of data collection requirements, from simple time studies to controlled experiments monitoring the mechanical performance of forest machines. These studies require the measurement of variables that are relatively stable, such as soil moisture, or variables that are rapidly changing (i.e. engine rpm, line pull, torque, or stress). To meet the diverse requirements of forest engineering research, a broad range of data acquisition systems is currently available. This paper will briefly discuss data acquisition and will describe three systems that are currently employed by the Harvesting Research Unit of the U.S. Forest Service, located in Auburn, Alabama.

DATA ACQUISITION SYSTEMS

Data acquisition is the process of measuring and recording values of variables during a research project. The variables are sensed by some type of transducer and a signal is generated that describes the value of the variable. The signal may be a continuously varying voltage (analog) or a binary code that identifies the state of the variable. Transducer outputs may require further processing (signal conditioning) to prepare the signal for recording. The properly conditioned signal can then be recorded on a storage medium.

In the recent past, transducer outputs have been connected to strip chart recorders to produce a record of analog signals over time. These systems provided continuous sampling with a complete record of the signal trace. Unfortunately, strip chart recorders are also sensitive to vibration and dirt, have limited resolution, and require digitizing the signal trace for further data analysis. Digital inputs, with the exception of dichotomous variables such as the state of a relay, cannot be recorded on a strip chart.

Advances in microcomputer technology, particularly the development of analog-to-digital (A/D) converter chips and high-speed microprocessors, have opened the door to solid-state DAS's that promise to replace strip chart recorders. Solid-state systems are relatively insensitive to environmental conditions, can be packaged in compact configurations, readily accept digital and analog inputs, and store the data in digital form--ready for later analysis without the need for manually transcribing recorded data.

System Construction

Solid-state DAS's may be custom built at the chip level, constructed of board level parts, or purchased as a turnkey multi-purpose DAS. Many researchers have built their own systems to meet specific project requirements. Bedri, Marley, and Buchele (1982) and Clark and Gillespie (1982) constructed tractor performance monitors from individual electronic components (chip level). Clemens, Tennes, and Murphy (1984) also worked at the chip level to build a DAS for automatic steering control of agricultural vehicles. Chip level systems are generally highly specialized. They may require extensive development time, specialized programming skills, and/or special expertise to operate and maintain the system.

Board level systems are assembled from purchased circuit boards that are interconnected by a standard set of electrical connections called a bus. Kendall (1984), for example, constructed a multi-purpose DAS based on the STD bus. The basic system consisted of a microprocessor board, an input/output (I/O) card, a memory card, and a serial communications card all connected to the common STD bus. DAS circuit boards are commercially available that can be plugged into the bus on a personal computer (PC). Burcham and Matthes (1985) used a Compaq Portable[2/] computer with special DAS cards to measure pressure at the

[2/] Mention of trade names is solely for the information of the reader; does not indicate endorsement by the U. S. Department of Agriculture.

soil-tire interface of a rubber-tired skidder. Hendrick et al. (1981); Marshall, Buckley, and Kahler (1984); Cline and Perumpral (1982); Reynolds, Miles, and Garner (1982); and Palmer (1984) describe other applications of board level systems for field studies. Board level systems may require some technical expertise to properly interface the DAS, depending on the system.

DAS circuit cards that plug into PC's generally offer simple system configuration, but require a dedicated microcomputer. As an integral part of the DAS, the PC must be able to withstand the rigors of the field environment. Most desktop PC's are not designed for such conditions.

Turnkey DAS's are completely assembled systems specifically designed and packaged for the data acquisition task. A wide range of commercially available turnkey systems offer a selection of sampling rates, interface capabilities, memory capacities, and special features such as digital control functions. Wiedemann and Cross (1982) describe the use of a Datamyte 400 to measure drawbar pull in a disking operation. Swetzig (1986) reports the application of two Daytronics turnkey systems for testing agricultural equipment. Morrison and Bartek (1986) used an Omnidata Polycorder to record cone index readings from a hand-held cone penetrometer. In general, turnkey systems require little technical expertise to operate and maintain. High reliability and factory support reduce the problems associated with equipment failures.

When obtaining a DAS for a project, the researcher should carefully weigh the pros and cons of chip level, board level, and turnkey systems. Chip level systems may be the most cost effective for some highly specialized applications with unique constraints, but the commitment of technical expertise and development time becomes costly for even moderately complex systems. Board level and turnkey systems are increasingly available with a wide range of capabilities that should satisfy most study requirements.

While determining the appropriate type of system construction narrows the range of choices, the researcher must also select a system with features that are appropriate for the intended study. Some of the most important specifications are the A/D converter resolution, sampling rate, availability of signal conditioning, and the data storage medium.

A/D Conversion

A primary component in solid-state analog sampling systems is the A/D converter. The A/D converter samples an analog signal and converts the voltage level to a digital value that can be manipulated by the DAS microprocessor. The conversion process is characterized by the resolution of the converter and the conversion rate. The resolution of the conversion is dependent on the type of A/D converter. A 12-bit converter, for example, can digitize the input signal into one of 4096 discrete levels (2^{12}) for a resolution of $\pm 0.024\%$ of full scale. In contrast, it is difficult to digitize a 50mm strip chart better than to the nearest ±0.5mm or ±1.0% of full scale. The conversion rate, or number of conversions per second that an A/D converter can perform, is often expressed as a frequency--so many kilohertz, for example. While it may appear in manufacturer's literature that the A/D converter frequency is the sampling rate of the DAS, in actual practice, the sampling rate of the entire system will be limited by other hardware components or by the software.

Signal Conditioning

Signal conditioning circuitry is used to alter the output of a transducer to a calibrated value that can be recorded in the data storage device. In addition, signal conditioning provides necessary interfaces for particular transducers, such as cold-junction compensation for thermocouples, bridge circuits for strain gage inputs, or amplification for low-level voltage inputs. Special signal conditioning circuits are also available to provide functions such as measurement of maximum and minimum values. Mitchell (1984) provides an extensive discussion of signal conditioning for digital signals. Most standard signal conditioning circuits can be obtained as plug-in cards (i.e. voltage conditioner card, thermocouple input card, etc.) for commercially available data acquisition systems. The specifications of particular cards should be carefully reviewed to insure that the electrical characteristics are appropriate for a given application.

Sampling Rate

The sampling rate is one of the most important characteristics of a data acquisition system. The requisite sampling rate for a given study will be determined by the nature of the variable of interest. A variable that changes slowly can be sampled at a lower frequency than a variable that fluctuates more rapidly. For some sampling situations specific sampling rate requirements can be calculated. Frequency analysis, for example, requires a sampling rate that is at least twice the highest frequency of interest (Doebelin 1980).

Another consideration in specifying a sampling rate is the "picket fence" effect. Because A/D conversion is a discrete process, it produces values of a continuously varying signal at distinct points in time. It is like viewing the signal through a picket fence--the behaviour of the signal between sample points is unknown. If peak values are of interest, the sampling rate should be higher to increase the possibility of sampling the signal near the peak.

Data Storage

The two primary concerns with data storage in a DAS are the type of storage medium and the available storage capacity. Data can be stored on a wide variety of media, ranging from solid-state devices (i.e. RAM and bubble memory) to magnetic disks and tapes. The medium may be fixed in the machine or recorded on removable cartridges. Floppy disks and tape cartridges are well-known examples of removable media, but solid-state memory is also available in removable designs.

Data storage requirements are determined by the sampling rate, data format, and length of test. For example, a system that sampled one channel at 100 Hz, with 10 bytes of data per sample, and a total test length of 30 minutes would require a data storage device that could hold at least 1.8 Mbytes of data. In many research situations, data storage can become a limiting factor.

Several researchers have attempted to address the problems of data storage by reducing the amount of memory that is required. Lawrence, Cottell, and Sauder (1982) describe a data compression algorithm for reducing the amount of data that is generated during a test. Basically, their system examines the difference between the previous value of a variable and the current value of the variable. If the difference does not exceed a specified limit, the new value is not recorded. In effect, the values of variables are only recorded as they change. In an application on a high-lead yarding study, the amount of data recorded was approximately 52 times less than with continuous recording. Data summarization can also reduce memory requirements by combining individual samples into mean, standard deviation, or other population measures. The Datamyte 400 used by Wiedemann and Cross (1982) sampled at 2400 Hz, but only recorded a frequency distribution of signal levels. Hendrick et al. (1981) maintained a running sum of the sample values as well as the sum of the sample values squared for post-test calculation of the mean and standard deviation.

Matthes, Watson, and Sirois (1983) used a video camera system to record data during a study of the forces involved in skidding operations. Four variables were monitored and displayed on a digital readout. A video camera was set up to record the display. By replaying the tape and recording the values on the display in each video frame, a sampling rate of 25 Hz was attained. This unique method of data storage is limited only by the time capacity of the videotape. Like strip chart recorders, however, the data record on the video tape must be transcribed to a computer readable format for further data analysis.

DATA ACQUISITION SYSTEMS AT THE HARVESTING RESEARCH UNIT

The Harvesting Research Unit of the U.S. Forest Service, located in Auburn, Alabama, is involved in a wide variety of forest harvesting studies. The mission of the Unit is to develop new and improved harvesting systems for better utilization of the South's timber resource. This broad mandate has led to research in human factors, site impacts, time and production, and mechanical performance of harvesting equipment.

In the past, data acquisition was accomplished with strip chart recorders and custom-built signal conditioning. A two-channel, battery powered AstroMed Dash II recorder was available for field studies. A four-channel Gulton recorder provided more capacity, but required an AC generator for field operation.

While the strip chart recorders were used sucessfully in many studies, their limitations in timber harvesting research were obvious. Environmentally sensitive and bulky, the Gulton recorder had to be shock-mounted in a large, ventilated aluminum case. Only four channels of data could be simultaneously recorded. The smaller AstroMed was more rugged, but lacked a takeup roll, hampering its use in unattended operation. The primary limitation of both recorders was the need to digitize strip charts for subsequent data analysis.

Over the last several years, as the technology has become available, the Unit has acquired three solid-state DAS's that provide a range of capabilities for our research needs. A Hewlett Packard calculator-based system is a compact DAS for applications with low sampling rate and minimal data storage requirements. Two OmniData Polycorders offer moderate sampling rates and extended data storage. The top end system is a Daytronics 10K2 DAS coupled with an Ampro 186 computer. For applications requiring extended data storage, a Bernoulli Box can be connected to the Ampro to provide up to 10Mb of memory. These systems have been used in several current studies and are proving their worth.

Hewlett Packard/CMT System

Corvallis MicroTechnology produces two peripherals for Hewlett Packard 40 series calculators that combine to form an inexpensive and compact data acquisition system. The CMT-300 Programmable Measurement System is a module that enables the calculator to operate as a digital multimeter, measuring voltage, current, or resistance. Table 1 lists the measurement capabilities of the CMT-300. The CMT-200 Data Acquisition and Control System is a module that adds 8-bit digital I/O and three special-purpose control lines to the calculator. Both of the CMT modules plug into ports on the back of the HP and operate on battery power from the calculator.

In operation, a data acquisition program is written and stored in the HP calculator. Special functions supported by the CMT modules are included in the program to access the measurement and control capabilities. For example, the program line "READX" returns the value of the CMT-300 multimeter measurement to the X-register of the calculator. The function "IDX" returns the 8-bit integer corresponding to the state of the input data lines of the CMT-200. The measured values can be manipulated and stored in calculator memory.

Special timing functions are available if the calculator has the HP 82182A Time Module or equivalent capabilities. The RATE function of the CMT-200 counts the number of state changes in an input line during a specified time interval. Other time functions can be used to start or stop sampling at certain times or to record the length of time an input line is in a given state.

Table 1. Input measurement ranges of the CMT-300.

Type of signal	Range (±)	Resolution
DC voltage	.2 V	.1 mV
	2 V	1 mV
	20 V	10 mV
	200 V	100 mV
	350 V	1 V
AC voltage	2 V	1 mV
	20 V	10 mV
	200 V	100 mV
	350 V	1 V
Resistance	2K Ohm	1 Ohm
	20K Ohm	10 Ohm
	200K Ohm	100 Ohm
	2000K Ohm	1000 Ohm
DC current	.2 A	

Memory in the HP/CMT system is limited. An HP41CX, for example, has 319 memory registers. The data acquisition program will be saved in part of memory, leaving room for less than 300 observations. With extended memory modules added to the calculator, the available data storage is almost 600 observations. Mass storage devices can also be connected to the calculator to provide indirect file storage of up to 100,000 observations, but this capacity is difficult to access during continuous sampling.

The sampling rate of the HP/CMT is also a limiting factor. A simple sampling program, with no data manipulation or control logic may attain a sampling rate of 2 samples/second. Adding program complexity reduces the sampling rate considerably. In addition, the response time of the measurement circuitry should be considered in determining an acceptable sampling rate. The response of the ohmmeter to a full scale step, for example, requires 3-7 seconds. Sampling highly variable signals at a faster rate would introduce some error.

Multi-channel DAS configurations can be created by using the CMT-200 to control a multiplexer or a relay. The control logic however, increases the amount of memory required for program storage and reduces the sampling rate.

The cost of the entire system (1987 suggested prices) is about $850. An HP41CX calculator costs approximately $250, the CMT-200 $250, and the CMT-300 $350.

Temperature Measurement Application. The HP/CMT system was used to measure cab temperatures in a study of airconditioned feller/bunchers. Two temperature measures were required--a dry bulb temperature and a wet-bulb globe temperature (WGT). The DAS was configured with two thermistor probes connected to the CMT-300 through a switching relay. The calculator controlled the relay through the CMT-200 module.

At the beginning of the workday, the sampling program was started from the calculator keypad. Every fifteen minutes during the day, the program turned on the calculator, measured one temperature probe, switched the relay to the other probe, took the second temperature measurement, recorded the temperature data and time into memory, and turned the calculator off until the next observation time. The data logging program required 50 registers of memory, leaving room for about 270 data values. Since three values were recorded at each observation time, the program could have run for 22 hours before the available memory was filled.

Data were manually transcribed from memory at the end of the day, but a communications device is available that supports serial data transfer between the HP 40 series calculators and other computers.

The HP/CMT system proved to be a compact, reliable DAS for this application. Packaged in a foam-lined wooden box that fit behind the operator's seat, the hardware was completely out of the way. Dirt and debris did not affect the system. In addition, the system ran unattended through the entire workday.

OmniData Polycorder System

The HP/CMT DAS is obviously limited by channel capacity, memory, and sampling rate. For studies requiring better sampling capabilities, the Harvesting Research Unit obtained an Omnidata Polycorder Model

516C-64-A. The Polycorder is an electronic notebook that can also read and store transducer voltages, convert them to engineering units, and then transmit the stored information to a computer for analysis. The electronic notebook capabilities give the user an "electronic data sheet" that can be easily programmed for timber cruising or inventory; however, the Polycorder is primarily designed for data acquisition.

The Polycorder has 64K of memory, of which 31,735 bytes are available for program and data storage. Memory requirements for program files vary with the application. Sampling rate also varies with application. According to the manufacturer's specifications, the Polycorder has the capability of 10 samples per second per channel. This relation decreases with the number of channels and the complexity of the program code. Each line of code requires about 4 milliseconds to execute.

Transducers, sensors, or other instruments with digital or analog outputs can be directly wired to an interface board that connects to the top of the Polycorder. The interface board allows easy mapping and connection of instrumentation wiring. The Polycorder can accept 10 analog inputs, 10 digital inputs, and control 5 digital outputs, allowing the use of external devices while collecting data. No signal conditioning is provided with this Polycorder model. Analog inputs can be measured in two programmable ranges -- $\pm$50mV or $\pm$5V. Selecting a transducer or sensor with an output in this voltage range is generally not a problem.

Information can be displayed on a 2 line by 16 character liquid crystal display. With the display, the user can be prompted by short messages, be given a warning that a measured parameter is out of bounds, or preview stored data. The data in memory can be transferred directly to a computer, printer, or modem via the RS-232 communications port.

The Omnidata Polycorder cost $2,950. Accessories such as the field carrying case, interface cable, interface board, and recharger added an additional $250 for a total cost of $3,200.

Central Tire Inflation System Application. A prototype central tire inflation (CTI) system was installed on two 10-wheel log trucks to investigate the effects of reduced tire inflation pressures on log-truck performance, and the implications of these pressures on road construction and road maintenance costs (Ashmore and Sirois, 1987). The two log trucks were instrumented to measure vehicle speed and tire inflation pressures as the trucks drove through test strips established along an unsurfaced forest road. Two pressure transducers (Dynisco PT150-5C) were installed in an in-cab control box to measure inflation pressures of the tires on the steering axle and rear tandem axle. An automotive tachometer generator (ServoTek Products, type S/N 763A-2) and tachometer adapter (Reliance model R101018) were installed between the speedometer cable transmission and speedometer cable to measure truck speeds. An infrared sensor (Scientific Technology, Inc. model 2070 series) was mounted on the front bumper to signal the Polycorder as the truck entered and exited test strips. Reflective stripping mounted on posts placed along the side of the road marked the beginning and end of the test strips.

The instrumentation was selected to produce an output between 0 and 5 volts for the range of inflation pressures and speeds tested. The pressure transducers required a 5-volt excitation, which was provided by the Polycorder. An external charger plugged into the cigarette lighter connection of the truck helped provide power. This allowed for 5 to 6 days of use before the Polycorder had to be recharged with the 120-volt AC battery recharger.

Once the Polycorder program was executed at the start of each day, it displayed the message "7 BEGINS". The user then pressed 7 on the keyboard to start the main program. As the Polycorder looped through the main program, the display flashed a message "0 ENDS RUN, WAITING ON IR", which meant the program was waiting for a digital signal from the infrared sensor before starting the sampling procedure. Also, in each loop through the main program, the program checked an alarm subroutine that would stop the program and warn the user if either the tachometer generator was disconnected (or the truck stopped) or if the inflation pressure in the tires had dropped below 20 psi. The display would show either "PRES INVALID, PRESS 3" or "TACH LOOSE, PRESS 3" on the Polycorder screen and sound an alarm mounted in the cab of the truck.

Once the Polycorder was signaled by the infrared sensor, the sampling procedure began. For test identification purposes, the date and the time were recorded at the top of the data each time the sampling procedure was initiated. As an example, the data might have looked like this:

11.000	3.000	.000	(date)
9.000	38.000	6.000	(time)
.281	.231	3.178	(data...)
.281	.234	3.305	
.282	.236	3.230	
.284	.237	3.197	
.283	.242	3.370	
.280	.232	3.048	
.281	.236	3.263	

To maximize the sampling rate, the data was not scaled during the sampling process. The data values were converted to appropriate units after being recorded to disk.

When a second signal was received from the infrared sensor, the sampling procedure stopped and the message "0 ENDS RUN, WAITING ON IR" returned. The program then resumed looping through the main program until another digital infrared signal was received. This program required 845 bytes of memory. The sampling rate, measuring three analog channels, one digital signal, and performing various limit checks, was approximately 2.3 samples per second. At this rate, the Polycorder could store approximately 3800 observations (28 minutes of continous sampling). Twice daily, the Polycorders were removed from the trucks and the data uploaded to a Toshiba T1100 Plus portable computer for long-term storage on disks.

Drawbar pull tests. In a second application on the CTI study, the Polycorder was used to record drawbar pull of a CTI-equipped truck. An 89-kN (20,000-lb) load cell was mounted between the loaded, 10-wheel log truck and a Franklin 170 forwarder. The Franklin was used as the dynamometer vehicle.

The load cell was calibrated and a millivolt calibration curve was developed. To maximize the sampling rate, the millivolt analog signal from the load cell was recorded directly by the Polycorder with kN conversions performed after the data was recorded to disk. No calibration or data conversion was performed during sampling.

The load cell measurement program required 413 bytes of memory. The 64-line program sampled one analog channel with no limit checks at a rate of 3.7 samples per second. Subsequent discussions with the manufacturer indicated that a higher sampling rate could have been obtained with slightly different program code.

In both CTI applications, the Polycorder proved to be a reliable DAS. Some time was required to learn the special Polycode programming language, but minimal technical expertise is necessary. Directly uploading the recorded data to a field microcomputer permitted rapid examination of test results.

Ampro/Daytronics System

For applications where a higher sampling rate is necessary, the Harvesting Research Unit assembled a DAS based on a Daytronics Model 10K2 DataPac controlled by an Ampro 186 computer. The DataPac is a versatile data acquisition system that contains a microprocessor, a communications port, and slots for signal conditioning cards. A variety of signal conditioning cards are available including thermocouple, linear variable differential transformer (LVDT), low-level voltage, thermistor, and digital I/O cards. Up to 160 channels can be configured in the system. The DataPac central processor accesses installed signal conditioning cards in response to commands entered on the removable keyboard or received through the communications port. Commands consist of a three letter mnemonic and appropriate numeric parameters. For example, "DMP 2 TO 5" commands the DataPac to transmit the scanned values of channels 2 through 5 out the communications port. As a stand-alone unit, the DataPac can configure and calibrate measurement channels, scan selected channels, perform limit checks, and output control signals in response to extreme values, but unattended data logging is not possible without a peripheral computer.

An Ampro 186 single-board computer was selected as the control unit for the DataPac. The Ampro runs an Intel 80186 microprocessor at 8 MHz. With 512K of random access memory (RAM), there is sufficient room for programs and RAM disk data storage. Permanent storage of programs and data is obtained with the single floppy-disk drive. Additional permanent memory can be obtained by plugging a Bernoulli Box into the Small Computer Systems Interface (SCSI) port of the Ampro. A custom high-speed serial interface card was built and installed in the Ampro to permit data transfer between the computer and the DataPac at 153.6K baud. In addition, the Ampro power supply was modified to operate on a 12 volt DC source. A Radio Shack TRS-80 Model 100 battery-powered portable is used as a terminal to operate the Ampro.

In operation, a data acquisition program is written for the Ampro. Programming can be done in any MS-DOS language. The choice of programming language however, can affect the sampling rate. The data acquisition program will send DataPac commands as ASCII text data over the high-speed serial interface. Responses from the DataPac are received in the Ampro, manipulated if desired, and stored in memory.

Total system cost is approximately $7000. The Ampro costs $330, a basic 10K2 DataPac with the 12 volt power option $4300, and the Radio Shack TRS-80 Model 100 is about $600. The custom interface card would be difficult to price, but Daytronics recently introduced a similar item that plugs into an IBM PC bus for about $800. Signal conditioning cards for the DataPac vary in price between $300 and $600. Finally, if the additional memory is needed, a 10M Bernoulli Box can be obtained for about $1000.

Vibration Measurement Application. The Ampro/Daytronics system was used to record ride vibration in a rubber-tired skidder. A Bruel & Kjaer triaxial seat accelerometer (Type 4322) detected ride vibration. The signal was amplified through three B & K charge amplifiers (Type 2634), filtered through custom built Butterworth low-pass analog filters, and sampled at the DataPac through a voltage conditioner card. A Scientific Technologies infrared (IR) emitter/detector (STI Model 2070) was used to start and stop sampling as the skidder passed reflective posts at the ends of the vibration test track. The IR device was connected to the SCSI ID port of the Ampro computer through a flip-flop circuit. The first IR signal set a digital input to the ID port high, initiating sampling, the next IR signal pulled the digital input low again, ending data collection. The data acquisition program for this application was coded in Turbo Pascal.

At the beginning of each test run, the TRS-80 computer was connected to the Ampro and the data acquisition program was initiated from a floppy disk. After the program started, opened a data file, and was idling in a loop waiting for an IR signal, the floppy disk was removed and a cardboard insert was placed in the disk drive to protect the drive from shock. The TRS-80 was disconnected, and the case containing the DAS was closed. As the skidder passed the first reflective post, the IR circuit triggered sampling as described above. The timer card in the DataPac started, and the Ampro began requesting data. During sampling, the Ampro sent the command "DMP 3 TO 5" to the DataPac, received the channel data, stored it in memory, checked the IR signal on the SCSI ID port, and continued. When the second IR signal stopped the sampling routine, the program recorded the ending time from the DataPac timer card and closed the data file. Finally, the TRS-80 was reconnected to check the data file, transfer the data to a floppy disk, and re-initialize the program for the next test run.

With the data acquisition configuration described above, a sampling rate of 180 samples/second was obtained. The manufacturer publicizes the internal scan rate of 2500 samples/second, but notes that the sampling rate is dependent on programming language, number of channels sampled, data conversion within the DataPac, communications baud rate to the storage device, as well as other constraints.

CONCLUSIONS

Our experience with solid-state data acquisition systems has shown a number of advantages over previous DAS for forest engineering research. All three of the systems that were discussed in this paper successfully operated in the harvesting research environment, significantly reduced the labor involved in data processing, and were relatively inexpensive. In addition, features that were not available in strip chart recorders, such as programmable control functions, have added new possibilities to data acquisition.

While many earlier solid-state DAS were custom-built at the chip level, this is no longer necessary. The availability of a wide variety of DAS board level components and turnkey systems should meet the needs of most research projects.

Finally, although solid-state DAS offer many advantages over strip chart recorders, there are still applications where the recorders may be more appropriate. The initial project planning should carefully consider data acquisition needs and select the most cost effective DAS for the study.

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OPTIMAL BUCKING AT THE STUMP

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ABSTRACT: The Forest Engineering Department at Oregon State University, in cooperation with Oregon Digital Systems Incorporated, is testing the feasibility of using an optimal log bucking program (BUCK©) during felling and bucking in western Oregon. Research will assess the human (bucker) and machine (HP 94 computer) interaction, and relate the magnitude of gains possible. Both old-growth timber (diameters up to 100 inches) and second-growth timber (diameters down to 6 inches) will be included in the "proof-of-concept" tests. The program is on both a handheld computer (Hewlett-Packard HP-94) and a desktop computer. Solution times are in the 3-6 second range.

Introduction

Improving log bucking has been an area of considerable interest for various research and development activities. Early work by Pnevmaticos and Mann, 1972; the United States Forest Service Fall and Buck Program (Pease, 1982); Dykstra, 1984; Conway, 1973; Garland, 1985; Sessions, 1987; and others describe various approaches to the problem of log bucking. Computational solutions include linear programming, dynamic programming, network algorithms, knapsack algorithms, and other evaluation schemes. Overall system approaches include optimization at the mill or central processing yard, mainframe (or desktop) evaluation or monitoring systems, and basically human auditing and improvement efforts. All of these approaches identify potential benefits in excess of costs, but until recently, computational efficiency and hardware has hindered implementation beyond the mill or central processing yard. This paper addresses an effort by Oregon State University to bring optimal bucking to the stump in the western United States

Descriptions of similar approaches worldwide and in the United States reflect a high level of research activity to bring bucking optimization and computational power together (Lawrence, 1986-1; Lawrence, 1986-2; and Cooney, 1987). Our approach at Oregon State University tries to combine optimal bucking at the stump with a handheld computer solution with the definition of a workable human system for realizing potential gains. Our proposed research moves from "proof-of-concept" research to system evaluation, forward through the mills and backward to inventory and appraisal procedures. Fundamental research is coupled with commercial development efforts and extension programs to bring education to the logging industry in the west.

Two Scenarios

Consider two scenarios for bucking in the western United States. The first involves large, valuable timber and the second involves less valuable, small timber.

Scenario I: You have just cut a Douglas-fir tree that is 48" on the stump and 175' tall. It broke at 127' and the top beyond 153' is shattered into small pieces. There are 6 mills that receive up to 7 grades each from these type of trees depending on quality. If you examine each foot of the tree there are well over 100,000 combinations possible. A wrong cut can lower the log value by $200. A long segment of the tree is suspended over a gully leaving some sections where a cut would be unsafe. To help you, the company has supplied a plastic card with preferred lengths for peeler logs and sawlogs. As you make the first cut, brown sawdust tells you rot is present. If you make too many quality or length mistakes, the quality supervisor will be out to "counsel" you. Your immediate supervisor, the Bullbuck, wants to keep production up and he is a vigorous "counselor" in that regard. After about half the unit is cut, the company changes its specification and you get a new plastic card to memorize.

Scenario II: You are working in second growth Douglas-fir less than 24" on the stump. There are about 4 mills and 5 grades to worry about. While the value swings of $10-$30 for each mistaken cut may not be significant, you must produce more than 120 trees a day with two or three cuts per tree. That's a tree every three or four minutes! Consistent errors really add up. They scream just as loud when errors increase or production falls off. How much time can you spend figuring and measuring these trees?

Research Questions

There are many questions posed by the two scenarios above for research. A partial listing is developed below:

* What are the gains possible by using an optimal bucking program at the stump for high value timber and lower value timber?
* What are the time/cost tradeoffs for the felling and bucking activities?
* Is it humanly feasible to have buckers enter data into a handheld computer under field conditions and implement solutions?

* Can buckers make the quality decisions and measure the diameters and lengths with sufficient precision to capture potential gains?
* Are new measurement techniques required?
* What mix of log grades and lengths are produced by optimal bucking at the stump?
* What company data are needed in the way of grades, prices, logging, and hauling costs? Proprietary issues arise.
* What problems are created for downstream logging, hauling, and distribution systems?
* What technical problems are posed for environmental housings and data transmission to and from the computer.
* What is the match between bucker's decisions and scaler's decisions on log quality?
* What opportunities exist for improved resource management of timber from inventory through the mill with optimal bucking technology?

Research and Product Development

The Forest Engineering Department in cooperation with Oregon Digital Systems Incorporated has embarked on a research and development effort to bring optimal bucking technology to the stump in the west. Two other Oregon firms are providing timber, buckers, and data resources in old-growth timber and smaller, second-growth timber. A strategy of research and extension activities are shown in figure 1 to help guide a series of projects on improving bucking.

The approach to the bucking problem was developed by John Sessions for the IBM-PC desk-top computer known as Buck©. Oregon Digital has developed Handheld Buck© on a Hewlett-Packard HP-94 industrial computer (256K).

In general terms, the bucking program allows users to specify log characteristics, mill prices, grades, logging costs, hauling costs, other user costs (slash treatment, etc.), for a large number of potential mills or purchase points. These data are entered by desktop computer and downloaded to the HP-94 for optimal solutions at the stump once log characteristics, length, diameter, and must/can't buck points are entered. Solutions are reached in 3-6 seconds. As new data are discovered (the presence of rot), the best remaining solution can be quickly recomputed.

Opportunities exist for data storage and management of bucking information. Changes in specifications could be made quickly to match changing markets or mill requirements. Upstream and downstream operations can benefit by better bucking information.

BUCK©, Forest Engineering Department, Oregon State University

Handheld BUCK©, Oregon Digital Systems Incorporated.

Oregon Digital is working to develop a commercial system and an environmental housing. Their prior experience with digital scaling computers makes them especially valuable cooperators. Assuming tests proceed as planned, commercial units could be available by 1988.

Additional research is planned once the handheld computers are on the market. Funding for the initial project is through the Centers for Wood Utilization Research. OSU researchers include the authors and graduate students Steve Pilkerton and Mark Beaulieu.

Computers and Human Capacity

What the computer brings to the bucking decision are lightning fast comparisons and financial calculations plus an ability to store, update and manipulate some kinds of information. What the bucker brings is the capacity for visual information, measurement, and judgment. The bucker can improve these capacities with training and experience. The bucker must also balance the mixture of goals for timber harvesting, e.g. production, safety, and quality into a satisfactory outcome for the firm.

Currently in Oregon, there are over 3,000 workers in felling and bucking. Outside of the few large corporations with their own cutters, most cutters are employed in sole proprietorships and partnerships with a few larger cutting contractors organized as corporations. Most firms employ less than 6 employees. They may work for a variety of timber owners or sale purchasers. Most are completely unfamiliar with computer or programmable handheld calculators. The current bucking decisions mostly revolve around length measures with some limited guidance on quality and grade.

Loggers are somewhat resistant to change, but change is possible! In 1976, a few hydraulic rams were used to help directionally fall timber to save valuable timber or other resources. By 1978, 1500 sets of these hydraulic rams were in use on the west coast. The same success is possible in adopting bucking improvements.

We believe that buckers can be shown how to use the handheld computer, make the appropriate quality judgments, take the necessary measurements, and implement the solutions that will make more money for the firm and themselves. A major training effort will be required for buckers (and the timber firms who employ them) to use the new technology.

In addition, an information service is needed to prepare the price and quality data for use in the handheld computers. Issues of confidentiality and data handling will need to be resolved to make such a system work. A parallel system is already in place with the various log scaling bureaus who use some of Oregon Digital's computers in log measurement once the timber is out of the woods. Further system design depends on the outcomes of our "proof-of-concept" research.

Important Matches

Solving the bucking problem with handheld computer solutions in a practical, operational environment requires that a series of matches be made between related operations and between the data evaluated within the computer. A few important matches are listed as Table 1. "Proof-of-concept" research will illuminate the strength of some of these matches and suggest areas for additional research.

Some Preliminary Results

Data collection is barely underway in the research but using some of the initial trees in the study can provide an insight into the magnitude of potential gains. Figure 2 shows the potential for a given old-growth Douglas-fir tree. There were more than 7 mills and 38 products for the 208 feet of tree under consideration.

Figure 3 makes a like comparison for second-growth Douglas-fir with a narrower range of potential products and mill destinations (4 mills, 21 products, 90 feet in length). Recall that daily production rates vary and when expanded to a like number of trees in an operational setting, the daily gains in this type of timber could be $3832 and $900 for old-growth and second growth respectively. This assumes a pair of cutters producing eight trees in old-growth and 100 trees in second-growth.

Summary

We are just beginning to realize the potential of optimal bucking decisions at the stump with handheld computers. Our knowledge of the timber harvesting industry tells us a long term sustained program of research, commercial development, and extension education efforts will be needed to capture the potentials identified. Our efforts will extend back to standing timber and forward into the processing plants.

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Table 1. IMPORTANT MATCHES FOR OPTIMAL BUCKING WITH HANDHELD COMPUTERS

Operation A or Data A } Must Match }	Operation B or Data B	Comments
Bucker's measurements: diameter, length, quality.	Accurate computer entry for optimal solution.	Eliminate data entry errors. Improve accuracy of measurements if needed. Training of Buckers.
Computer solution as bucked for log grades and destinations.	Sorting procedures and scaling results.	Log marking or bucking tied to sorting. Quality determination must reflect grades in computer solution. Buckers must be trained to accurately depict quallity.
Mill prices for grades and specifications in computer.	Market contribution to firm's profit through milling, sales, etc.	Firms need help in establishing price table.
Computer cost function.	Firm's cost function including relevant costs of slash treatment of material left on site, etc.	Firms need help in establishing cost functions.
Data transmission and handling capabilities of computer.	Functional system of desk-top to handheld computer communication and return with complex industry structure needing data security.	System design needed.
Objectives of firm for the bucking and associated decisions.	Computer algorithm to allocate log resources.	Research and experience necessary to identify various objective functions and appropriate algorithms.

Figure 1. BUCKING IMPROVEMENT PROJECT

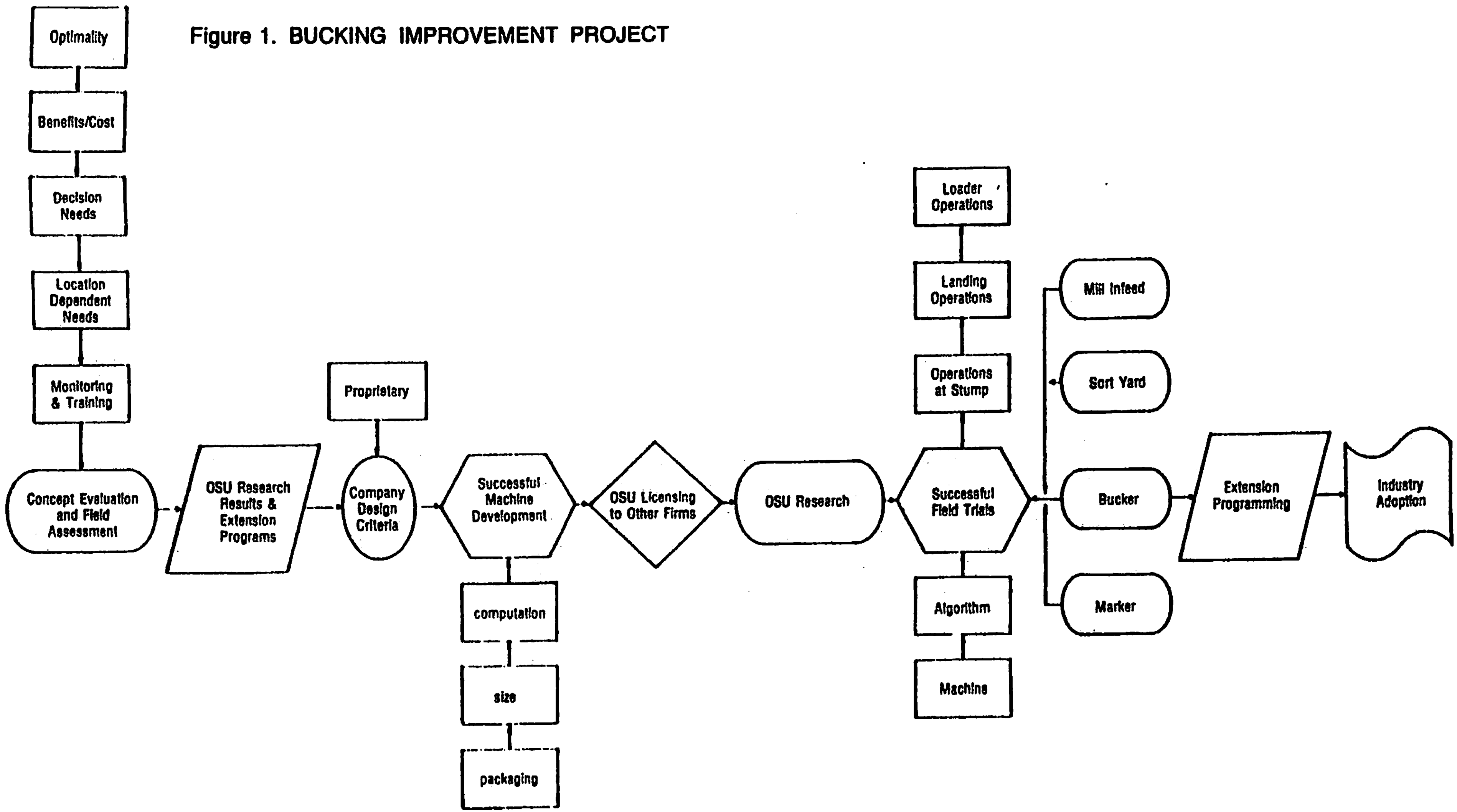
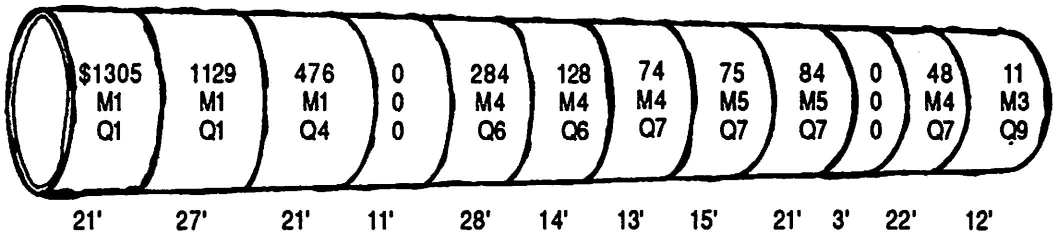
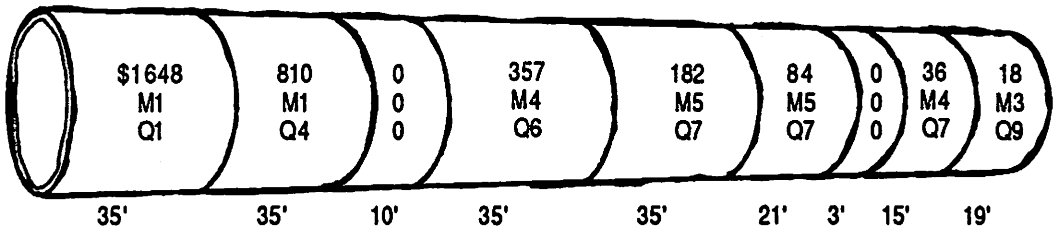


Figure 2. A VALUE COMPARISON IN OLD-GROWTH

OPTIMAL TOTAL VALUE: $3614



AS BUCKED TOTAL VALUE: $3135

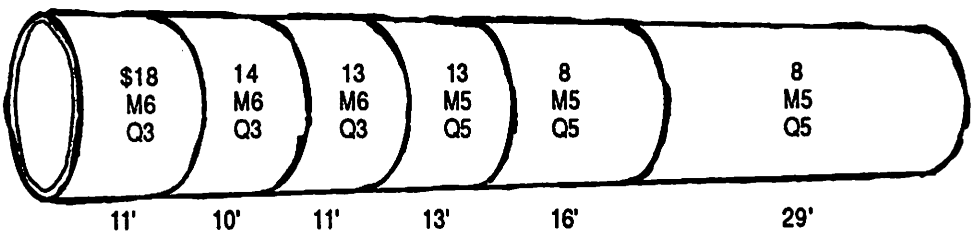


DIFFERENCE: $479

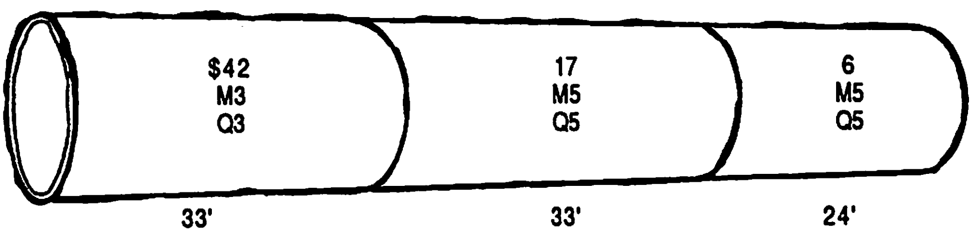
15.3%

Figure 3. A VALUE COMPARISON IN SECOND-GROWTH

OPTIMAL TOTAL VALUE: $74



AS BUCKED TOTAL VALUE: $65



DIFFERENCE: $9

13.8%

Key		
	$ XXX	Net Value per Log
	MX	Mill Allocation
	QX	Log Quality
	0 0 0 }	Broken Section

VOICE RECOGNITION TECHNOLOGY FOR TIME AND MOTION STUDY: CONCEPTUAL FRAMEWORK AND ASSESSMENT[1]

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Abstract: Greater benefits of logging systems performance studies could result if they were conducted by loggers themselves, provided the technology for doing so were reliable and relatively inexpensive, and provided the methods of data collection did not interfere with the loggers' primary production functions. Modern voice recognition technology might be combined with rugged, industrial grade computers to enable logging systems operators to collect detailed time and motion data. In combination with appropriate analysis software, such capabilities could yield results that are more timely and reliable, yet less expensive, than those produced by conventional work study techniques. In this paper we describe a data collection and analysis format that seems well suited to the capabilities of modern data logging systems, we discuss the current status of voice recognition technology, and we show how voice recognition technology might be used to enhance the study of logging systems performance. We recognize certain pitfalls, including interference from background noise; but we conclude that the potential benefits to be realized warrant further development and testing.

Keywords: Computerized voice recognition, data logging, work study, logging production

INTRODUCTION

Among the more important factors affecting utilization of wood are the costs of harvesting and transporting it to market. The payoffs of improvements in timber harvesting are potentially large, and applications of scientific work study principles are among the ways that such improvements might be realized. Timely summaries of the performance characteristics of tree harvesting and processing systems, related to various site and stand conditions, should aid in predicting future performance and provide a basis for innovating and testing performance improvement ideas. However, collection and analysis of time and motion data can be costly and time-consuming, requiring

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passive observers to record data in the field and subsequent manual entry into computers for analysis. Moreover, summary and communication of results may be too slow or ineffective to meet many loggers' needs.

We are interested in the development of hardware and software to meet the needs of loggers themselves for methods of data collection, analysis, and display that will enable rapid assessment of their systems' performance. This should help them to more rapidly and reliably evaluate their operational procedures or circumstances, thereby abetting gains in efficiency.

Significant improvements in collection of time and motion data may soon be realized through emerging computer speech recognition technology, by which the machine operator could directly enter the majority of data via a headset into a computer located on the machine. At the completion of a shift, a stand, or at any desired time, the data could be analyzed locally or be transferred to a disk, which then could be forwarded to a central location for further analysis. Cost savings would be realized through more timely analysis and a reduction or elimination of both field and data entry personnel.

This paper discusses the basics of voice recognition, briefly describes hardware requirements, and provides a framework for data collection.

BACKGROUND

The United States logging enterprise consists mainly of many independent, relatively small firms. In 1983 there were nearly 12,000 logging firms with about 83,000 employees nationwide. Over half these employees were in firms with fewer than 20 employees each. Such firms made up nearly 95 percent of logging contractors and logging camps in the nation (U.S. Bureau of the Census 1985). Moreover, the advantages to large manufacturing corporations of relying on independent contractors (vis-a-vis company crews) may indicate a trend toward an even greater proportion of small firms in the future (Black 1984).

The nation's timber resource may be characterized as declining in size and quality (USDA Forest Service 1980) especially in the Western United States (Conway 1982; Stere 1983; Combes 1986). The general effect of smaller tree size is decreasing value accompanied by increasing harvest cost per unit volume (Brown and others 1982). Mechanization of timber harvesting has substantially alleviated the financial penalties of declining tree size, nevertheless not enough to eliminate such penalties entirely (Satterlee 1982; Gonsior and Johnson 1985).

Other trends affecting the logging industry are more difficult logging chances; volatile market forces and unsteady employment; renewed and continuing pressures for wages comparable to other attractive industries; increased variability of the labor force involving women, city dwellers, minorities, and better educated workers; and continuing government regulation in areas of safety and environmental performance. Both management and workers need to work together to lessen the negative impacts of these trends (Garland 1984). Obviously, improving efficiency and safety is important to managers and workers alike.

Apart from improvements through mechanization, perhaps the most effective way for logging firms to remain competitive and prosper is through methods improvement (Conway 1968a). The merits of various work study methods applicable to logging have been discussed widely (Lussier 1961; Conway 1968b, c, and d; Miyata and others 1981; Olsen and Kellogg 1983) and the body of literature describing the results of studies employing such methods grows steadily, both here and abroad. Without providing an extensive bibliography of such studies, we do note that most are conducted by researchers and academicians and are usually reported some considerable time after observations are made. This literature can aid forest managers, logging engineers, and equipment manufacturers in estimating logging costs, and it can also provide insights for improvements. However, to be of use to logging operators, productivity measures must be timely--that is, they must be available at the end of the same day or, at most, the following morning (Conway 1982). Unfortunately then, the literature probably has not served loggers in their day-to-day operations.

Traditional work study methods have involved the use of stopwatches and manual recording methods, often with cumbersome, specialized data forms (Gibson and Rodenberg 1975). Subsequently, the data have been entered into computers by keypunch or console operators. Such methods often are incompatible with timeliness constraints. Moreover, because of the nature of time studies, workers are distrustful of anyone with a stopwatch (Conway 1968b). Consequently, loggers and logging managers have had to rely on themselves to collect and analyze data to meet their immediate needs. However, loggers cannot be expected to keep detailed time and motion records; so compromise regarding data quality and level of detail is necessary, with gross daily estimates of tree or log counts and downtime usually having to suffice (Conway 1982).

In recapitulation, the American logging industry consists mainly of small, independent contracting firms faced with many adverse trends. Some of the larger firms may have the wherewithal to incorporate scientific work study and improvement methods in their ongoing operations; but the majority of firms have not had ready access to such methods.

Within the last decade, advances in electronics technology have significantly altered the potential for work study. F. James McDonald, executive vice president of General Motors, pointed out in 1979 that the image of the industrial engineer as someone with a stopwatch and a clipboard is obsolete--the stopwatch has been replaced by electronic data collectors that have great memory capacity and that can be patchcorded to a large computer for further data processing (Brisley and Eady 1982). Surprisingly, modern domestic industrial engineering texts acknowledge automated data collection methods only in passing (Niebel 1982; Aft 1983; Mandel 1985).

Portable, battery-powered, microprocessor-controlled data collectors have been employed in forestry--mostly research--since the mid 1970's (Cooney 1985). With respect to logging work study applications, however, the Canadians and Europeans seem to have taken the lead (Cottell and others 1980; Guglhör 1979; Wencl 1983; Bloch 1984; Backhaus 1984; Bloch and Eisenhauer 1985). Even so, while the efficiencies of data collection, transmission, computer entry, and analysis have been improved thereby, still there appear to be no systems designed specifically for use by loggers themselves.

The successful advent of voice or speech recognition should minimize the difficulty of data entry during work measurement (Mishra 1982). Artificial-speech technologies have been under development for over 20 years and have been most widely used in factories (Restaino 1984). New signal processing techniques are more noise tolerant (Wagers 1984), which will be important in most logging applications (Cottell and others 1980). The future prospects for virtually instantaneous data transmission via satellite, including transmitter coordinates, also appear promising (Gasvoda 1986), but this may be beyond the needs or means of individual small logging firms. Ultimately, it may be possible to combine speech recognition with artificial intelligence to go beyond data entry to machine control (McCallig 1984; Morgen 1985), but this is beyond the scope of our current interest.

VOICE RECOGNITION

Voice recognition is the computer's ability to match a spoken word, or other utterance, to a previous recording of it, called a voiceprint. When a match has been obtained, computer software typically translates the voiceprint into keystrokes, which then may be used as either data or instructions. Because the voice recognition module mimics the function of a keyboard, these systems find their greatest use in situations where the user's hands or eyes are occupied.

If it is required that a machine recognize any speaker--known as speaker-independent recognition--then, under current technology, the vocabulary will be severely limited. Nonetheless, speaker-independent systems find applications such as airline reservation check stations, where the traveller must answer with a simple "yes" or "no" to a variety of questions appearing on a video terminal.

Much better performance is achieved with systems that are trained to recognize a particular person's voice--known as speaker-dependent recognition. In state-of-the-art speaker-dependent systems, vocabularies are increased to thousands of words with success of correct matches typically in the neighborhood of 98 percent. These systems are becoming more commonplace in industry, finding applications in such areas as material inspection, machine control, and inventory control.

There appears to be little standardization in terms of which aspects of speech a system is capable of recognizing (Bristow 1986). Some of the more commonly used categories, in order of increasing complexity, are:

1. recognition of isolated words--pauses are required between utterances
2. recognition of discrete words in connected speech
3. recognition of strings of words in connected speech
4. true speech understanding--the system is capable of identifying meanings without constraining the speaker's sentence structure.

The majority of speech recognizers available today are of the speaker-dependent, isolated-word type. Progress is being made in categories 2 and 3 above, and systems with limited connected-speech capabilities are commercially available. Although no true speech understanding system yet exists, extensive research in this area is under way here and abroad. The Japanese, in their nationally funded "fifth generation" computer project, have set speech understanding as a major project goal.

The most advanced speaker-dependent systems today, having vocabularies approaching 20,000 words, are unsuitable for field use due to extensive hardware requirements. However, some systems with smaller vocabularies are compatible with inexpensive microcomputers. A speaker-dependent, isolated-word system with a vocabulary of approximately 150 words could be assembled for $5,000 to $7,500 per unit. Such a system, although not ideal, would likely be adequate for many field applications.

HARDWARE

Figure 1 is a block diagram showing major system components. The microcomputer is similar (exceptions are noted below) to a standard IBM-PC/XT[1] (or compatible) unit. The speech recognizer circuit board would plug directly into one of the expansion slots provided within the microcomputer. Because the display would likely be used only occasionally, a small flat-panel type would suffice.

Potential problems exist. Because of vibrations and other harsh conditions in which a machine-mounted computer must operate, problems would quickly arise with a standard, commercial grade microcomputer. However, currently available industrial grade microcomputers are designed to operate in such conditions. Rotating disk drives are replaced with solid-state memory units, boards are assembled with

[1]Trade or firm names are for reader information, and do not imply endorsement by the U.S. Department of Agriculture.

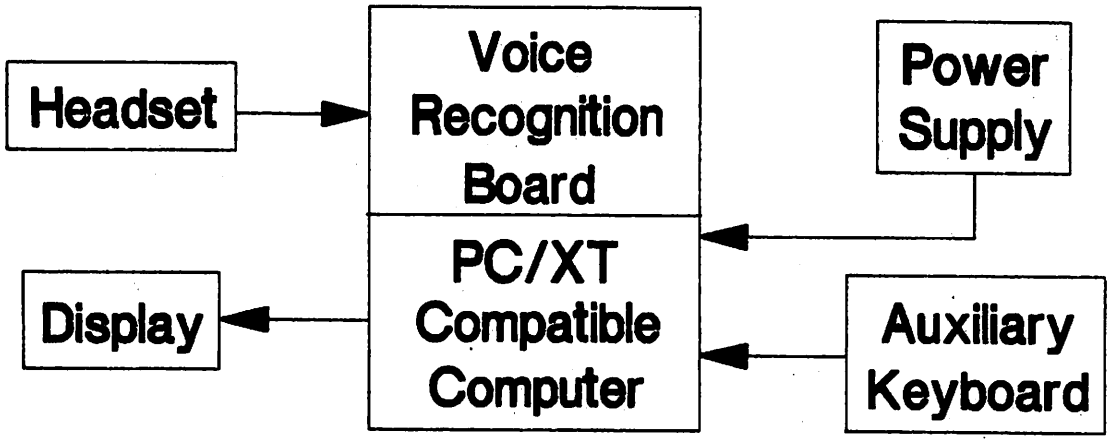


Figure 1--System block diagram.

components that are less susceptible to shock and vibration, and the system has a much wider operating temperature range. Some reconstruction of speech recognition hardware would probably be required to meet industrial grade specifications. Such modifications make industrial grade systems considerably more expensive than their commercial grade counterparts.

Interference due to background noise is likely to be a more difficult problem than hardware reliability. Sources of interference will include squeaks, rattles, and engine noise. Use of standard electronic filtering techniques to reduce background noise will be difficult without simultaneously affecting the spectral characteristics of the spoken word. Highly directional microphones, or possibly throat microphones, could be used to increase the ratio of the desired signal-to-background noise. Where the operator is in an enclosed cab, it may be feasible to reduce external noise by soundproofing. In any case, simulation of field conditions will be difficult, and an assessment of the severity of the problem and effectiveness of the solutions will have to await field testing.

DATA COLLECTION SCHEME

The data collection scheme we envision is based on segregating each discrete event with the mean solar time. Using this scheme, the event or process under way (and any associated data) is recorded and, upon its completion, the mean solar time is entered. The only limitation is that there be sufficient time to record the event (and any associated information) before the next process commences. This method of recording events is especially well suited for use with small computers having internal real-time clocks.

Consider the case of collecting production information on a feller-buncher. The majority of the data input is likely to be associated with repetitious operations (e.g., cutting and bunching or moving to a new position) and such operations would be good candidates for voice entry of data. Data on other, less frequent operations (such as scheduled maintenance or a commute to a new unit) could be entered by a keyboard without an excessive demand on the operator's time.

As an example, figure 2 contains data collected by this scheme during a recent joint USDA Forest Service/Champion International study of the in-woods performance of a Timbco feller-buncher (Gonsior 1986). Data in this figure were manually collected and entered into the computer. The first 11 lines are the file header. Along with the structured entries, such as FILE NAME, UNIT, and DATA, flexible data entry is permitted under COMMENTS.

The first event recorded in figure 2 was the cutting of a single tree (SINGCUT), 7 inches diameter at breast height (d.b.h.), which was completed at 09:27:48 and took 20 seconds to complete (timing was started at 09:27:28 as indicated by the header data). Next, three 4-inch d.b.h. trees were cut and accumulated (a MULTCUT event), then bunched with the previously cut 7-inch tree. This was followed by single cuts of 6- and 8-inch d.b.h. trees, which were completed at 09:28:55 and 09:29:14, respectively. Next, a position-to-position move in which two trees were cut, accumulated, and carried to the new position (a PP-CC event) occurred. Again, a sequence of single- and multiple-tree cutting events took place, each having an associated mean solar time at which it was completed.

```
****************************************************************************************************
INPUT FILE NAME:            TH100301.DAT
THIS FILE NAME:             TI100301.DAT
MACHINE:          TIMBCO
UNIT:             25-84-2
DATE:             10/03/84
SLOPE:            (2)SLOPE 22.5(20-25)%
OPERATOR:         S SCHEFF
OBSERVER:         D ABBOTT
COMMENTS:         CLEAR
START TIME:       092728
END TIME:         114318
****************************************************************************************************
EVENT       TIME        DELTA T     TREE 1      TREE 2      TREE 3      TREE 4      TREE 5
SINGCUT     09:27:48    20          7
MULTCUT     09:28:30    42          4           4           4
SINGCUT     09:28:55    25          6
SINGCUT     09:29:14    19          8
PP CC       09:30:56    102         6           5
SINGCUT     09:31:14    18          8
SINGCUT     09:31:32    18          7
SINGCUT     09:31:55    23          7
SINGCUT     09:32:16    21          6
SINGCUT     09:32:34    18          7
MULTCUT     09:33:10    36          6           5
SINGCUT     09:33:35    25          5
SINGCUT     09:34:18    43          10
PP CC       09:35:28    70          7           5
SINGCUT     09:35:44    16          6
SINGCUT     09:36:01    17          6
SINGCUT     09:36:19    18          6
MULTCUT     09:36:51    32          6           4
MULTCUT     09:37:30    39          4           4
SINGCUT     09:37:52    22          5
MULTCUT     09:38:36    44          6           3
PP          09:39:35    59
UDT         09:43:28    233         OTHER       (O POW WOW DECIDED TO MAKE ANOTHER STRIP)
SS          09:48:37    309
UDT         09:55:57    440         MECH        (M STOP ON ROAD CENTER RIGHT TRACK ON TOP ROLLERS)
PP CC       09:56:30    33          6
MULTCUT     09:57:09    39          5           5
SINGCUT     09:57:25    16          6
MULTCUT     09:57:51    26          5           5
MULTCUT     09:59:03    34          5           5
EOF
```

Figure 2--Typical data record for feller-buncher.

Other events in figure 2 include a position-to-position (PP) move completed at 09:39:35, two unscheduled downtime (UDT) events (one which was completed at 09:43:28, the other at 09:55:57) and a strip-to-strip (SS) move completed at 09:48:37. Additional event types used but not shown in this figure included commute (COM), ancillary activity (AA), scheduled downtime (SDT), and delay (DEL). All followed a similar pattern in that event termination was denoted by a mean solar time.

Had the data collection scheme just described been used in conjunction with a voice recognition system (assuming a system having a limited vocabulary), it would have been mandatory that all data associated with "productive" time be entered via voice. For a feller-buncher, this would include data such as tree diameters and move events. In addition, it would be desirable to have the capability of entering the more common "nonproductive" events by voice, such as those associated with DELs and AAs. Descriptive data accompanying events such as UDT and SDT could be entered via the keyboard.

Error detection and correction pose a challenge when dealing with real-time systems. The operator of a piece of heavy equipment likely would not be able to make frequent visual checks to a video terminal without seriously affecting his or her performance. Audio feedback of each word recognized could become annoying and confusing, and it probably would reduce the rate at which data could be entered. However, a simple auditory tone, such as a "beep," could signify that a match had been achieved. With a careful selection of vocabulary, the beep would indicate with a high degree of confidence that a correct match had been made. Some types of errors (e.g., errors due to improper data entry sequence) could be determined under program control. In such cases an audio message could be sent to the operator.

Even when a fault has been detected, it may be impossible for the operator to correct the mistake immediately. Consequently, provisions must be made for flagging erroneous or questionable data whenever they have been detected.

DATA ANALYSIS AND REPORTING

From recorded information, summaries can be generated to suit the user. For example, the machine operator could quickly obtain a summary showing time spent in each type of activity or the total units produced in a specific activity. A feller-buncher operator might check performance at the end of the day by generating summaries such as size distribution of trees cut, total trees cut, and the amount of time spent in various activities. Information transferred to a central location could be added to larger data files and used for more complex analyses. Even without report generation in the field at day's end, results should be available from the central location by the following morning.

To appreciate the value of the types of data analyses and summaries we envision, consider the following results from the aforementioned Timbco study (Gonsior and Mandzak in press). During one part of that study, in an area called Black Cat, two units of predominately lodgepole pine were harvested in accordance with a seed-tree prescription that constituted a clearcut, for all practical purposes (only about four trees per acre were designated to be left). Preharvest inventory of these units showed they were similar in topography and tree size distribution; but the stand density in Unit 25-84-2 was about twice that in Unit 25-84-3 (see table 1).

From our time and motion studies, which accounted for nearly half the scheduled hours, we were able to confirm that tree size distributions in the two Black Cat units were, indeed, virtually identical (see figure 3).

We found that, although the proportion of time spent in the basic fell and bunch activity was almost the same in each unit (a little under 58 percent in Unit 25-84-2 and a little over 58 percent in Unit 25-84-3, as shown in figure 4) a much greater proportion of time was spent in position-to-position (PP, PP-CC) and strip-to-strip (SS, SS-CC) moves in Unit 25-84-3 than in Unit 25-84-2. That is, in Unit 25-84-2, about 16 percent of "scheduled" time was spent in repositioning the Timbco, whereas in Unit 25-84-3 about 23 percent of scheduled time was so spent. In aggregate, the proportion of the Timbco system's scheduled time lost due to unscheduled downtime (UDT), scheduled downtime (SDT), and other activities (AA, COM) was higher in Unit 25-84-2 (about 26 percent) than in Unit 25-84-3 (about 18 percent). There were no causes for this difference in nonproductive time that could be attributed to unit characteristics per se.

Table 1--Statistics based on preharvest inventory, Black Cat Units 25-84-2 and 25-84-3.

Unit	Stand density	Volume	Basal area	Net volume
	Stems/ acre[1]	Ft^3/ acre	Ft^2/ acre	Bd ft/ acre
25-84-2	484.6	2686.9	135.7	6146.7
25-84-3	246.3	1479.5	71.8	3103.7

[1]Larger than 3 inches d.b.h.

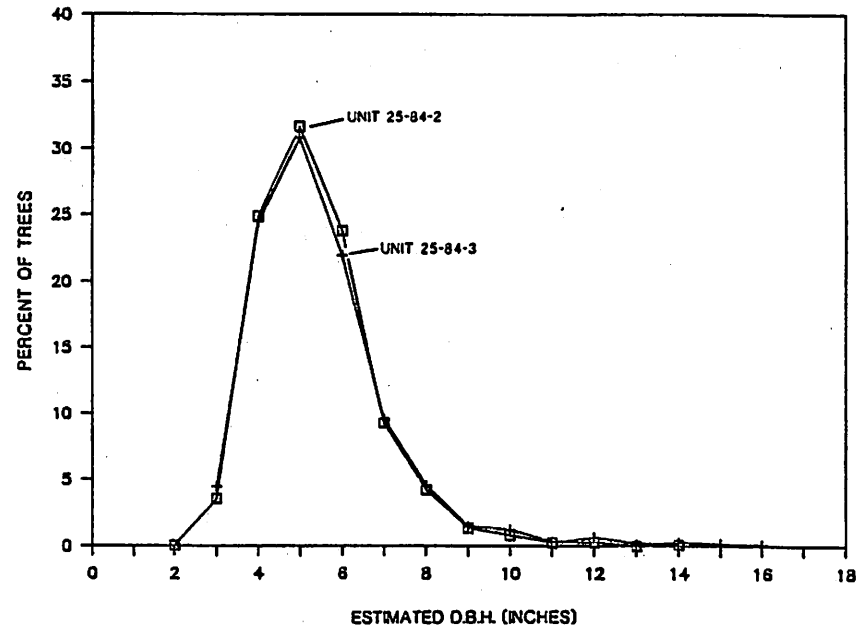


Figure 3--Tree diameter at breast height (d.b.h.) distributions, Black Cat Units 25-84-2 and 25-84-3 (based on time and motion study data).

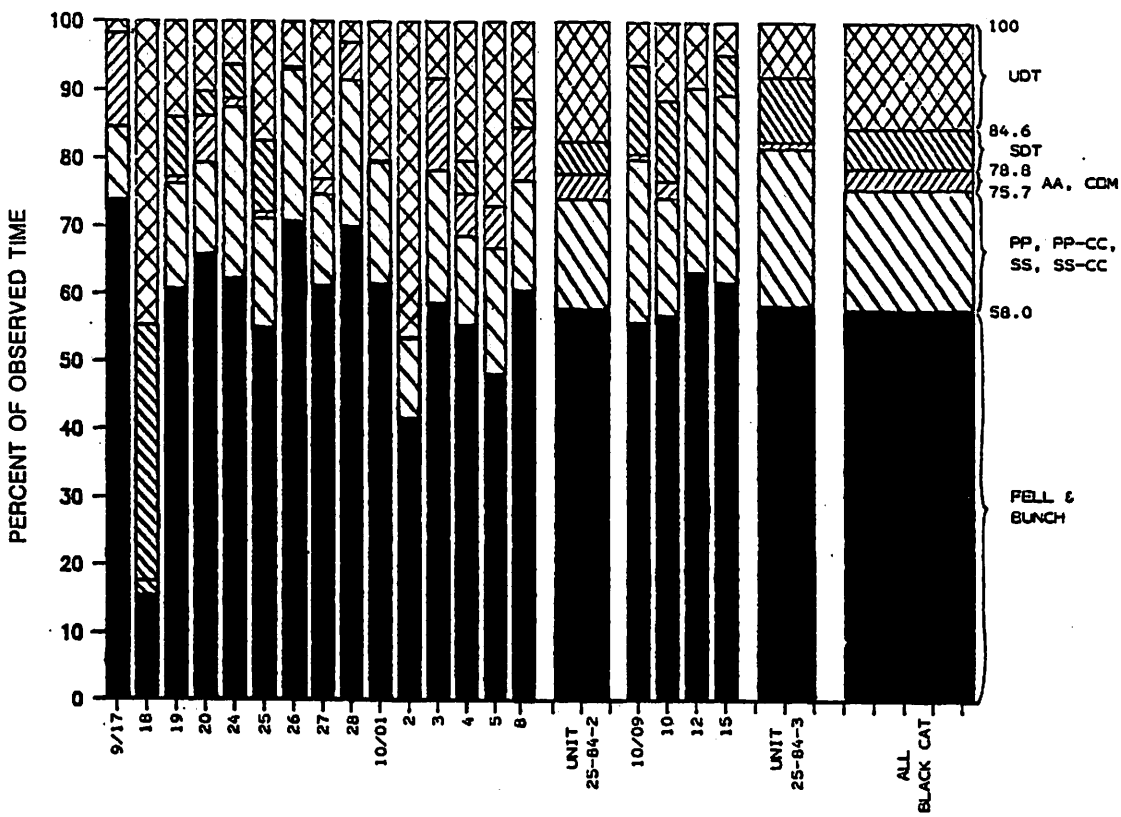


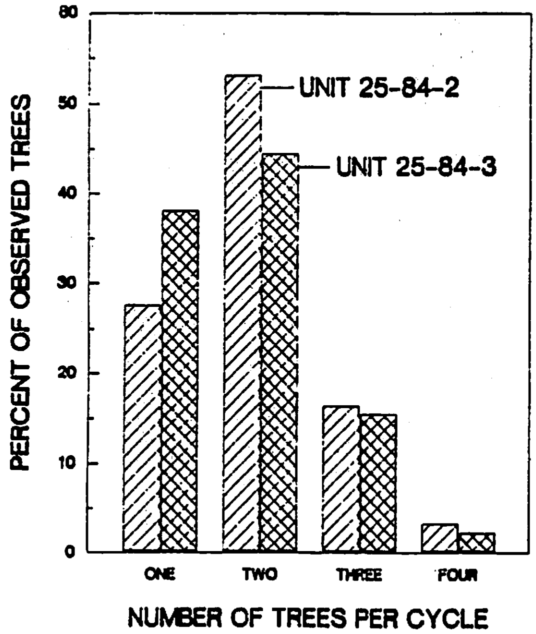
Figure 4--Timbco activity distributions (percentage of observed time excluding lunch periods) at Black Cat--daily, by unit, and overall.

It is apparent that, in Unit 25-84-2, the Timbco system spent a higher proportion of its productive time in the basic fell and bunch activity--correspondingly a lower proportion in repositioning (PP, PP-CC, SS, SS-CC)--than it did in Unit 25-84-3. Moreover, we found that about 6 percent of all the trees cut in Unit 25-84-2 were accounted for during PP-CC and SS-CC activities--referring to the act of cutting and carrying one or more trees during the process of moving from position-to-position or from strip-to-strip--whereas about 9 percent of the trees cut in Unit 25-84-3 were so accounted for. These results seem consistent with the anticipated effects of stand density. That is, the higher the stand density, the lower the proportion of time spent in repositioning. Also, given the desire to minimize the number of bunches to be skidded, lower stand densities tend to encourage cutting and carrying more trees while moving greater distances between bunch positions.

We also determined that the proportion of trees cut in single-tree cycles was lower in Unit 25-84-2 (about 28 percent) than in Unit 25-84-3 (about 38 percent), as can be seen in figure 5. Correspondingly, a higher proportion of trees were cut in multiple-tree cycles in Unit 25-84-2 (about 53 percent in two-tree cycles and about 19 percent in three- or four-tree cycles) than in Unit 25-84-3 (about 44 percent in two-tree cycles and about 18 percent in three- or four-tree cycles). These results also seem consistent with the expected effects of stand density; that is, the opportunity for multiple-tree cycles should increase as stand density increases.

Lastly, we determined that basic productivity--that is, the mean time per tree for felling and bunching while the machine is stationary--was somewhat better in Unit 25-84-2 than in Unit 25-84-3, for which no explanation is apparent. In Unit 25-84-2, the mean times per tree were 23.3, 16.7, 14, and 11.4 seconds in one-, two-, three-, and four-tree cycles, respectively; and the overall mean for Unit 25-84-2 (excluding trees cut in PP-CC and SS-CC operations) was about 17.9 seconds per tree. In Unit 25-84-3, the mean times per tree were 26.5, 18.6, 14.8, and 13.9 seconds in one-, two-, three-, and four-tree cycles, respectively; and the overall mean for Unit 25-84-3 (excluding trees cut in PP-CC and SS-CC operations) was about 20.9 seconds per tree. Figure 6 shows the mean times per tree versus d.b.h. for one- and two-tree cycles only. Figure 6 also exemplifies another more detailed type of summary that can be obtained from the data we envision loggers might be able to collect. Such a summary provides insights into the effects of stand and individual tree characteristics on system performance, provides a basis for experimentation to test hypotheses explaining certain effects, and provides the wherewithal to test new ideas for improving system performance.

When we combine the more detailed information just described, we conclude that basic productivity was about 168 and 135 trees per productive hour in Units 25-84-2 and 25-84-3, respectively. If we are correct in our assumption that the difference between nonproductive



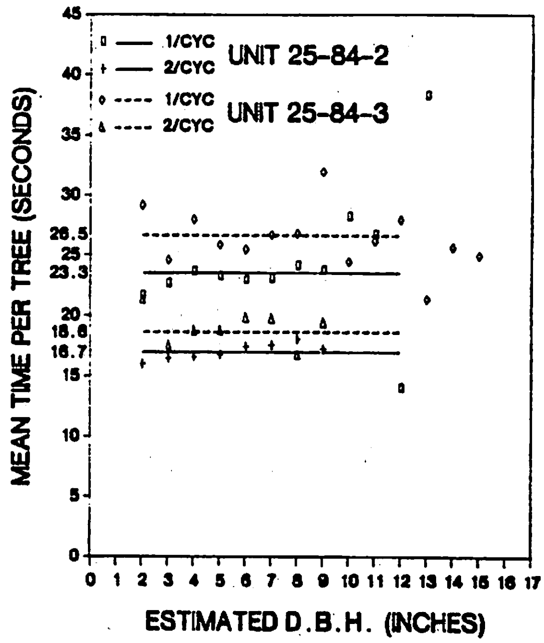


Figure 5--Percentage of observed trees cut in one-, two-, three-, and four-tree cycles, Black Cat Units 25-84-2 and 25-84-3.

Figure 6--Mean time per tree vs. d.b.h., Timbco system, one- and two-tree cycles, Black Cat Units 25-84-2 and 25-84-3.

proportions of time in the two units were due to chance and not due to characteristics of the units per se--and if, say, 75 percent of scheduled time were productive--then the corresponding effective production rates would have been about 126 and 101 trees per scheduled hour in Units 25-84-2 and 25-84-3, respectively. Thus, we conclude that the production rate in Unit 25-84-2 would have been nearly 25 percent greater than that in Unit 25-84-3 had utilization of the system been identical in the two units.

The Timbco operator's daily records of trees produced and hours worked yielded mean production rates of about 103 and 89 trees per scheduled hour in Units 25-84-2 and 25-84-3, respectively, indicating that the production rate in Unit 25-84-2 was about 16 percent higher than that in Unit 25-84-3. This is appreciably less than the 25 percent just derived--a difference that could be important for purposes of predicting system performance and corresponding production costs in future circumstances.

It may be noted that the derived production rates of 126 and 101 trees per scheduled hour in Units 25-84-2 and 25-84-3, respectively (on the basis of 75 percent utilization of the system), are appreciably higher than the rates of 103 and 89 trees per hour, respectively, which were derived from the operator's gross daily records. If our time and motion study results are unbiased, then the latter production rates should reflect system utilizations of about 74 and 82 percent, respectively (see figure 4). If adjusted for 75 percent utilization, the corresponding production rates would have been about 104 and

82 trees per hour, respectively. This results in a production rate in Unit 25-84-2 that is about 27 percent higher than that in Unit 25-84-3, reflecting reasonably good agreement with the conclusion we reached from our time and motion study results regarding the relative productivity in the two units. Nevertheless, there remain appreciable differences in the absolute magnitudes of the production rates derived from the two data sources.

Apart from the possibility that the operator's records contained errors, there may have been bias in our time and motion study data. Even though our detailed study records represented about half the total hours tallied by the operator, such a heavy sampling may still be insufficient for many logging systems. In particular, there may have been higher incidence of both scheduled and unscheduled downtime at the beginnings and ends of the workdays, whereas the time and motion data collection periods may have been more concentrated during the middle parts of the shifts. Regardless, these discrepancies among derived production rates provide additional basis for favoring more complete, operator-collected records vis-a-vis sampling by time and motion study procedures.

One additional message, contained in figure 4, is that proportions of time spent by logging systems in various activities can vary widely from day to day. Thus, there may be hazards in drawing conclusions from brief and infrequent time and motion studies that would be overcome with more complete, operator-collected records.

SUMMARY

Potential benefits of time and motion studies can best be realized if loggers are provided the wherewithal for collecting and analyzing data themselves. The technology for accomplishing this may now be available. Systems incorporating voice recognition technology and industrial grade computers should enable logging equipment operators to collect information at least as detailed as that now obtainable by passive observers, yet without substantial interference with the equipment operators' primary tasks. Moreover, the quality and accuracy of such data should be appreciably better when collected by the operators themselves, not only because their vantage is invariably superior, but because they know precisely what they are doing and when they have started or ceased doing it.

We have described herein a general data collection and analysis format that we believe is well suited to take advantage of the opportunities that modern voice recognition technology might provide; and we have attempted to show how a system incorporating this technology might be used. We have also identified certain potential pitfalls--notably hardware reliability in the typically harsh logging environment and interference from background noise. To determine whether such pitfalls can be overcome, and whether the benefits we envision can be realized, will require development and testing.

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CHAIN-FLAIL DELIMBER-DEBARKERS: TECHNOLOGY FOR PULP-GRADE INWOODS CHIPPING OPERATIONS

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Abstract: The pulp and paper industry in the Pacific Northwest is obtaining an increasing share of its fiber supply by chipping small diameter trees. In order to meet clean-chip standards, the timber must be debarked prior to chipping. Traditional single-stem debarking operations are only marginally productive in small timber, while stationary multiple-piece handling installations have very high capital costs. In an effort to develop a relatively inexpensive, portable, multiple whole-tree processing alternative, three equipment fabricators have introduced chain-flail delimber-debarker prototypes into the Northwest. Two of the prototypes are trailer mounted, four flail-drum units. The third is a two-drum machine, which mounts directly on a chipper. Chip bark content in samples obtained during short-term productivity studies averaged 0.5%-0.7% for both four-drum machines. The two-drum unit produced chips with an average bark content of 1.5%, when debarking stems which had been pre-processed by a chain flail delimber. Productivity ranged from 5.6 to 13.9 Bone Dry Tons per scheduled hour, with utilization under 50% at all operations.

THE DEBARKING PROBLEM

The pulp and paper industry in the Pacific Northwest has traditionally received the bulk of its raw materials from sawmill residues. As old growth timber stands are depleted and sawmills modernize, the availability of sawmill residues is diminishing. The industry is filling the residue shortfall by chipping small diameter materials from thinning removals, insect infested stands, and stand conversions.

Although the pulp industry's raw material sources are changing, the mills retain rather rigid quality requirements. Foremost among these is the need for a uniformly sized, bark free chip. Modern portable disk chippers are able to meet chip size standards in a wide range of stem sizes, providing knife sharpness is maintained. Bark removal poses a much more difficult problem in small timber.

While whole tree chips are used to a limited extent, the industry prefers to obtain pulp grade fiber with less than 0.5% bark content by weight. Clean chips have a 65%-100% higher value per Bone Dry Ton (BDT) than chips which contain bark, limbs, and needles. Depending on need,

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certain mills will relax pulp chip standards to allow as much as 4% bark content, but standards of 1% are more common for materials produced in the woods. Thus, there is a need for debarking equipment capable of meeeting mill bark tolerances in small timber.

Traditionally, single-stem debarkers such as ring (cambium shear) and rosser head machines have been used in the Pacific Northwest. Contemporary ring machines are able to debark stems down to a three inch top diameter, but production rates drop off substantially when encountering small diameter materials. Multi-stem or batch debarking machines are more able to maintain a given level of production regardless of stem size.

Drum debarkers have traditionally been used to handle small diameter materials in other regions of the United States. Large, fixed installation drums are able to delimb and debark multiple whole-tree or tree-segment loads, but have very high capital costs. And, because public highway load size restrictions make the highway hauling of limby tree segments unfeasible at present, delimbing and topping remain a part of such processing systems.

Two relatively inexpensive portable drum debarkers are currently on the market, but each can only process pulpwood length materials. Although the fixed and operating costs of these machines have become more affordable, additional costs incurred in delimbing, slashing, and loading operations remain a problem.

Several equipment fabricators have turned to chain flail technology in an effort to develop a portable, low cost, multi-stem whole-tree delimber-debarker.

CHAIN FLAIL DEVELOPMENT

Most of the early developmental work on chain flail technology focused on the delimbing process. Delimber manufacturers all use a common design, based on a single, horizontally rotating drum to which rows of short chains are attached. The chains remove limbs on impact and by a scraping action which occurs when they wrap around and slide along the stem bole. During this activity, a portion of the bark is also removed from the stem surface.

Borrowing from delimbing technology, most of the debarker designs utilize two or more horizontal, counter-rotating chain flail drums. The Weyerhaeuser Company was one of the first to build such a machine, introducing a portable double-flail prototype into the southeastern United States (Selby and Iff, 1986). During in-woods testing, productivity was limited by the harvest system's ability to supply wood to the machine. In order to increase utilization, Weyerhaeuser moved the prototype to a satellite yard. Productivity increased to 60 green tons per scheduled hour, working in Loblolly pine. Chip bark content was consistently under 1%, even during winter conditions.

Concurrent with the Weyerhaeuser work, three Pacific Northwest equipment fabricators introduced prototype chain-flail delimber-debarkers designed for in-woods application. Mischel Brothers Logging of Port Orchard, Washington, developed a portable four-drum machine which was briefly marketed as the Bigfoot D/D 20 Delimber/Debarker (Figure 1). The drumsets are mechanically driven by a 150 horsepower diesel engine and are run at approximately 600 rpm. Bark and limb debris are removed from the bottom of the machine by a series of drag chain conveyors.

In early 1986, Gibson Chip Company of LaGrande, Oregon re-designed and built a larger prototype based on the first Bigfoot design (Figure 2). All four chain flail drums on this 375 horsepower machine are hydraulically driven. Drum speeds can be varied to accommodate the level of bark adhesion experienced in a particular species or operating season. A single conveyor is used to remove bark and branch materials from the machine.

Peterson Pacific Corporation of Pleasant Hill, Oregon has manufactured a series of two-drum flail debarker prototypes. The first two models utilized carbide-tipped tire cord flails, which were replaced with chains on their third prototype. Peterson's third unit mounts directly on the chipper infeed and is powered hydraulically by the chipper (Figure 3). Flail rotational speed is 350 rpm. Bark and limb debris are pushed out from under the debarker by a hydraulic ram. The Edman Company of Tacoma, Washington is currently using this model. Edman has found that the machine cannot simultaneously delimb and debark whole-trees satisfactorily. Therefore, they use a Hydro-Ax chain flail delimber to pre-process stems.

Figure 1. Mischel Brothers Bigfoot delimber-debarker.

Figure 2. Gibson Bigfoot delimber-debarker.

Figure 3. Peterson Pacific Corporation debarker, mounted on a Morbark Model 22 chipper.

OBJECTIVES

Except for shift-level production and the average bark content per van load, little was known about the capabilities of the three Pacific Northwest chain flail delimber-debarker systems. In order to examine each machine in more detail, field studies were conducted during the months of July, August, and September, in 1986. The specific objectives of our studies were to determine machine throughput and in-shift utilization, and explore how changes in stem size and stem count (per debarker payload) affect debarking capabilities.

This paper will present the results from two three-day throughput studies conducted at the Gibson and Edman operations. Results presented for the Mischel Brothers operation are estimates only, and are included for comparison purposes.

SITE DESCRIPTIONS

At the time of the study, Mischel Brothers were conducting a low thinning operation in a Douglas-fir stand near Bremerton, Washington. The 30-35 year old stand had an average DBH of 10 inches. Harvest volume was estimated to be about 35 green tons per acre.

The fully mechanized operation employed a three person crew. Felling, skidding, and processing operations went on simultaneously. Trees that contained a stud log were merchandised by a loader-activated hydraulic shear, and placed on a solid-frame trailer. Tree tops and whole-trees unsuitable for stud log manufacture were loaded into the delimber-debarker, from which they were automatically fed into a Sumner two-knife chipper.

The Gibson prototype was studied at a Lodgepole pine clearcut operation near Heppner, Oregon. Stand stocking averaged 528 trees per acre, nearly half of which had been killed by a beetle infestation. Volume per acre averaged 15.1 cunits (35.9 tons).

Gibson employed a three man crew to run his processing operation. A hydraulic loader fed multiple-stem payloads into the delimber-debarker, from which they automatically entered the chipper. Two of the employees monitored the delimber-debarker and a Morbark Model 23 chipper, and shuttled chip vans between the landing and a staging area.

The Edman Company's Peterson prototype was mounted on a Morbark Model 22 chipper. Edman used a Hydro-Ax Model 521 chain flail delimber to pre-process the stems on a series of short skid trails near the landing. A Mobark Logger was used to assist in sorting, skidding, and removing debris that accumulated around the debarker. Stems were loaded into the debarker with the chipper's sliding boom. Three crewmen worked in the vicinity of the landing-- the chipper operator, the delimber operator, and the Morbark Logger operator, who spent half of his time shuttling vans.

At the time of the study, the operation was working in a Douglas-fir--Western Hemlock low thinning near Port Gamble, Washington. The 35-40 year old stand averaged between 700 and 1500 stems per acre. Approximately 35 tons per acre were harvested, consisting primarily of hemlock stems.

RESULTS

The Gibson machine had an average production of 13.9 BDT per scheduled hour (Table 1). Debarker utilization averaged only 36.5% over the three day study period. Thus, throughput averaged 38.1 BDT-- or 2.2 (18 unit) chip van loads-- per productive hour. Average bark content during the study was 0.5%. Total costs for delimbing, debarking, and chipping were $10.63 per BDT.

The debarker actively processed payloads during 85% of the productive time per shift. An additional 10% of productive time was spent removing jammed limbs and tops from the machine's debris conveyor. Loading time and chipper jamming accounted for the remaining 5% of productive time.

Disturbance, maintenance, and repair delays accounted for 63.5% of the total scheduled operating hours (Figure 4). The largest single delay component occurred during van shuttling operations. Rain and snow created poor traction for transporting and positioning vans at the landing. In combination with a limited landing size, this eliminated the common practice of parking two vans side-by-side at the chipper blower.

Table 1: Production data for three chain-flail delimber-debarker prototypes.

	Mischel Bigfoot	Gibson Bigfoot	Peterson (Edman Co.)
Avg. Piece Size (cu. ft.)	6.1	8.7	5.1
Bone Dry Tons (BDT) per Scheduled Hour	5.6	13.9	12.9
Utilization[1]	50%	36.5%	45.3%
Processing Cost[2] ($/BDT)	$12.45	$10.63	$11.39
Bark Content	0.7%	0.5%	1.5%

[1]Productive hours per Scheduled hour

[2]The sum of loading, delimbing, debarking, and chipping costs

Van scheduling problems formed an additional source of delay time. Because of a long haul distance, the contractor had difficulty supplying vans at regular intervals throughout the day.

Debarker maintenance and repair activities were lengthy, but the prototype was only in its third month of operation. Several mechanical problems, including a tendency for the debris conveyor to jam, and hydraulic oil cooling difficulties, were still being worked out.

At the Edman operation, production averaged 12.9 BDT per scheduled hour (Table 1). Debarker utilization averaged 45.3% during the study period. On a productive hour basis, throughput averaged 28.5 BDT. Average bark content during the study was 1.5%. Total delimbing, debarking, and chipping costs were $11.39 per BDT.

The debarker spent 93% of productive time processing payloads. Loading activities accounted for approximately 5% of productive time--slightly more than at the Gibson operation.

The major delay consisted of waiting for wood to be delivered to the landing (Figure 5). Because of the very small stem sizes being harvested, five feller-bunchers and two grapple skidders could not supply enough wood to keep the debarker busy. Van shuttling delays were also a problem, although much less of one than for Gibson.

Debarker repair and maintenance delays accounted for 17.4% of the total scheduled operating hours. During the study, a hydraulic pump powering one of the debarker flails failed. Edman had a replacement pump on-site, so the repair time was kept under two hours.

At the time the chip sampling study was conducted, Mischel Brothers' operation produced an average of one stud log load and 2 to 3 van loads (12.5 BDT per load) of chips per day. Approximately one-half of the log loader's time was spent merchandizing the stud logs. The operator felt he could produce 4 to 5 van loads of chips per 10 hour shift if no stud logs were processed. However, it appeared that felling production limited the overall productivity at the site.

Based on a 50% utilization rate and an estimated production rate of 5.6 BDT per scheduled hour, the total cost for delimbing, debarking, and chipping was estimated to be $12.45 per BDT.

DISCUSSION

Delimbing, debarking, and chipping costs for all three operations fell between $10.50 to $12.50 per BDT. Whole tree chipping costs would have been roughly one-half that cost per BDT. Since the value of clean chips often exceeds that of dirty chips by as much as $30.00 per BDT, the additional value created by the delimber-debarkers greatly exceeds the additional costs incurred.

In-woods processing and chipping operations are not always practical,

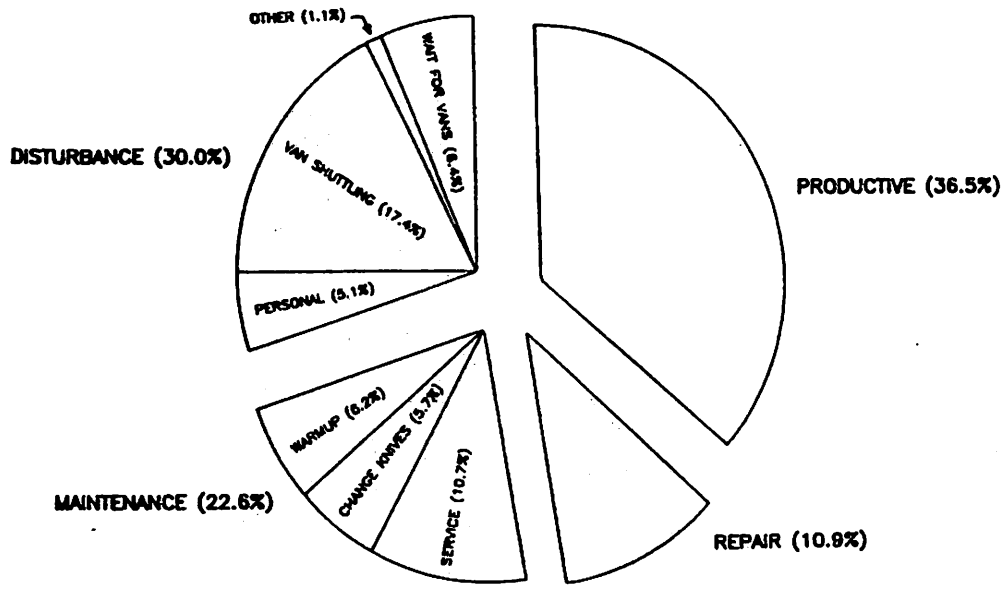

Figure 4. Debarker activities as a percent of total scheduled time for the Gibson operation.

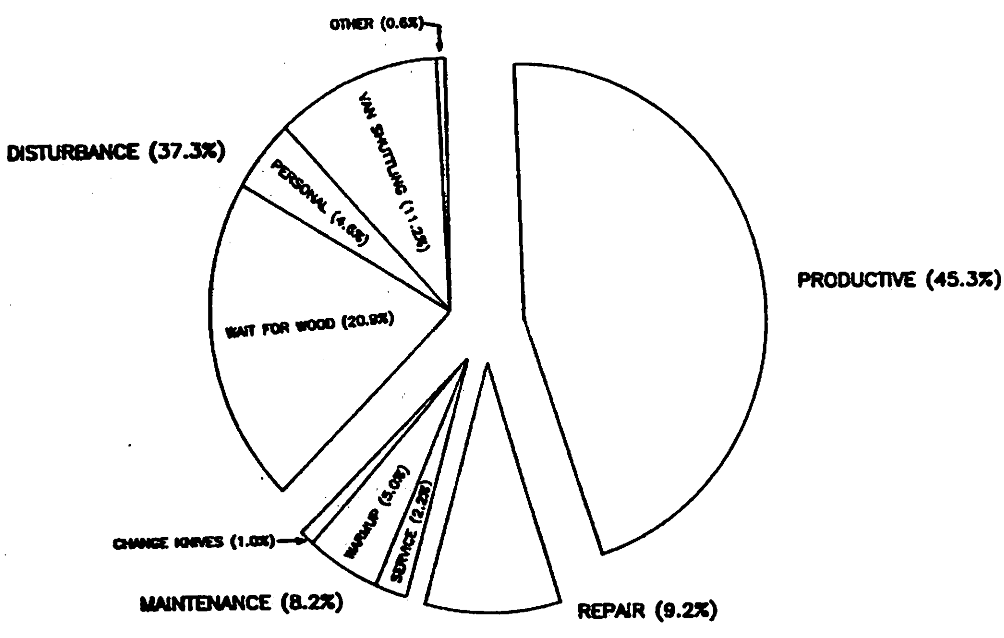

Figure 5. Debarker activities as a percent of total scheduled time for the Edman operation.

however. To be suitable, a site must have roads which are negotiable by chip trucks and a staging area near the landing for van storage. Landings must be fairly flat, one-fourth to one-half acre in size, with an adjacent area for piling bark and limb debris. In addition, harvest units must contain sufficient volume to minimize moving and set-up delays.

Harvest system balancing is also important. At both the Edman and Gibson operations, a large portion of each shift was lost to chip van related delays. In essence, these delays cost Edman and Gibson about 26 and 111 BDT of chips per shift, respectively. The Edman operation also had trouble keeping enough wood supplied to the landing, costing an additional loss of 48 BDT per day. With better system balancing, delimbing-debarking-chipping costs might have been reduced to $6.68 per BDT and $6.45 per BDT, for the Edman and Gibson operations, respectively.

System balancing could be achieved by down-sizing the delimber-debarker and chipper to match the wood and van flow that can be supplied to them consistently. The Mischel Bigfoot system, with its much lower throughput capacity, offers one example of this approach.

An alternative would be to move processing operations to a central woodyard location, as Weyerhaeuser has done. Several logging operations could supply wood to a large, high-throughput delimber-debarker and chipper. The Gibson Bigfoot would be well suited to a central woodyard location. Debarker residues could easily be processed into hog fuel at the site.

While central site processing offers a number of advantages, additional handling costs are incurred when preparing stems for highway transport. There is also a potential loss of recoverable bole wood fiber, since it may not be cost-effective to prepare very small stems for transport to the processing site.

CONCLUSIONS

Although the delimber-debarker systems studied were built by relatively undercapitalized fabricators, all three were able to turn small, low quality stems into marketable pulp quality chips. With improved system balancing, in-woods productivity could be substantially increased.

By consolidating delimbing, topping, and debarking functions, chain-flail delimber-debarkers have changed the cost structure of roundwood harvesting and processing operations. Pulp quality chips can be manufactured in-woods, eliminating the need to manufacture, load and transport pulpwood to a central site.

Depending on local market and stand conditions, these machines have improved the profitability of intensive stand management practices. Materials which previously had little market value have become an additional source of pulp quality fiber for the pulp and paper industry.

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MECHANIZED HARVESTING SYSTEMS

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The woods harvesting systems are mechanizing rapidly due to the need for a safer work environment, better quality wood, and higher production at lower cost. The trend to smaller wood and shorter rotations has further accelerated the mechanization of woods operations. If timber is 24 inches diameter or less on the stump it is possible to totally mechanize the job with ground based systems. These systems will be some combination of track, wheel and swing vehicles.

The combination of track, wheel and swing machines in a given area depends on a number of variables such as: timber type and size, terrain, underfoot conditions, land ownership patterns, silvicultural practices, environmental regulations, and weather. These variables will also determine how the machines are equipped in terms of: guarding, tires, tracks, operator protection, and working attachments. Such innovations as flotation tires, wide track shoes with quad links, leveling devices, disc saws ... have made it possible to mechanize most operations. There will, however, always be some situations where hand felling, cable or even helicopter logging is desirable.

Loggers, equipment dealers, and equipment suppliers/manufacturers must all work together to find mutually beneficial (i.e. profitable) relationships. This will determine the direction and pace of woods mechanization.

World wood consumption is now over 3 billion cubic meters annually and growing at a compound rate of 0.75%. While the growth is modest the rate of mechanization of woods operations is rapid in industrialized countries. This mechanization is more evolutionary than revolutionary. As an example it is not feasible to transplant Scandinavian harvesting systems into the Southeastern United States overnight. The reasons are both social, and economic. However, it is possible to introduce disc saws on feller bunchers into the Southeast at this point in time. Just like the wheel skidder, the saws were born in Canada and have evolved while moving South.

Mechanization has been accelerated by the need to get hand labor up and off the ground. Operators need to be in a safe and productive work environment. The scarcity of good woods labor and the insurance crisis have driven this trend, along with the need for better quality wood to the mill, and higher production at lower cost. As we move from dimensional wood products to wood fiber products the size of the timber is not as important. This means smaller and smaller timber grown on shorter rotations and in plantations. If the wood is 24" diameter or less on the stump, the technology already exists to totally mechanize the harvesting operation.

Loggers can now choose from three different menus (machine categories) to create ground systems best suited to their regional needs. All machines are either Track, Wheel or Swing vehicles. The track and wheel vehicles shuttle from job to job to do their work. The swing machine uses long reach and a swing circle to sit in one place and to its work with less frequent moves. The skill comes in properly mixing and matching machines.

Every region will require a different combination of Track, Wheel and Swing machines based on a number of variables to include; timber type and size, terrain, underfoot conditions, silvicultural practices, land ownership patterns, environmental regulations and weather. Such innovations as flotation tires, wide tracks with quad-link, carbody levelers, disc saws, custom skidders, etc. have greatly extended the application zones of machines. The regional variables also make it necessary to have a tremendous variety of guarding packages, operator stations and working tools/attachments. As a result, a large number of auxiliary equipment manufacturers (AEMs) must join the major equipment suppliers in meeting these needs. To the suppliers this translates into a multitude of small volume opportunities.

It is common knowledge that the woods harvesting business has switched over largely to contract loggers who are generally more efficient and cost effective than company crews.

Many of these contract loggers have a very tight cash flow, and cannot afford to take many risks or to make any big mistakes. They are often quite dependent on the company they log for. The company may direct them as to what they should purchase and assist with the financing. The company can let them grow larger or can simply add more contract loggers when times are good. The company determines their quota when times are tough. The bottom line is that the contract logger is in a profit squeeze and must be an astute businessman to survive. The ones who are surviving and growing our mechanizing their operations.

The smaller contract loggers all look to a small core of larger and successful contract loggers who set the trends.

The contract logger usually doesn't have the luxury of being able to do a lot of long range planning. He may not know what he will be doing in the next month. The company crews, however, have the benefit of owning their own lands, and being able to plan long range. They will be the first to experiment with different systems, and can afford to take some risks. Equipment dealers and suppliers must recognize these two groups and try to meet everyones needs. The woods harvesting operations are generally more short term oriented and cash flow sensitive than the high production millyard operations.

Profit should be the focus in any business venture. The direction and the rate of mechanization will depend on the relationship between the end users (loggers), equipment dealers, and equipment suppliers. To survive they must all be profitable. The best way for this to happen is for them to work together in mutually beneficial relationships. To do these they must be keenly aware of each others needs.

To the equipment supplier this is not a high margin/high profit business. It is highly competitive and equipment prices have remained relatively flat (in real dollars) since 1981. The application is extremely demanding and warranty costs are very high compared to construction machines. The forest products industry is cyclic and when in a slump dealers are often covered up with returned or repossessed skidders and other machines. This makes it imperative to identify the successful loggers and to work with them, large or small, as they mechanize. There will always be a new crop of unsuccessful loggers who somebody will finance. This is unfortunate because it exacerbates the profit squeeze on the good loggers. It also means that there are always some loggers who the equipment dealers can't afford to do business with.

Mechanization will accelerate the "shake-out" in the logging industry. The average contract logger doesn't exist but if he did he would have well over $500,000 tied up in his machines. This demands a thorough understanding of Equipment Investment Analysis (EIA). The four factors which determine the contribution of a product to bottom line profitability are:

- Owning Cost (after tax)
    - Initial Price
    - Interest
    - Resale Value
- Operating Cost
    - Maintenance & Repair
    - Fuel, lubricants
    - Tires
    - Etc.
- Mechanical Availability
    - Work hours vs. scheduled work hours
    - Uptime in another term for availability
- Productivity
    - Cords/hr
    - Bd ft/hr
    - Tons/hr

Many loggers focus all their attention on Owning Cost while it is by far the least significant factor over the ownership period. However, this is understandable if a loggers cash flow will not allow him to meet the monthly payments on a given machine. As the logger grows, and becomes better financed, he can better afford to take the long term view and an EIA approach to his equipment purchases. Relatively minor reductions in operating cost, or improvements in availability and productivity can have a major impact on bottom line profitability.

Academia has a role to play in teaching tomorrows industry leaders to be bottom line oriented and entrepreneurial. New and better ways must be found to grow, protect, manage, harvest, process, and transport wood fiber. The mechanization of woods harvesting has been evolutionary to date. We must get out on the cutting edge of technology and search for ways to produce revolutionary change. To do this, however, we need to remain profitable so we can generate the funds necessary for research and development. The North American forest products industry is a competition in a world market. Like all other industries it must become even more efficient and must reduce costs, while improving productivity. The same goes for equipment suppliers. To make decent profit margins they must drastically reduce the cost of producing a product while at the same time making it functionally better, more productive, and less expensive to operate. This translates into factory automation outsourcing to the lowest cost suppliers, more CAD/CAM, shorter test periods, and maximum use of high volume components (i.e. engines, axles, transmissions, etc.). Every product improvement program must also be a cost reduction program. Every quality improvement program should also reduce production costs.

The logger, timber company, equipment dealer and equipment supplier/ manufacturer are all in the same boat. We are all in business for one reason only and that is to make a profit. Our ability to grow, expand, invest, provide jobs, contribute to charity, pay taxes, and send the kids to college all depend on our ability to remain profitable. Everything we do should be measured against the COST/PRICE/VALUE relationships which can be described as follows:

COST/PRICE - cost to produce a product vs. the price we sell it for the difference is our profit.

PRICE/VALUE - always purchase the product that gives you the best combination of price and value.

COST/VALUE - don't add any cost unless it adds value in the eyes of the consumer (end user).

Forest Engineers will have a major role to play in the direction and pace of mechanization. They will run woodlands operations for timber companies, they will go to work for equipment manufacturers and dealers, they will join governmental agencies, and they will teach at the Universities. In addition to understanding forest engineering, they must be good communicators, entrepreneurial, and have a keen focus on the need for bottom line profitability.

As the industry continues to mechanize the equipment suppliers must have a keen understanding of the industry. This would include tomorrows end products (dimensional wood/panels/pulp and paper, etc.), their consumption, where and how they will be manufactured, and the way the raw material will be grown, harvested and transported. Then the end users who actually do the work must be profiled. All of this must then be translated into functional requirements for equipment. What must it do? How fast must it do it? How long must it last? What quantities will be sold? What must it sell for? What must the production cost be?

Engineers then take these functional requirements and translate them into functional specs for a machine where a specific engine transmission, axle, or torque converter are called out. The idea is to meet the functional requirements while designing a machine that offers low production cost, excellent durability, availability, productivity and low operating cost. Engineers have the opportunity to be very creative and must use all of the tools at their disposal.

This presents an all encompassing view of forest mechanization in a nutshell. If one thing is taken from this paper it should be a heightened awareness of the need for profitability and the increasing challenge of remaining profitable in a much more competitive environment.

DESIGN FEATURES OF A TWO-LOADLINE CHRISTY CARRIAGE[1/]

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Abstract - A two-loadline, cable logging carriage has been invented (Patent No. 4,500,004). The principal advantage of the carriage is expected to be the ability to yard higher average logs per turn. Christy manufacturing has built a proof of the concept prototype for testing by the Northeastern Forest Experiment Station. This paper describes the expected advantages, operating principles, and the design features of the two-loadline carriage, and current status of the testing program.

Introduction

Cable yarding is slowly increasing in Appalachia, as more machines are introduced into the area to harvest timber from the steep Appalachian slopes. From past studies on cable yarding systems, it has been determined that most are only loaded to about 40 percent capacity, because the average logs per turn is too low.

One way to increase the average logs per turn is to use two-loadlines. The purpose of this paper is to describe the benefits, operating principles, and the design features of a two-loadline carriage (TLLC) that has been invented.

Potential Advantages of Two-Loadline Carriage

- Applicable in clearcuts and partial cuts.

- Covers a wider area per turn, making it easier for chokersetters to hook a capacity turn when logs are scattered over a wide area.

- Reduces hooking time as well as increasing average volume per turn because both sides of the skyline corridor can be worked at the same time by using two men.

- Reduces cable rubs on residual trees along the skyline path because two loadlines should keep carriage centered better in the skyline corridor.

- Increases production by increasing the average volume per turn.

- Increases choker capacity; thus when harvesting small stems (pulpwood), it would be easier to hook a capacity load on the carriage.

1/ Presented at the 10th Annual Council on Forest Engineering meeting, Syracuse, NY, August 3-6, 1987.

The Two-loadline Christy Carriage (TLLC)

The concept of the two-loadline carriage and multiple-loadline carriage has been patented. Patent rights have been assigned to the U.S. Department of Agriculture by coinventors Peters, Biller, and Johnson. Nonexclusive rights to build the TLLC may be obtained from the U.S. Department of Agriculture for a nominal fee. The patent number is 4,500,004.

The first step in making the proposed carriage practical was to design and fabricate a proof of concept prototype. The Northeastern Forest Experiment Station contracted with Christy Manufacturing of Orofino, Idaho, to build the two-loadline Christy carriage (TLLC). Christy carriages with a single loadline are relatively inexpensive, and they are used with most cable yarding systems in Appalachia because they are reliable and have very few moving parts to wear out. Performance goals of the two-loadline carriage were that the carriage would:

- Operate on conventional yarders without modifications to the yarder except for a wide throat sheave on the tower for the mainline shackle to pass.

- Allow two loadlines to pass through the carriage for attachment of chokers to each line.

- Hold each of the two loadlines on the travel loaded and travel empty element of the cycle.

- Use conventional Christy carriage stop.

- Use conventional Christy parts in the carriage where possible.

Operating Principles and Design Features of the TLLC

The carriage needs at least two winch drums on the yarder to operate. One winch drum is needed for the skyline cable that is suspended between the tower and tail tree. The carriage will move down the skyline cable by gravity, and it is pulled up the skyline with the other winch drum and the mainline cable. The two loadlines are attached to the end of the mainline cable by a swivel and shackle arrangement. These two-loadlines pass through the bottom of the carriage on sheaves that rotate to the direction of pull on the cable. A subscale model has been constructed of wood and Plexiglas to demonstrate the operating principles and design features of the TLLC.

The carriage returns to the hooking area by gravity (Fig. 1), hits a movable carriage stop attached to the skyline cable, turning a notched wheel in the center of the carriage upward, which simultaneouly releases the loadlines and holds the carriage to the stop (Fig. 2). Note the location of the locking balls. The notched wheel in the center of the carriage is the heart of the TLLC, and it is basically the same design as all Christy carriages. The loadlines are pulled out to the logs by the chokersetters and attached to the logs. The two loadlines move across sheaves that can rotate to the side for better alinement with the load (Fig. 3). Upon a signal from the choker- setters, the yarder operator will winch in the logs. As the log turn is brought up to the carriage, a ball, the one on the right, on one loadline will pass under the notched wheel (Fig. 4). As the second ball on the other loadline approaches the notched wheel, it reverses the direction of the notched wheel, moving it downward, which simultaneously releases the carriage (Fig. 5). The carriage and load secured to the carriage are pulled up the skyline by the mainline (Fig 6). Note the locking balls secured in the notched wheel. When the logs have reached the landing, the skyline is slackened, and the logs are lowered to the ground for unhooking. The skyline is then raised and the cycle repeated.

Current Status of Testing Program

Functional tests have been performed on the TLLC to determine if loadlines and the carriage function as designed. The TLLC was operated without loads and the locking mechanism operated as expected. The next step is to test the carriage under actual logging conditions.

The factors that need to be studied are:

- How much twisting and tangling of the two loadlines will be generated? Will this twisting hinder the operation of the carriage?

- There will be a man working on each side of the skyline, thus safety will be a major consideration. Both chokersetters will need to communicate with each other so both are in safe positions before the mainline is tightened to pull in the logs.

- There may be a problem with two sets of chokers twisting together when dropping to the ground; how much problem will this cause for the chokersetters?

- What yarder modifications are needed to accommodate the TLLC to accept the swivel and shackle where the two loadlines are fastened to the mainline?

Testing will reveal problems in the operation of the TLLC. After the problems are corrected, a set of general practices and operation procedures will be developed. With general practices and operational procedures tried and proven, the carriage can be used in production studies to determine the production capability of the two-loadline yarding system.

Comparative studies of two-loadline yarding systems with one-loadline yarding systems are also of interest. Functional tests of the TLLC under load were done in July 1987. Preliminary results of these tests were orally presented at the 10th Annual Council on Forest Engineering Meeting.

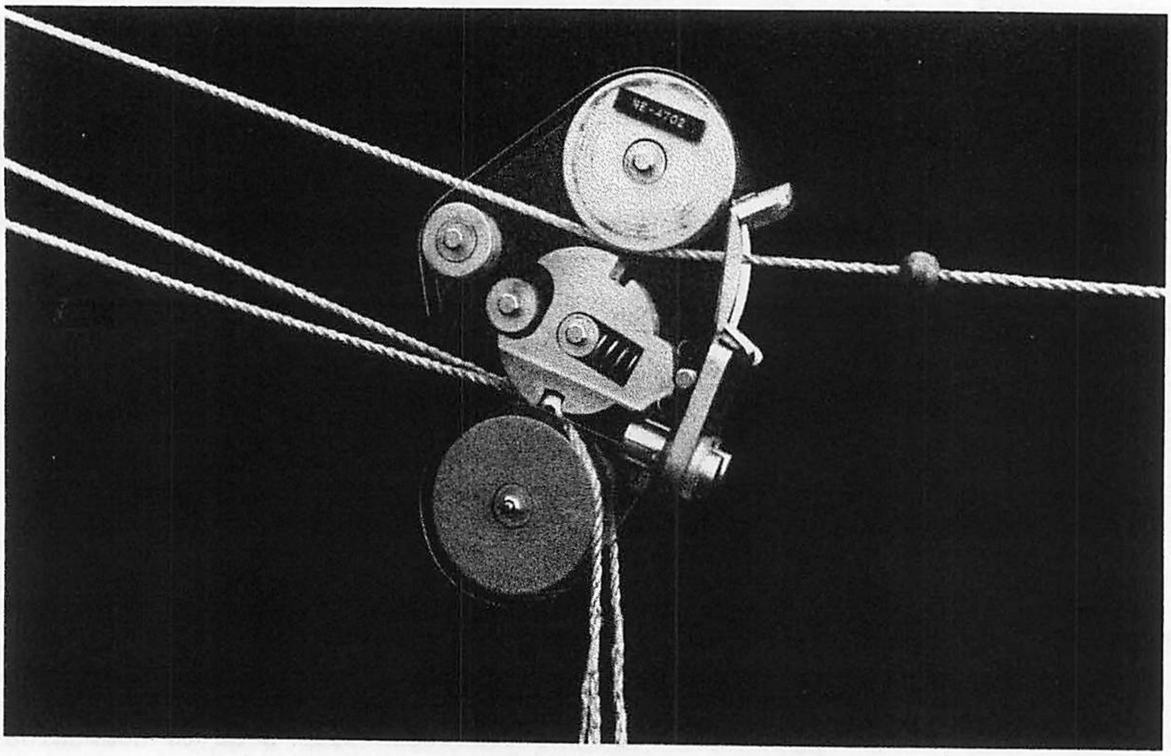

Figure 1.--Carriage returns to hooking area by gravity.

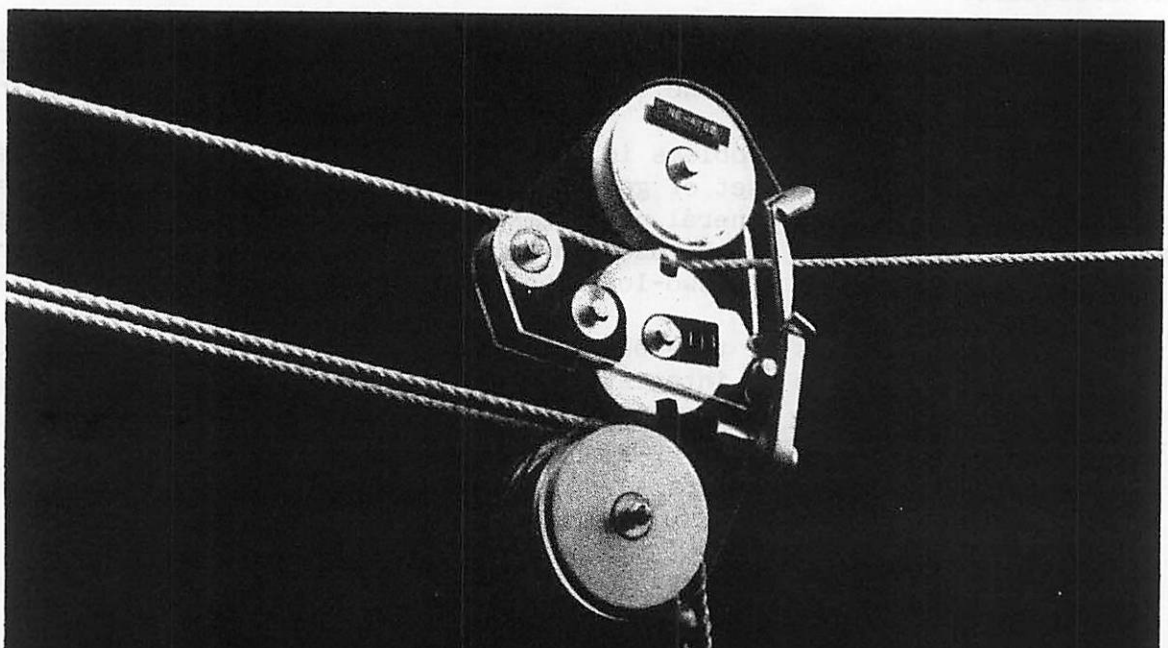

Figure 2.--Carriage engages the stop and the two loadlines move off the lower sheaves.

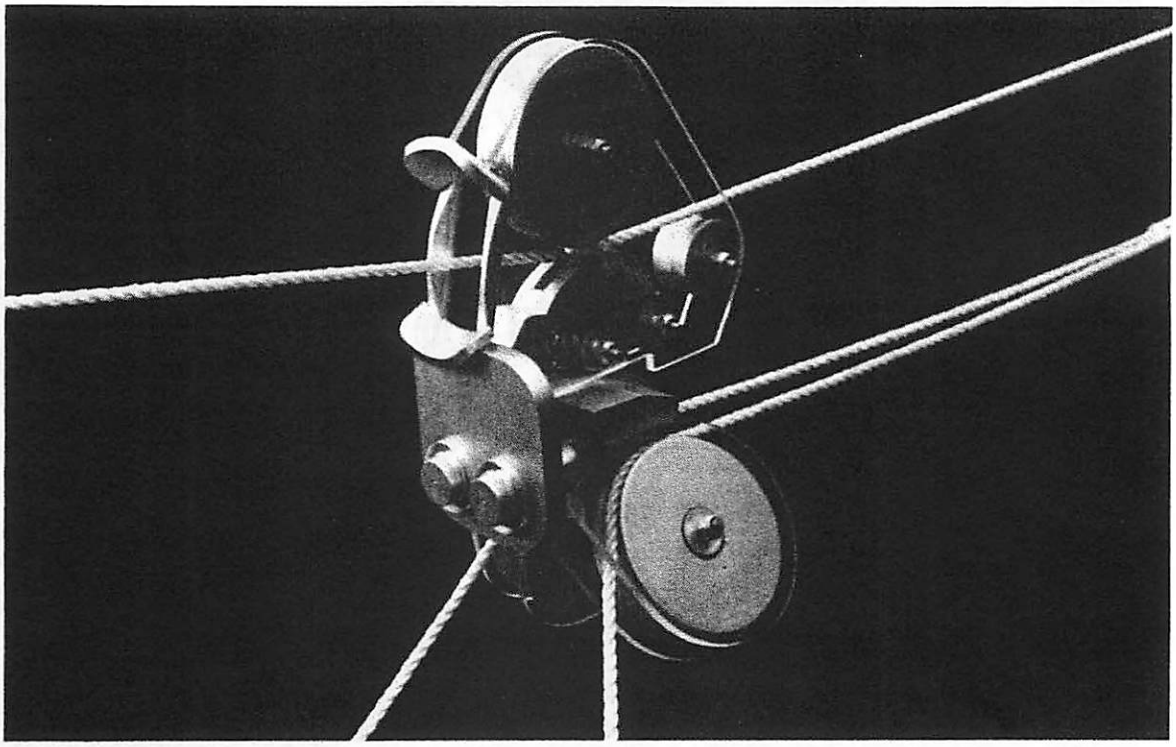

Figure 3.--The two loadline sheaves swivel to allow better alinement with load.

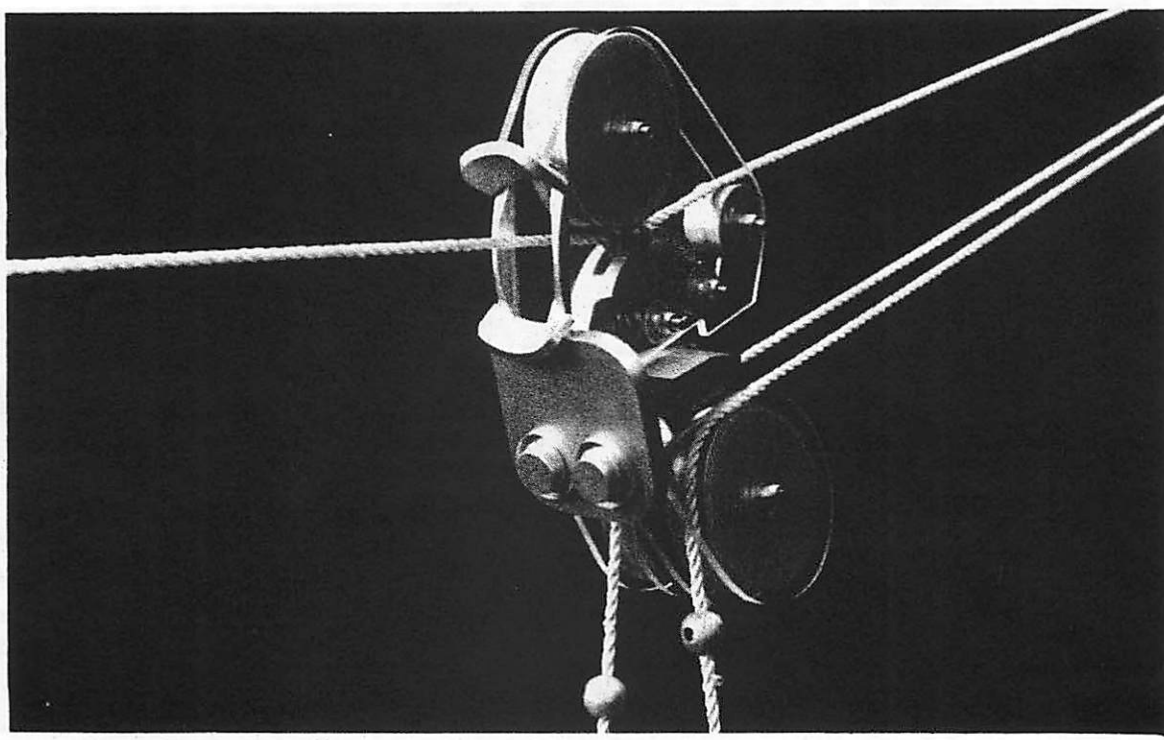

Figure 4.--The locking balls are being pulled towards the carriage. The ball on the right moves past the lock first.

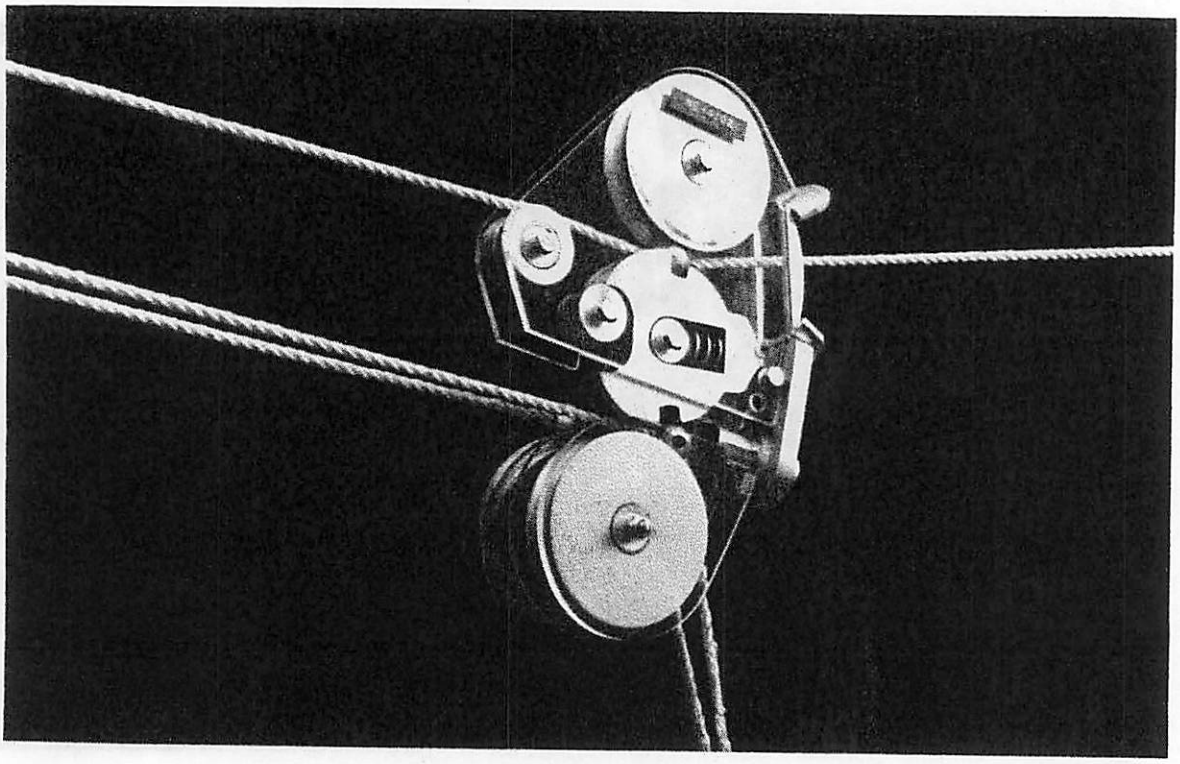

Figure 5.--Both lines are locked onto the carriage.

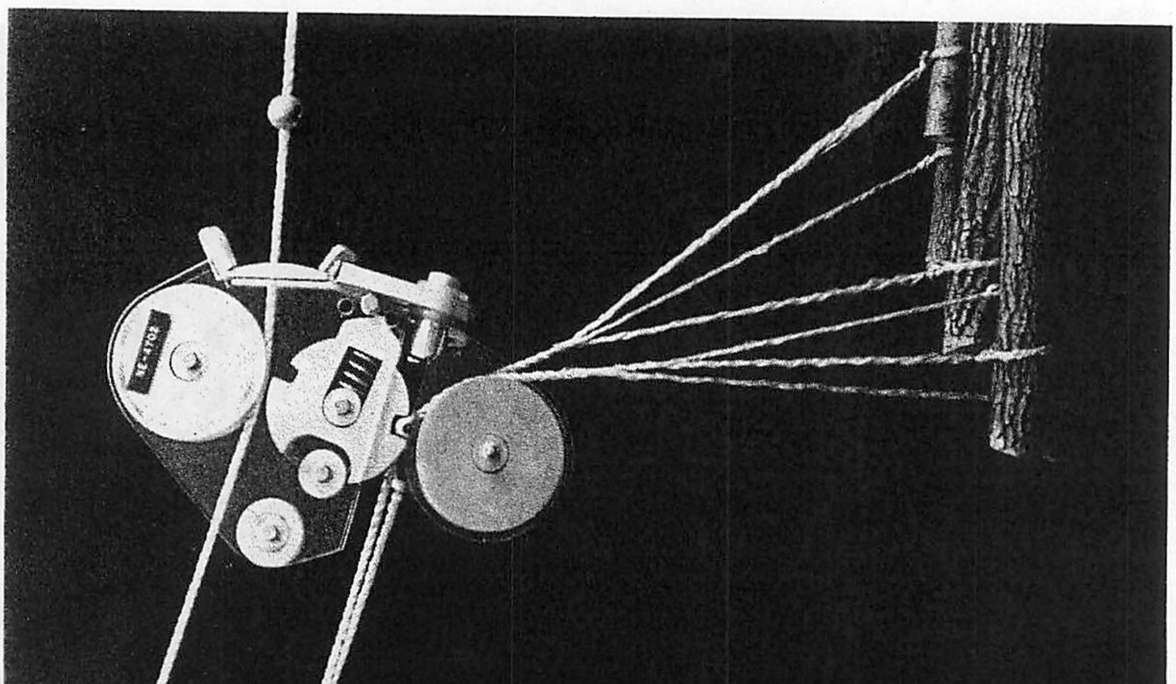

Figure 6.--The carriage moving uphill with a load of logs.

AN INSTRUMENTATION SYSTEM FOR MONITORING SKYLINE LOADS

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Skyline yarders are expensive logging machines which depend on the forces generated in a number of wire rope lines in order to operate. The actual force in any particular line is almost always unknown even though the efficiency of the yarder is dependent on optimum line loading and the safety of the machine and crew is dependent on not overloading a line to the degree that it will fail. The significance of this issue is punctuated by the fact that in northern California alone, during a three month period in the fall of 1985, at least four yarders overturned for reasons related to guyline loading.

Most previous attempts to monitor yarder loads have concentrated on approximating the load in the skyline itself. A few yarders are equipped with skyline tension meters, but it is very unusual to find one in working condition. There are several reasons for this. The systems have been relatively expensive, but a more serious problem has been their reliability. They have been plagued by maintenance problems, particularly related to the integrety of signal wires running along the yarder. Also, it has recently been shown (Hartsough, 1985 and 1987) that there are a number of individual machine characteristics which may well be more important to development of maximum load than skyline strength, and that many machines have the capability of significantly overloading their lines.

The work described here concentrates on monitoring the guyline loading. It is the failure of a guyline or anchor which most commonly causes a yarder to overturn. It is also quite possible to overload a guyline without overloading the skyline. Guyline dynamic characteristics were predicted by Xu (1986), and now the low cost availability of portable computers and dataloggers makes it feasible to use computer technology to continuously monitor the loads in a number of lines and warn the operator of unsafe or changing conditions.

Partial support for this study was provided by the Center for Wood Utilization Research, Department of Forest Engineering, Oregon State University.

The first part of this problem is designing a system for sensing the guyline load. The severe environment on the yarder dictates that the measurement devices should not be located on the machine. Guylines are almost always segmented with a variable length segment attached to the yarder and a number of fixed length extensions which are used to reach any particular anchor. The most logical place for a measurement device seemed to be at an interface between two segments. Figure 1 shows a typical "double ender" (or "D") which is used to join segments together.

A search for a commercial loadcell which was also economical and well suited for this task was not successful. Loadcells which would measure the desired loads were expensive, heavy and required substantial modification in order to adapt them for use on existing guyline systems. Past experience also indicated that yarder operators are very hesitant to allow the addition of any new or unknown component to their systems which could possibly fail. Since the operators have little or no experience with loadcells, concern regarding the possibility that a loadcell might be a weak link in the guyline system has been frequently expressed.

For these reasons the it was decided to attempt to use a standard "D" as the basic element in a loadcell. A smooth surface, approximately one square inch in area, was milled on each side of the casting. Two orthogonal strain gages (Micro-Measurements 350 ohm gages) were bonded on each side of the "D" and were wired together to form a temperature compensating full bridge loadcell (Dally, 1965) as shown in Figure 2. A moisture seal (Micro-Measurements polysulfide M-coat, JL-1) was applied over the strain gages and connecting wires and an aluminum shield was bonded over the bridge and connecting wires to provide mechanical protection for the strain gage system (Figure 3).

The instrumented "D" was then placed in a Tineus-Olsen tension testing machine and the output of the bridge was compared to the applied load. This was done for five separate "D's" and in each case a linear equation was found to fit the data with a correlation coefficient of 0.99 or greater. Because of slight differences between the "D's", each one was represented by a slightly different linear equation.

A Campbell Scientific CR10 datalogger was selected to "manage" the loadcells. The CR10 provides power for each bridge, measures each bridge output, applies calibration equations and stores data for four separate loadcells, sampling each loadcell eight times per second. It can also be programmed to sample a single loadcell 64 times per second. With 64k of RAM, the datalogger will store about 30000 data points. This is slightly less than eight minutes of data recorded at the 64 samples per second.

There are two methods for transferring the data from the datalogger to a larger storage device. In most cases, the CR10 was hardwired to a Data General One, Model 2, battery powered computer. In this mode the loads in each line could also be continuously displayed on the computer screen, whether or not data was being recorded. Recorded data could be transferred to the hard disk on the computer at 9600 baud. The system also contained a radio link which allowed the computer to communicate with the datalogger. The radio link limited the communication speed to 1200 baud and only recorded data could be displayed on the computer screen.

This system has been used to collect data on four different running skyline yarder operations. Figure 4 shows the loadcell location on the guylines. The loadcells have been covered with a length of six inch diameter PVC pipe (Figure 5) to provide mechanical protection and to insulate the loadcell from direct sunlight. (The full bridge loadcell design, with two strain gages aligned with the applied load, and two strain gages perpendicular to the load will self-compensate for changing temperature as long as the whole loadcell is at the same temperature (Dally,1965). Figure 6 shows the CR10 datalogger and the Data General computer in use.

Figure 7 shows a typical plot of guyline tensions during part of an inhaul cycle with data recorded at the rate of eight samples per second from each guyline. The variation of the load between guylines is extremely common and any one of the guylines could carry the maximum or minimum load depending on the setting geometry and the pretensioning of the guylines. Figure 8 shows the variation in the tension in a single guyline when the tension was sampled 64 times per second. This type of data has been collected for each guyline of each of the four yarders which have been monitored. Two vibration frequencies are apparent. The primary vibration frequency is about 1 hz and a second frequency is apparent at about 5 hz. No evidence has been found to indicate loadings at frequencies higher than about 5 hz.

While a detailed data analysis has not been completed, a number of observations are pertinate. Each of the yarders observed used three guylines which should ideally share the load applied by the working lines. In every case, the load measurements have shown that under normal operating conditions (no feedback to the operator about his actual line loadings) one guyline will have a tension of at least three times the load in the least loaded line. There is no consistent trend as to which line will have the maximum load unless one line is substantially shorter than the others. In this case, the shortest line will almost always carry the maximum load. Only one setting was observed where the guylines were loaded above the safe working strength of the wire rope, and in this case, reducing the pretension in the shortest guyline reduced the maximum tension from over one half the breaking strength of the wire rope to one third of the breaking strength, without causing the other guylines to exceed their safe working loads. While one example will not support a statistical argument, the observed disparity in guyline loadings leads to the belief that when overloadings do occur, they are probably concentrated in one particular guyline, and could be eliminated by adjusting the pretension in the guylines.

On each operation, the yarder operator was asked if they could identify which of the guylines carried the most tension. Initially, none of the operators could correctly answer the question. After obtaining feedback on their actual loads, they were able to rate their line tensions from highest to lowest if there were substantial differences between loadings.

The load monitoring system described above has proved to be an inexpensive and reliable research tool for determining dynamic loads in various yarder lines. It is light weight and does not require modification of the normal yarder configuration. It serves as an excellent research or training tool. It may also be the basis of an operational tool. It is the authors opinion, however, that a load monitoring system will not be an acceptable operational tool until all signal wires are eliminated.

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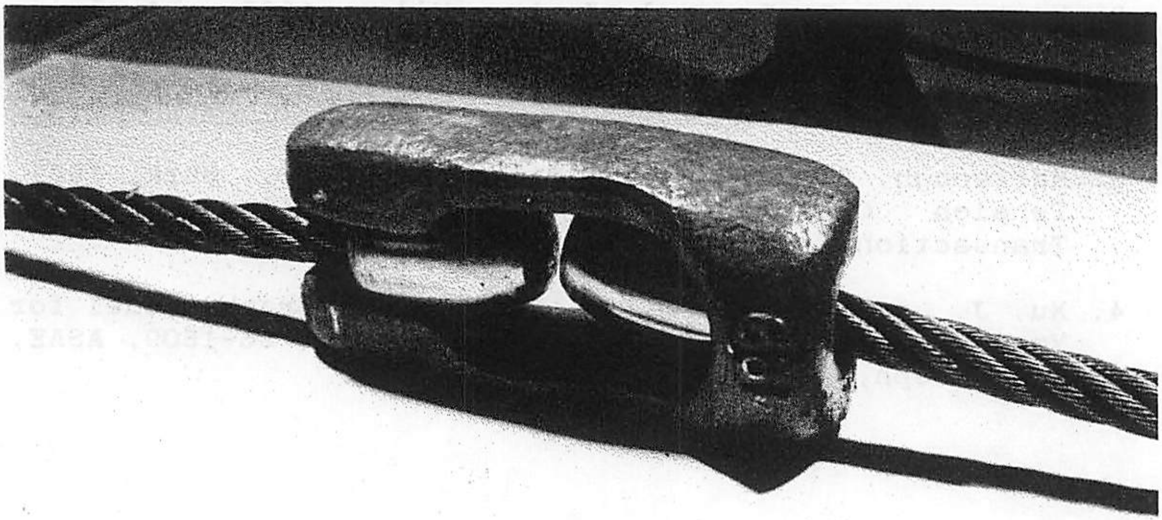

Figure 1. A "D" connector used to join guyline segments.

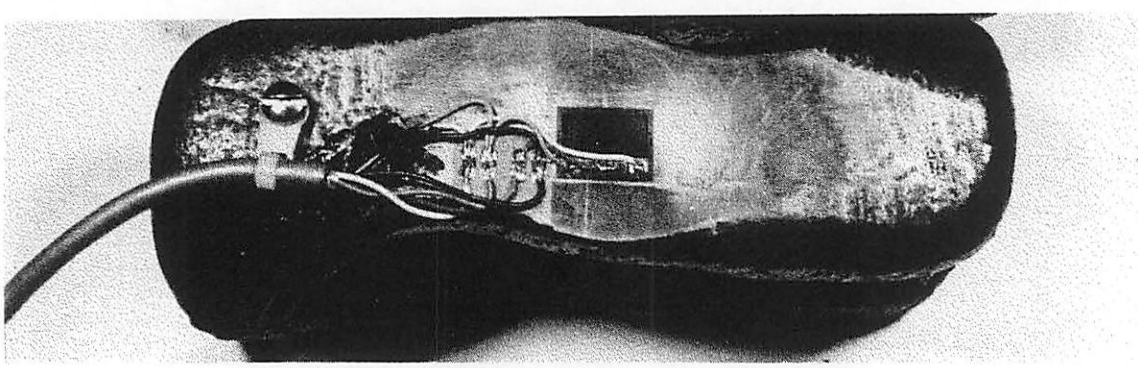

Figure 2. Strain gages mounted on one side of a "D" connector.

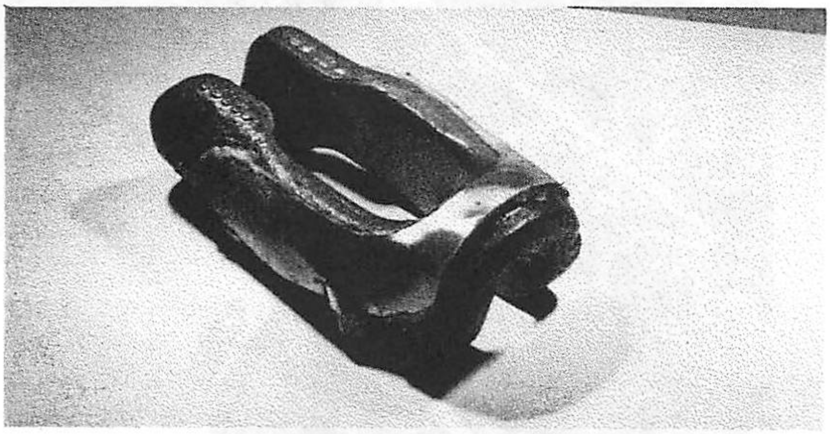

Figure 3. An aluminum shield bonded over the strain gages and wires

Figure 4. The location of the loadcells on the guylines is shown by the dark circles.

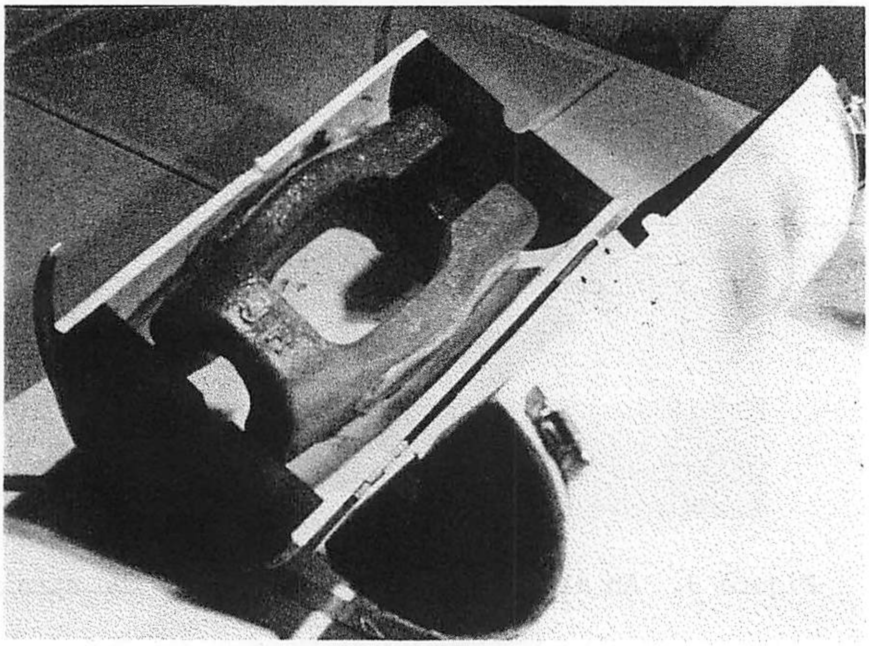

Figure 5. A "D" enclosed in a hinged PVC protective cover

Figure 6. The CR10 and Data General One at use monitoring guyline loads.

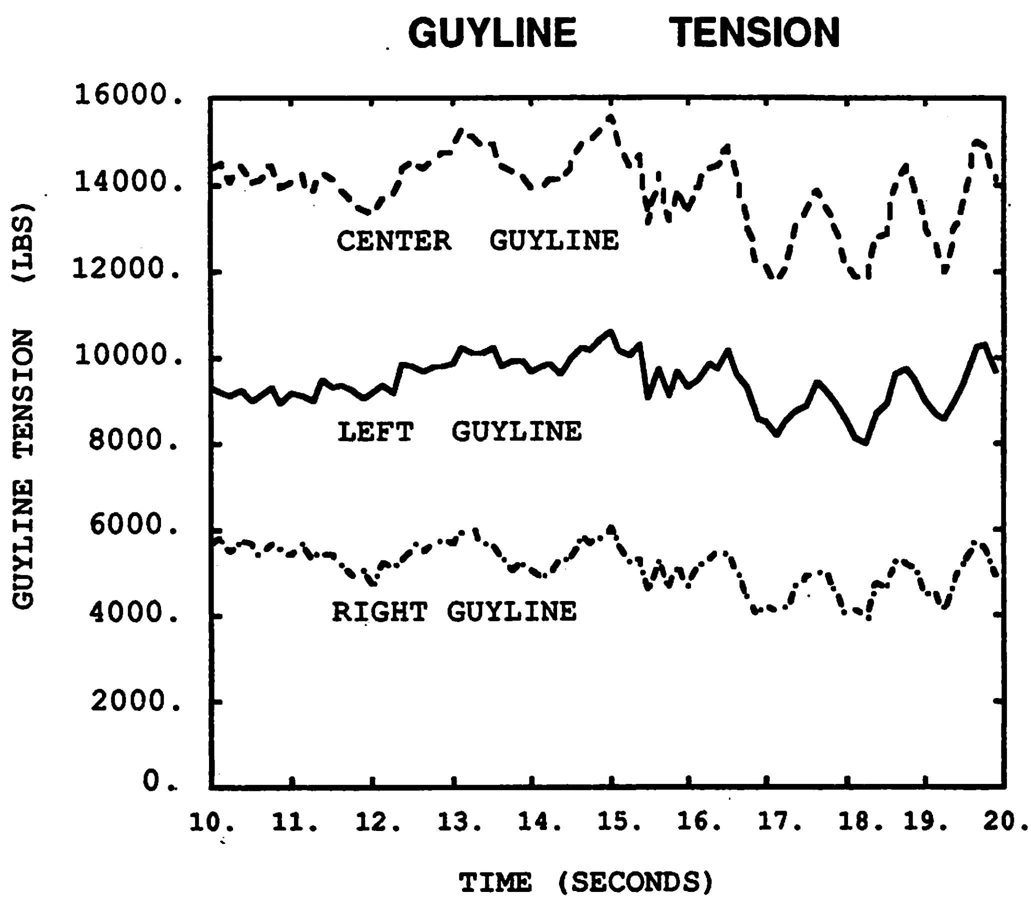

Figure 7. A plot of three guyline tensions during part of a typical inhaul cycle.

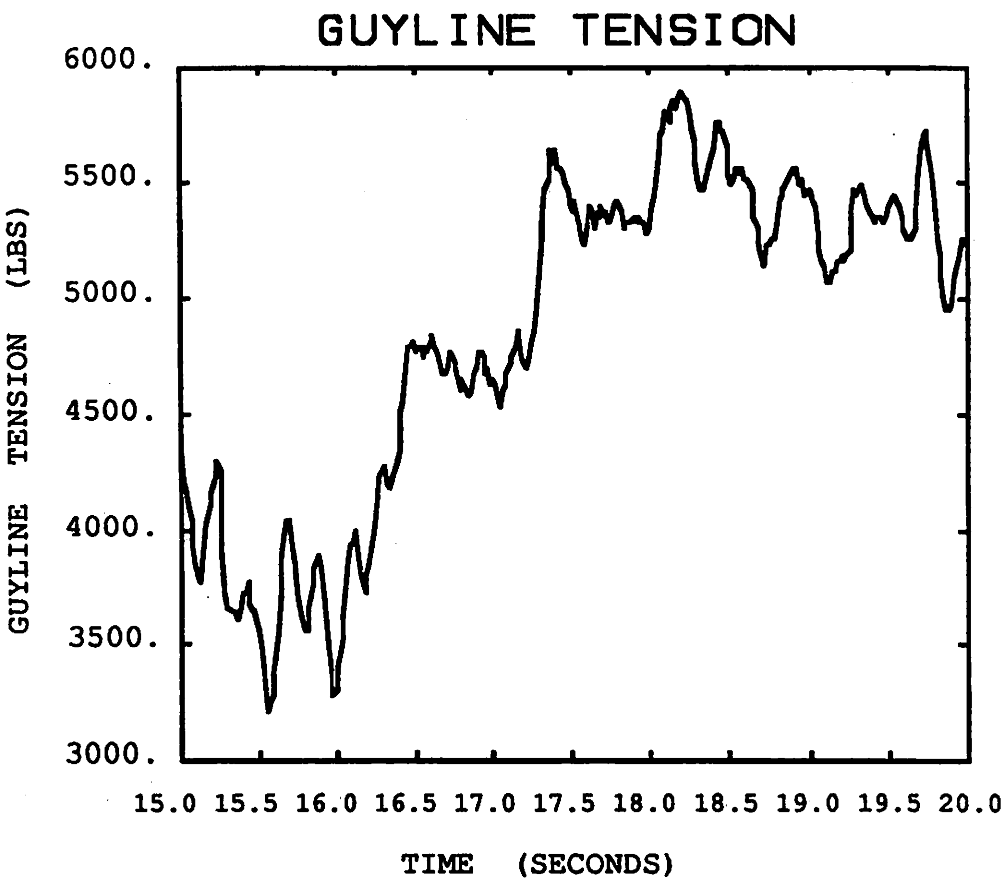

Figure 8. A high speed (64) samples per second) plot of data from a single guyline during part of an inhaul cycle.

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