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IMPROVING PRODUCTIVITY THROUGH FOREST ENGINEERING

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Edited by Robert Tufts

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Report from the West[1]

John J. Garland, P.E.[2]

The forestry sector in the western United States is emerging from the "depression" of the early 1980's with a changed industry structure. Several of the changes in the timber harvesting industry are identified here for review by members of the Council on Forest Engineering (COFE).

The last two years of timber harvests have reached record or near record levels. Not all firms have seen acceptable profit levels return, and mill closures and cost cutting continues. Some union mills have been sold and re-opened under non-union management. A number of companies have phased out corporate logging operations.

Mill employment has declined even with high volumes processed, but logging employment has returned to levels commensurate with harvest levels. A large amount of timber from the U.S. Forest Service will be sold as timber buyback and default volumes will again be put up for bid.

The timber size continues to decline to eventually hit diameters in the mid-teens; however, much of the current harvest volume is in excess of 30 inches. Most harvesting is clear cut operations with few thinning operations until log prices rise a bit further. Hundreds of thousands of acres in the interior or west are affected by insect attacks.

Roads still dominate harvesting operations in steep terrain both from economic and environmental perspectives. Regulatory pressures continue to add more requirements to harvesting operations.

Felling operations are changing to reflect the high costs of cutting small timber with chainsaws. More feller-bunchers are being used with some new machines capable of operating on slopes in excess of 60 percent.

Skidding operations are becoming forwarding operations of whole trees in some areas. Designated skid trails are being used to minimize soil compaction impacts and to extend the harvest season. Wide skidder tires are allowing wheeled machines on steeper slopes. Grapple skidding machines are quite common.

Yarding operations use mostly medium to large yarders with a few small machines in use. Long yarding distances and remaining big timber favor bigger machines. The number of yarder manufacturers has declined.

Flying logs is extremely rare with few balloon or helicopter shows in operation. The flight disaster of the Heli-stat will leave its future in the hands of the courts. The Cyclo-Crane is still in development on the Oregon Coast.

More processing at the landing is occurring and delimbers, debarkers, chippers and log processors are used for small timber. Several chain-flail machines are being tested for delimbing/debarking for clean chip production. Larger logs are still bucked in the woods with some saw work needed at the landing.

Trucking is primarily log length hauling, but steep road grades (20-25 percent) are making for some interesting operations. Low tire-pressures controlled through central tire inflation devices may have important impacts on future road decisions.

The logging labor force has materially changed as the industry restructuring continues. Many skilled workers took early retirement and other skilled workers left the logging industry. Well-trained workers experienced in logging are currently hard to find. Training in logging is a hit or miss proposition even though safety codes require training in logging.

Safety performance is worse than before the depression. Insurance rates vary by state from as low as $18 to over $38 per hundred dollars of payroll.

Wage rollbacks were common during union negotiations with base wages dropping $3-$4 dollars per hour. Incentive systems have been used to improve productivity and maintain worker pay levels. Strikes occurred but were settled for the next two years or so. Union membership declined with more independent contractors entering the logging business.

The near future in harvesting could be dominated by political and institutional issues in the west. Debate over U.S. Forest Service plans calling for 20-40 percent reductions in harvest levels will move from the public comment arena quickly to the U.S. court system.

In the Pacific Northwest Region of the U.S. Forest Service, plans to set aside 2,200 acres of old-growth timber for each pair of spotted owls are hot newspaper topics. Other real or perceived conflicts of harvesting with wildlife, fisheries, or recreation deal out charges of mismanagement to environmental ignorance. Tree-sitters and spikes are new wrinkles for western loggers.

In spite of the problems ahead for harvesting in west, the economic recovery of the industry is welcome to timber dependent communities. Research and development continues to improve the productivity of western timberlands and processing industries. The logging industry has always risen to the challenges facing it, but now the challenges come from the courts, special interest groups, and agency managers. Exciting times lie ahead for western loggers and forest engineers.

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Lake States Forest Resources
and Industrial Expansion:
A Regional Report[1]

John A. Sturos[2]

Abstract: The Lake States economy has recently been expanded by more than $2.5 billion investment by the forest products industry. More than 6,000 jobs have been created by the building of new plants and expansions of others. Some of the reasons for this are the abundant and relatively low-cost timber resources, the proximity to markets, and the support of State and local governments.

Keywords: forest products, utilization, economics, industrial expansion, hardwoods, employment

This is an exciting time for forestry in the Lake States of Michigan, Wisconsin, and Minnesota. Forest industry is expanding, and much capital is being invested. Some of the reasons for this increased activity are: the region has an expanding resource base, principally hardwoods; timber prices are low compared to those in other major forested regions of the United States; and the area is close to the large market centers of the Midwest, unlike the historical sources of finished forest products--the Pacific Northwest, the Southern States, and Canada. Finally, the political climate is good for obtaining the support of State and local governments. The steel, heavy machinery, and automotive industries that once dominated the region's economy have recently shrunk in importance. Major programs have begun in all of the Lake States to develop and diversify the regional economy, led by the Great Lakes Governors Association. Forest resources and industries are an important part of these efforts (Webster 1986).

Lake States forests have contributed much in the past to the region's development and well-being. Now, as the forests continue to rebound from the cutover and burned conditions of the early 1900's, they are more important than ever before.

FOREST RESOURCES

Forty percent of the Lake States commercial forest is publicly owned, much of it by States, counties, and municipalities (table 1) (Spencer 1985). The 6.8 million acres of State-owned commercial forest in the Lake States represents 29 percent of the Nation's total in that owner class, and the 4.7 million acres of county and municipal forest is 69 percent of the U.S. total. Michigan leads the Lake States in commercial forest area (table 1).

Table 1--Area of commercial forest land in the Lake States by ownership class - 1983.

Ownership class	Total	Michigan	Minnesota	Wisconsin
		Million acres		
Federal	5.8	2.5	1.9	1.4
Indian	0.8	-	0.5	0.3
State	6.8	3.6	2.6	0.6
County and municipal	4.7	0.2	2.3	2.2
Forest industry	4.0	2.0	0.8	1.2
Farmer	10.0	3.1	3.4	3.5
Miscellaneous private	13.9	6.1	2.2	5.6
TOTALS	46.0	17.5	13.7	14.8

The Lake States is the only region in the U.S. where sawtimber stands do not predominate. But the forests continue to rebuild and mature. Poletimber stands account for 46 percent of the commercial forest land, more than any other stand-size class (table 2). Wisconsin has a larger percentage of sawtimber stands (32 percent) than either Michigan (29 percent) or Minnesota (23 percent).

Table 2--Area of commercial forest land in the Lake States by stand-size class - 1983.

Stand-size class	Total	Michigan	Minnesota	Wisconsin
		Million acres		
Sawtimber	12.9	5.1	3.1	4.7
Poletimber	21.0	7.8	7.0	6.2
Saplings and seedlings	11.5	4.4	3.4	3.7
Nonstocked	0.6	0.2	0.2	0.2
TOTALS	46.0	17.5	13.7	14.8

The growing-stock volume in the Lake States increased 84 percent between 1952 and 1983--faster than any other region in the country (Spencer 1985). Softwood volume rose from 6.7 to 12.5 billion cubic feet during the period. This represents only 3 percent of the Nation's softwood volume, but this proportion has grown from 2 percent in 1952. Hardwood volume increased from 18.3 to 33.6 billion cubic feet. This equals 13 percent of the total U.S. hardwood volume, which is up from 10 percent in 1952. Aspen is the dominant species, with 8.6 billion cubic feet--almost double the volume of its closest competitor, hard maple, with 4.4 billion cubic feet.

Recent forest surveys of the Lake States indicate that growth is double the harvest (Spencer 1985). Since 1962, growth has increased 14 percent, and removals have increased 58 percent. In 1982, growth equaled 1,518 million cubic feet; removals equaled 753 million cubic feet. The largest share of timber removals from growing stock in the region came from pulpwood (table 3), in contrast to the national picture where the largest share came from sawlogs.

Even though pulpwood dominates the harvesting scene, the three Lake States have large quantities of export-quality hardwood sawlogs. Compared to the

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eastern United States, Michigan and Wisconsin are much above the average in the amount of select export species (Araman 1986). Minnesota is below the average. Even though Michigan and Wisconsin have timber to export, hard maple, the region's most abundant exportable species, needs to be actively promoted.

Table 3--Timber removals from growing stock by item in the Lake States - 1982.

Item	Total	Michigan	Minnesota	Wisconsin
		Million cubic feet		
Pulpwood	333.5	104.6	89.9	139.0
Sawlogs	200.7	93.8	27.5	79.4
Veneer logs and bolts	9.2	4.8	0.4	4.0
Fuelwood	37.9	8.4	9.1	20.4
Miscellaneous industrial products	23.9	11.4	8.1	4.4
Logging residue	38.3	16.8	5.1	16.4
Other removals	109.7	34.8	53.5	21.4
TOTALS	753.2	274.6	193.6	285.0

FOREST INDUSTRY: MICHIGAN

Most of the recent forest products industry expansion in the Lake States has been in Michigan. Between 1983 and 1986, more than $1 billion of capital has been invested in forest products-related plant expansions or new plants that have created more than 2,200 jobs (table 4). The largest investment has been the $500 million Champion International pulp mill at Quinnesec near Iron Mountain in the center of Michigan's Upper Peninsula. It was completed in December 1985. The mill, designed to produce 850 tons per day of bleached hardwood market pulp, uses 450,000 cords of pulpwood per year (405,000 cords of shortwood and 45,000 cords of chips). The species mix is about 27 percent birch and 73 percent other hardwoods. It also uses 55,000 cords per year of energy wood (15,000 cords of hog fuel and 40,000 cords of whole-tree chips). The mill employs 320 people and has generated another 450 woods-related jobs. Fifty percent of the bleached hardwood market pulp is sold domestically, 25 percent is exported to Europe and Japan, and the remaining 25 percent is used internally in Champion International mills. A $200 million paper machine will be added in the near future.

The Mead Corporation recently completed a $370 million expansion at its pulp and paper mill in Escanaba, making it Michigan's largest forest products complex. It includes a new paper machine and other pulp mill modernization. Coated paper production was increased by almost 50 percent, and 200 new mill jobs were created by the expansion. Current pulp production is 1,400 tons per day. The expansion created an annual market for an additional 100,000 cords of aspen and 500,000 tons (167,000 cords) of energy wood. This created an additional 75 woods jobs. Annual usage now totals 700,000 cords of pulpwood. The corporation is now studying the feasibility of adding another paper machine in the near future.

Weyerhaeuser Company's first large investment in Michigan has been especially exciting. An $85 million oriented strand board (OSB) plant recently completed near Grayling (in the center of the northern Lower Peninsula) will use 240,000 cords of wood per year to produce 300 million square feet of OSB. It generated 160 mill jobs and another 150 woods jobs. The species mix is 65 percent aspen, 20 percent jack pine, and 15 percent soft maple.

Louisiana-Pacific Corporation has also made its first large investment in a fiber processing plant in Michigan. In the fall of 1985, a $19 million medium density fiberboard (MDF) plant that employs 130 people was completed at Newberry in the eastern part of the Upper Peninsula. This plant created a market for 75,000 cords per year of the dense hardwoods that are abundant in the area. However, the plant will take up to 10 percent aspen.

In addition to the new MDF plant, Louisiana-Pacific broke ground in July for a $30 million waferboard plant just north of Iron Mountain in the Upper Peninsula. It is scheduled to be completed in December 1987. The plant is designed to use 200,000 cords of wood per year (mostly aspen and also some basswood and other low-density hardwoods) to produce 260 million square feet of waferboard (3/8-inch basis). It will employ about 135 people.

Table 4--State-assisted forest products plant expansions in Michigan, 1983 - 1986.

Company	Product	Approximate investment	New jobs
		Dollars	
Biewer Sawmill	Architectural timbers	5,000,000	50
Champion International, Inc.	Hardwood market pulp	500,000,000	320
Hill Forest Products, Inc.	Pallets, crates, boxes	5,250,000	115
Louisiana-Pacific Corporation	Medium density fiberboard	19,000,000	130
Louisiana-Pacific Corporation	Waferboard	35,000,000	135
Manistique Papers, Inc.	Paper	13,900,000	200
Mead Corporation	Publishing paper	334,000,000	200
Menasha Corporation	Corrugated container medium	4,400,000	112
Steelcase, Inc.	Office furniture	40,000,000	500
Weyerhaeuser Company	Oriented strand board	85,000,000	160
Other	Lumber, furniture, etc.	5,816,000	319
	TOTALS	1,047,366,000	2,241

FOREST INDUSTRY: MINNESOTA

Since 1981, $890 million has been invested in Minnesota by the forest products industry, creating 1,155 jobs and using 1 million cords of wood each year (table 5). New developments include: three waferboard plants; two OSB plants; two new pulp mills; and a pulp mill expansion.

Minnesota is the U.S. leader in waferboard production. The first waferboard plant in the U.S. was built in 1972 by the Blandin Wood Products Company at Grand Rapids. Since 1980, four more plants have been built, primarily to take advantage of Minnesota's abundant aspen resource. These five waferboard plants collectively employ 700 people and annually consume more than 700,000 cords of aspen. They produce 40 percent of the waferboard and OSB manufactured in the U.S.

The following is a 1985 update on the size and use of Minnesota's aspen resource (Krantz 1986):

Resource	Cords
Allowable cut	1,963,000
Actual harvest	1,651,000
Net annual surplus	312,000
Backlog	6,652,000 (9 years)
Wood Use	
Export	81,000
Pulp and paper (Blandin, Boise Cascade, Potlatch, Champion, Hennepin)	450,000
Waferboard, OSB, hardboard (Blandin, Potlatch, Northwood, Superwood)	830,000
Other (lumber, veneer, energy chips)	290,000
Import	40,000

Minnesota's newest waferboard plant, built by Louisiana-Pacific Corporation at Two Harbors, was completed in 1983 at a cost of $16 million. It produces 75 million square feet (3/8-inch basis) each year, uses 60,000 cords of aspen, and employs 90 people.

A paper mill being built in Duluth is Minnesota's newest development in the forest products industry. It is owned by a new corporation, Lake Superior Paper Company, whose joint owners are Pentair, Inc. of St. Paul and Minnesota Power Company of Duluth. Construction began in 1986; the mill is scheduled to be operational in 1988, with an estimated total investment of $350 million. It will manufacture 236,000 tons per year of supercalendered paper, primarily for use as newspaper advertising supplements, using a mechanical pressurized groundwood pulp process. Annual wood usage is estimated to be 200,000 cords for paper and 90,000 cords of whole-tree birch chips for energy. The mix of pulpwood species will be 33 percent spruce and 67 percent balsam fir--good news for the State because these species are underutilized. Projected employment is 300 jobs at the mill and 300 jobs in the woods.

FOREST INDUSTRY: WISCONSIN

From 1980 to 1984, 193 new plants and expansions were completed in Wisconsin, equaling 14 percent of the State's total. The capital invested equaled $602 million that created 2,761 jobs in the forest products industry. These amounted to 27 percent and 12 percent of the State's total, respectively.

Wisconsin plays a major role in the Nation's forest products industry. It ranks first in paper making with 48 pulp and/or paper mills, third in value added by the manufacturers and capital spending, and fourth in annual payroll.

One recent noteworthy project is Louisiana-Pacific's waferboard plant expansion at Hayward, completed in 1984 at a cost of $19 million. The annual production was doubled to 320 million square feet (3/8-inch basis). The plant now uses 250,000 cords of aspen annually.

Ground was broken in January 1985 by Consolidated Papers, Inc. for a $215 million enamel paper machine expansion project at Biron. Scheduled to be completed in early 1987, it will increase the production of lightweight enamel printing paper by 512 tons per day or 180,000 tons per year. Annual pulpwood use will increase by 250,000 cords. The expansion will provide 125 new mill jobs and 165 in the woods.

Northern States Power Company (NSP) has begun an experimental whole-tree burning project at its subsidiary, the Lake Superior District Power Company plant at Ashland. The company has developed a new combustion process involving drying whole trees for 30 days under covered and controlled conditions

Table 5--Major forest products industrial expansion in Minnesota since 1981.

Company	Location	Type of development	Completion date	Investment	New jobs	Annual wood usage
				Dollars - in millions		Cords
Potlatch	Cloquet	Paper mill expansion	1981	100	-	30,000
Potlatch	Bemidji	OSB plant	1981	40	160	160,000
Northwood Panelboard	Bemidji	Waferboard plant	1982	45	160	200,000
Blandin Wood Products	Grand Rapids	Waferboard plant	1982	40	75	140,000
Champion International	Sartell	New paper mill	1982	250	225	60,000
Potlatch	Cook	OSB plant	1983	40	160	160,000
Louisiana-Pacific	Two Harbors	Waferboard plant	1985	25	75	60,000
Lake Superior Paper	Duluth	New paper mill	1988	350	300	200,000
			TOTALS	890	1,155	1,010,000

before burning them in 60-foot lengths. A furnace at Ashland has been converted to handle the long lengths for pilot testing. In 2 years NSP expects to know the feasibility of their new process. A 400-megawatt power plant that would use the new process is under consideration and may be built somewhere in the Lake States after 1990 at an estimated cost of $750 million. NSP plans to obtain fuelwood from three sources: natural stands; fast-growing hybrid tree plantations established, managed, and harvested by NSP on abandoned farmland; and farmers growing and harvesting hybrid trees as alternate crops.

SUMMARY

Forest industry has expanded in the Lake States because of the abundant and relatively low-cost resources, proximity to markets, and the support of State and local governmental bodies, among other reasons. Since 1980, more than 6,000 jobs have been created, and more than $2.5 billion has been invested. Production of various pulp and paper, composite, and solid wood products has greatly increased.

Dr. Henry Webster, Chief Forester of the Michigan Department of Natural Resources, summarized these developments accurately: "These activities all illustrate one very simple point. Forest resources are again a major part of the fundamental social and economic agenda of this region" (Webster 1986).

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A Northeastern Perspective On Graphics-Assisted Planning Systems[1]

Thomas J. Corcoran[2]

Abstract: The development of cartographic modeling techniques and their application to harvest scheduling in the spruce-fir forest of eastern North America is evaluated. The techniques permit the automatic combination of digital maps representing different thematic descriptions of an area into a single map representing a spatial model of a particular planning strategy. The techniques can be used to combine forest stand types relating to spruce-fir stocking and maturity with map layers relating to forest mortality, condition and protectability, in an effort to spacially model a continuum of harvest priorities.

In areas with high harvest priorities roads are needed to allow for the transportation of the timber. A forest road network location procedure was developed to optimize the location of a road system in areas not serviced by existing roads, constrained by a user-defined maximum service zone width. The procedure uses both the spatial and descriptive data bases of a map-based information system. Data transformation methodologies utilized by the procedure convert layered polygon map data into grid format, which is better adapted for spatial and computational analysis.

Keywords: computer graphics, harvesting, transport, optimization, decision-making.

Digital computers have become an integral part of forest planning over the last fifteen years. They are thoroughly incorporated into the forest inventory systems of virtually all major forest land management entities, and are widely used to model forest development. The past ten years have seen a rapidly increasing involvement of computers in the in-place aspect of forest inventory. The resulting association of inventory data with detailed map locations (typically forest stands) has generated an obvious next request: that digital maps be prepared which synthesize in-place data with forest management goals to develop geographically referenced strategic operating plans. This task represents the new frontier of computer use in the spruce-fir forests of eastern North America. It has strategic importance in a region where a spruce-fir fibre shortage has been forecast for the end of this century.

This forest, which is overbalanced by the mature and overmature age classes, must be sustained by judicious application of management techniques in order to maintain a continuous supply of spruce and fir as well as to build a well-balanced age distribution for the future. The tools of the forest manager are: 1) harvesting, both to salvage dead timber and to decrease the vulnerability of the forest to spruce budworm (Choristoneura fumiferana (Clem.)); 2) insecticide spraying to protect the budworm host species; and 3) intermediate treatments designed to accelerate growth and to control the species composition of the young stands which will comprise the forest of the future. A system has been developed to provide and apply computer methods which will assist in the development of an optimal long-term plan for allocation of these management tools.

A second area in which the use of computers is growing rapidly in northeastern United States and eastern Canada is the integration of transportation and road network analysis with the overall forest land management. It has been claimed that the most valuable real estate in many operational forests, on a per unit area basis, is 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.

A procedure has been developed to locate roads in forest areas not yet served by an existing road network, while minimizing construction cost. Each existing road serves a zone on both sides of the road, with a width directly related to the optimal yarding distance or defined by organizational policy. The goal is to create an equally-spaced, minimum-cost network throughout the forest ownership.

ESSENTIAL CONCEPTS OF THE MAP-BASED INFORMATION SYSTEM

The map-based information system (MBIS) utilizes a data base system which can be accessed interactively from digital maps. Maintenance of the data base and associated maps is done simultaneously through interactive editing processes on graphics workstations where the relevant maps are displayed. House (1979) describes the need for such a data base as a central store for information which can be accessed by various application programs such as timber cruise and continuous forest inventory processing. This thereby provides a centralized base for data on forest management activities. Such a data base can be accessed by query operations involving maps. This has potential for being a more user-friendly mode of data base access for forestry or other land management situations than conventional data base query languages.

HARVEST AND PROTECTION PLANNING SYSTEM CONCEPTS

To satisfy the methodology and goals of long-term planning in the spruce budworm epidemic, readily available information is essential and prominently includes up-to-date forest stand maps with an associated inventory. Three important inputs to the planning process may be identified.

As the first important input, forest stands are rated in terms of vulnerability to spruce budworm, based on their maturity and budworm host species density. As defined by MacLean (1980), the concept of vulnerability to budworm refers to the probability of tree mortality resulting from a given level of budworm attack. The basic

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hypothesis behind forest planning to reduce stand vulnerability is that vulnerability is host-density dependent, and that silvicultural treatments reducing host density also reduce forest vulnerability. In order of vulnerability, the principal budworm host species are balsam fir (Abies balsamea (L.) Mill.), white spruce (Picea rubens (Sarg.)), and black spruce (Picea mariana (Mill.) B.S.P.). Vulnerability of these host species is positively correlated with their density in a stand and their maturity. Highest vulnerability is thus generally associated with mature or overmature stands with a high proportion of fir. Of particular relevance is the recognition (Blum and MacLean, 1984) that vulnerability of individual spruce and fir trees increases when they are in a subordinate crown position relative to other host trees during a severe budworm outbreak, and the consequent importance in even-aged silvicultural systems of removing all residual overstory trees of spruce budworm host species to prevent larval dispersal to the regeneration. Forest stand maps, as sources of information about host species density and maturity, can be used to predict forest vulnerability. In attempts to extend the life of the mature forest, it is necessary to have a method for selecting the least vulnerable of the mature stands for the longest-term protection.

A second important input to the planning process is hazard rating, or condition. The rules regarding vulnerability are modified by the annual patterns of budworm feeding and the decline of tree vigor in proportion to degree of defoliation. Condition is commonly measured by an annual assessment of host stands where hazard is rated on the basis of current and previous year defoliation, tree vigor, and expected budworm abundance. This information can be used for short-term planning, as in deciding which portions of the forest are most in need of protection in a given year. The average tree vigor or stand condition component of the hazard rating is the most important long-term planning component, in that it can be used to modify the vulnerability rating of stands.

A final factor in the long-term planning process, protectability, relates to variables affecting crop protection spray operations. Protection is prohibitively expensive for small, isolated, and/or irregularly shaped units, and for areas of steep terrain. The manager must decide whether to include these areas in long-term protection, or target them for early harvest. To decrease the irregularity of protection areas, blocking of stands of similar vulnerability may be necessary. A second consideration is the higher cost of protecting forest areas which are in close proximity to water bodies, streams, or areas of human habitation. Methods appropriate for use in these areas are more expensive than those used in large, uninterrupted blocks of forest land.

PRINCIPLES OF COMBINATION OF FACTORS

The three long-term planning factors described above -- vulnerability, condition, and protectability -- have been combined in the planning process to arrive at a strategic harvest and protection plan (Boss and Corcoran, 1986). In order to create such a plan, the three factors, and others relevant to the policies under investigation, must be synthesized and ultimately presented in map form. Policies for different forest management concerns will differ, depending on fiber needs and broad strategies for dealing with predicted fiber shortages.

For example, one of the policy principles stated by Wright (1983) for a major pulp and paper firm, whose ownership (one million hectares) is the focus of an implementation described below, places emphasis on silvicultural improvement harvesting to clean up sparsely stocked mature stands, and thus decrease long-term protection costs. He observes that the trade-off, if such a policy is followed strictly, is an increase in harvest costs in the near term which may offset the savings in protection costs, and suggests scheduling the harvest of these stands in conjunction with fully stocked stands such that a total cost minimum is obtained.

AN IMPLEMENTATION

A cartographic modeling technique has been successfully implemented using the MBIS (Boss, 1985). It contributes to the long-term planning process by synthesizing the data of several map layers and presenting the results in a form which capitalizes on human abilities for grouping and ordering visual data. It does not, and cannot in itself, provide a fully prioritized and spatially organized strategic harvest and protection plan. It is but the first of four steps in developing such a plan. The other steps are: second, blocking areas of relatively homogeneous characteristics by foresters familiar with the region; third, the estimation by blocks of the value of current and future inventory, cost of protection per unit volume of host species, and other factors; and fourth, the application of optimization techniques to allocate each harvest/protection unit to an optimum harvest interval over a full forest crop rotation.

The method does provide an effective means of applying complex planning principles to a set of geographically-based factors. Appropriate use requires careful study of the goals and explicit application of planning principles. The planning problem may need to be decomposed into subproblems in order to state the modeling rules clearly and ensure that all input factors contribute monotonically to the goal(s). The problem of assigning weights to the component factors can be difficult, since it is important not only to identify the extremes, but also to prioritize correctly between the extremes.

Scan-line software was initiated in the implementation as an enhancement to the commercial cartographic information system, which had limitations in spatial analytical capabilities. The software provides an interface for the graphics and data base management components of that system. This interface allows full use of interactive graphics and data base commands while adding an efficient mechanism for map generalization, overlay, analysis, and area tabulation that can be applied to a very large cartographic data base. The graphics capabilities of the system are a very important component of the method, since color fill and shading, if used correctly, can aid in the visual grouping required for blocking stands into operation units. The original documentation (Boss, 1985) has color plates to illustrate these capabilities.

In the actual details of the technique, the method described is a departure from previous attempts at computer-assisted long-term harvest and protection planning in the spruce-fir forest (Hertz-Brown and Williams, 1981; Erdle et al., 1984). However, it fills the same basic role in the planning process as these applications in providing a mapped synthesis of data which forest managers are able to visually assimilate and process in strategic planning efforts. There are operational and biological factors which the computer-assisted techniques cannot take into account because of both data and algorithmic limitations. Therefore, in formulating the final plan, all of the approaches require considerable intervention of the forester familiar with a given unit of land.

ROAD SYSTEM ANALYSIS

One aspect of the forest operations planning which is often not included as an integral part of the present information systems is the harvesting and transportation of timber. Special harvesting decision-making support systems exist, but are uniquely designed for this purpose and do not allow for complete integration into a map-based information system. Making the transportation and road network analysis procedures a part of the overall system enables all data in the data bases to be shared by these subsystems, thus enhancing their utility and capabilities.

A particularly interesting part of road network analysis is the location of new roads within the existing network. Because of the growing need to control logging and transportation costs, road networks should be optimized in consideration of the costs of road construction, skidding and trucking. In many cases this will mean network expansion. New roads are also required in areas not previously subjected to intensive operations, and in areas of salvage operations (Corcoran and Nieuwenhuis, 1985). Other reasons for new road construction include changes in transportation systems (i.e. river drives are replaced by road haul), upgrading of existing network segments (i.e. straightening of important routes), environmental policies (i.e. minimum distances required between streams and roads), fire control, and recreation.

THE ROAD NETWORK ANALYSIS MODULE

Part of the developed MBIS is a road network inventory module (Nieuwenhuis, 1983). Because of the fast-growing complexity and size of the in-place road network, it has become necessary to automate the inventory procedures used for transportation and harvesting management. Making the inventory module part of the overall MBIS 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 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 (eg. company policy). These requirements include maximum uphill and downhill grades, minimum widths, maximum curvatures, and required surface materials for roads; minimum diameters, materials, and slopes for culverts; and minimum load capacities, minimum 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.

Other specific uses which were taken into consideration, but for which no special accommodations were made, 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. The changes do not require starting from scratch, but necessitate expansion of the data base model to include nodes and directed links. The modifications make it possible to use the inventory module for network analysis purposes, such as travel time estimations (taking into account vehicle type, weight, road conditions, etc.) and route selections (accounting for vehicle size and weight, road class limitations, etc.), including both simple shortest route determinations and more complex tour optimization procedures.

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.

THE ROAD NETWORK LOCATION MODULE

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 existing MBIS (Nieuwenhuis, 1986).

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 (using similar service zones) 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 minimum cost matrices. The algorithm does not guarantee an absolute optimal solution in all cases. Because of the complexity of this type of network locational problem, a proven optimal algorithm would be extremely time consuming (Tansel, Francis 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. In the presence of dividing rivers and streams, special attention must be paid to the entry cell configuration and possible bridge locations.

The integration of the developed location procedure with the existing MBIS is a rather complicated process, the reason being that the MBIS is not designed to be used for network analysis purposes. Data transformation from polygon format to grid format is necessary to perform spatial analysis, and requires a complex series of scanning and overlay procedures. The representation of roads and streams as linear elements further complicates the process, because only complex shapes are recognized by the scanning software (Figures 1 and 2). It should be noted that while these and the following figures are in black and white, terminal displays or hard copies thereof are typically multi-colored. If, in the future, the location procedure is to be used extensively, it may be beneficial to construct layers of graphic information which contain a representation of all linear elements as complex shapes. In addition, scan-line files for frequently used design file and data base information, such as soil types, elevation, and cover types, may be kept readily available (Figures 3 and 4). This will reduce the data retrieval and transformation processes needed to establish data files for the location procedure.

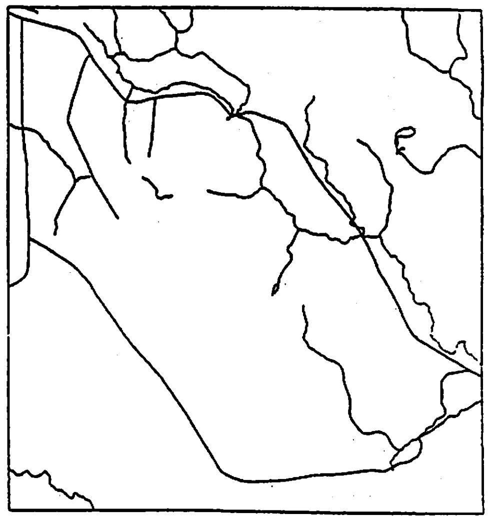

Figure 1. The existing road network and water bodies in the study area (scale: 1 cm = 0.7 km).

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 MBIS, which allows for output in both report and map form. The coordinates files has only to be transformed into a design file to display the solution in graphic form, on a screen or as a map (Figure 5).

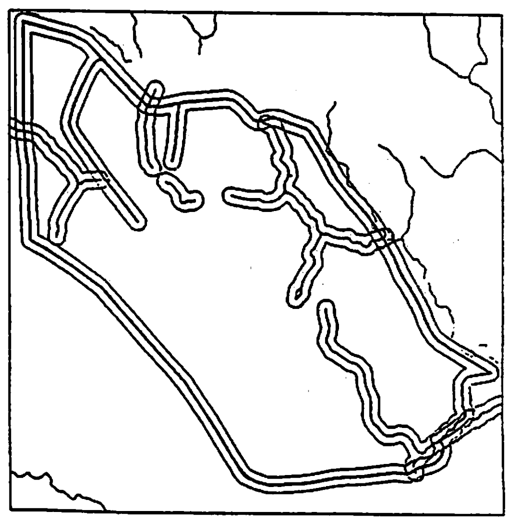

Figure 2. Both roads and streams have been converted into complex shapes.

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 among, the individual data layers has been conceptualized. Research is underway in this regard and results should be available within a year.

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 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 case existing roads are included in the data set, the user still has a choice between access from all existing roads, and selection of only part of this network for access. In the latter 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 access to selected grid cells, such as future gravel pits, by the resulting road network.

Figure 3. The existing roads overlaid with the cover type polygons.

Figure 4. Scan-line file overlaid on road and stream layers. Scan-line thickness represents road construction suitability. Only the area inside of the existing roads is considered.

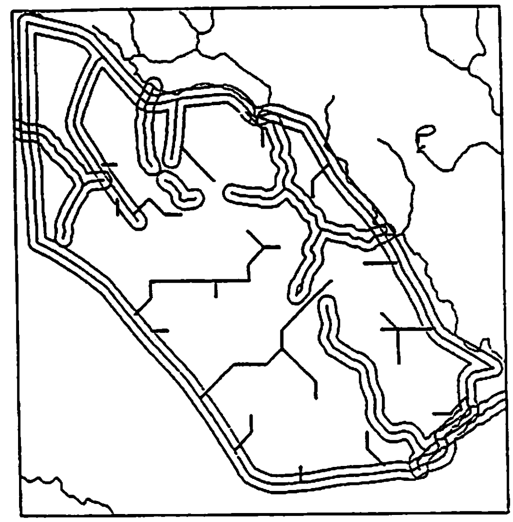

Figure 5. The new road segment design file combined with existing road, stream, and zone data layers.

As discussed above, several aspects of the total process of algorithm development and integration in the MBIS require additional research. Nevertheless, the ideas of both computerized road location and integration of the procedure in a MBIS have been shown to be feasible. The flexibility of area and entry cell selection in the developed program allows for the optimal use of the procedure under various conditions. Algorithm improvement and data base expansion will further enhance the capabilities of the total system and improve the efficiency and effectiveness of this management decision-making tool.

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The South - A Status Report[1]

Dr. Earl L. Deal, Jr.[2]

The story begins with the markets for Southern forest products and ends with the cost of doing business. The basic problem faced by the industry is survival. A brief and statistically unsound survey of the industry has shown that firms are in a better economic condition than in 1985. However, this does not mean they are having a good year. Many individuals indicate that they are "getting by" and hope to survive until better times get here.

Some Southern forest products are selling well. But the impact of Canadian imports and the continued relative high value of the U.S. dollar still exists. Markets have improved for some items such as pressure treated products and high grade speciality items being exported to Europe and the Pacific rim. Hardwood mills are doing much better in selling higher grades to the furniture market. However, lower grades and unpopular species are still difficult to sell. This results in only half the volume of a typical hardwood sale having a ready market.

Paper production in the South is doing much better. However, paper mills have become very selective in the type of wood they will purchase. This has resulted in the loss of many whole tree chip markets. The relative strength of demand for hardwood pulpwood has improved in many areas with several mills beginning to produce white papers rather than the traditional box and bag kraft. Many exceptions exist with a glut of low quality hardwood continuing in most parts of the region.

In general, the poor markets over the last few years have brought about major structural changes and cost cutting strategies by the entire industry. Mills have contracted their procurement areas in an attempt to reduce shipping cost. This has brought about some major changes in those areas where timber has had to be shipped long distances. The loss of rail service in many locals has also contributed to these problems. As mentioned above, the changes in product lines has also brought about the loss of markets for some timber products.

Today's economic atmosphere for highly capitalized industries in the United States has also forced all segments of the industry into making major structural changes in personnel and methods of doing business. A major reduction in the work force from top management to equipment operators has taken place. Reductions in capital spending and the use of independent contractors for site preparation, planting, harvesting and other activities is occurring. Many of these jobs have traditionally been done by company employees. Contract rates have also been reduced in many locals and are a direct reflection of the market for products.

Although inflation rates have been reduced, the general cost of doing business has continued to be high for everyone in the industry. The cost of energy has been one of the few bright spots. With the reduced cost of diesel fuel. However, the downward trend in this cost has ended and there appears to be upward pressure on these prices.

The cost of insurance seems to be the major topic of conversation for all businessmen. Liability, fire, workman's compensation and other insurance cost have more than doubled for many firms in the industry. The forest products industry has suffered more than others because of its poor track record and reputation. Obtaining reinsurance for self-insurers funds has also been difficult. One interesting note is that some equipment manufacturers and dealers have used insurance as a sales technique. They will find insurance coverage for any equipment they sell and finance. This coverage ends when the equipment is paid off. It is not unusual to see loggers making decisions to buy one brand over another for this reason. Some loggers have also made decisions to replace equipment earlier than they normally would because they cannot obtain insurance on older equipment.

The loss of the investment tax credit is having the opposite effect by postponing decisions to purchase equipment, even without insurance protection, because it is a good economic decision. However, parts and other supplies have continued to be costly. This is a continuation of the status quo and should remain the same in the near future. The general turmoil in the equipment business has brought about some real bargins on equipment over the past year. These opportunities have decreased over the past few months as people have gotten back into the market.

The weather throughout the South has been a boom and a bust for loggers. The dry conditions have made it possible to get better production. But mills have had loggers on such tight quotas for so long a time that no one can remember how it is to run at full steam. Some procurement organizations have also been forced to make some hard decisions to let individual contractors go. This again is a general statement with many exceptions. However, very few people in the South would complain about a little more rain.

A growing problem in the South is the increase or threat of regulation on all forestry operations. The enforcement of the Federal Bridge Weight formula in every state is going to have a major impact on transportation costs. Many of the trucks operating in our forests are going to become obsolete when this formula is enforced universally. They are not going to be able to meet the close enforcement tolerances on axle and tandem weights and continue to carry the maximum gross weights that are common today. Truck configurations will need to be changed and the wider use of some kind of in-woods weighing system will become common.

The elimination of forestry's exemption from state sedimentation laws is also a real threat. There is growing sentiment throughout the South for

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the timber industry to adhere to the same restrictions as developers and building contractors. Several civic and environmental groups in North Carolina are now proposing more regulation of logging operations at both the state and local levels. Fred Cubbage, University of Georgia, has reported this same trend in other Southern states.

Control burning is also receiving attention from regulators because of smoke problems. The outcry has lessened in North Carolina and other states as less agricultural land is cleared. But those people involved in control burning in the South are having to take a close look at the direction of the wind when burning is done near public roads.

The South is becoming urbanized with a smaller percentage of the population knowledgeable about farming and forestry. They think milk comes out of cartons and they never associate their consumption of wood products with the cutting of timber. We generally think of New York and its suburbs when we talk of an urban population. However, the residents of Richmond, Charlotte, Atlanta, and Mobile have become the same. The elected representatives from these urban areas are beginning to control our state legislatures. These people and those urban dwelers they represent view the typical harvested timber stand as a disaster area and they don't like it. And they are going to do something about it.

Just ask the folks with the U. S. Forest Service in the mountains of North Carolina. They receive constant pressure from the "outsiders" who have purchased summer homes adjacent to Federal lands. They want timber harvesting to stop. The harvest on these lands has significantly fallen and the existence of many forest industries in this region is threatened. Unfortunately, this trend is going to continue until professional foresters and the forest industry get their story straight and launch a better public education program for the general public and our elected officials.

Loggers throughout the South are becomming better business managers. This may be due to the elimination of those who were not, or it may be due to the IRS regulations, or it may be due to the requirements set down by the folks they borrow money from. The most likely reason is probably a combination of all of these. However, there is room for improvement within the Southern logging industry. Very few loggers know what their true costs are and at best, they work on rules of thumb and averages. As with most small businessmen, they generally think in terms of cash flows only. They do not know if they are making money on the tract they are presently harvesting or the one they just finished. It is generally tax reporting time before they realize that they have been losing money.

Loggers must realize that in the long run they must cover their variable and fixed cost. Some timber tracts have better timber, are closer to delivery points and are generally cheaper to log. The entire industry must begin to recognize the variability in the cost of harvesting individual tracts. Contract rates need to be adjusted for the situation. Neither the supplier or buyer of logging services can afford to work on averages and continue to be profitable in the economic atmosphere that exists today.

In summary, the Southern forest industry is getting by with business somewhat better than in 1985. However, there are many problems and opportunities. Without some major efforts on the industry's part, government regulations and land management policies are going to have major impacts on the cost of doing business and the industry's survival. The control of input cost and the influence of using good management techniques will continue to be the primary influence on individual firm's profitability. In addition, the Southern forest products industry and particularly the sawmill segment, must change from order takers and begin to actively market their products. The industry is faced with ever increasing competition from other timber producing regions throughout the world and other non-wood products such as brick, concrete, plastic, etc. It must become more active in marketing its products to remain in business.

Making Harvesting Research Work - A User's Perspective[1]

Charles W. Fudge[2]

Abstract: Harvesting research can play a significant role in helping timber managers reach their objectives. Tight budgets have limited harvesting research. Social and political issues influence research needs of users and conduct of research by scientists. Making timber harvest research work requires that: 1) users and scientists establish the role and scope of their units and coordinate their efforts; 2) broaden and build support for research development and use; and 3) develop effective information transfer.

Keywords: scientists, manager, opportunities, role, support, technology transfer

Today's timber managers, more than ever before, must focus on the bottom line of increasing revenues while containing or reducing costs. Harvesting research can play a significant role in helping these managers reach their objectives. Such research is essential to reducing costs, improving harvesting methods, making use of forest residues, and enhancing multiple benefits of forested lands. Yet, emphasis on cost control and budget limitations may reduce harvesting research and limit the transfer of results to the user. We users need to join with our research scientists and create the environment for the best use of our research dollars and application of results.

Let us look at the current situation and issues facing harvesting research and its application. Then we will cover some opportunities. Finally, I will propose some actions which will help us seize on the opportunities and make harvesting research work for the users.

Emphasis on timber harvesting research gained formal recognition about 25 years ago when the Forest Service created research work units for that purpose. Prior to that time, such research was relatively independent in academic, private, and public sectors. The origin of research work units which focused on harvesting systems and methods finally gave recognition of this role of research. Both academic and forest industry researchers joined this effort. Emphasis of research focused on development work for equipment. Industry related research had substantial success in advancing a variety of equipment for harvesting but lesser impact on the systems approaches to the equipment application and effects on the forests.

Where academic and public researchers developed management systems and methods for harvesting, results were readily applied and transferred from user to user. However, Forest Service researchers were not too successful in areas of development-oriented research. This largely resulted because they lacked the influence on creating, managing, and serving the market structure for equipment manufacture, marketing, and use. Such high risk work also required substantial investment in research dollars. Therefore, less emphasis on solving land management issues and problems resulted.

In the last five years, several actions have affected all sectors of harvesting research. The severe recessionary pressures felt by the forest products industry in the early '80s resulted in equally severe trimming of budgets and people. Harvesting research staffs, already limited in scope and numbers in both equipment manufacturing and forest products industries, took further slices. Today, only one forest products company maintains a staff in harvesting research. Even that is a token one.

Tight budgets spilled over into academia as states fought to keep expenses in line with revenues. Enrollment has dropped in forest engineering and forestry schools. These factors have reduced the money and staffing necessary to maintain the past level of harvesting research.

In the last 3-4 years, several outside groups have reviewed the Forest Service research program. A common theme of the reviews dealt with the role of public research and that of the private sector. They generally believe that the Forest Service should not perform harvesting or utilization equipment research which more appropriately belongs to the private sector. Reviews showed that 90 percent of our research was performed as basic research, to benefit national forest management, or to meet statutory requirements. Only 3 percent was defense related or of a commercial nature. Still, management emphasis directs that research avoid development-related projects and focus on identification of new knowledge. Both external and internal studies and reviews have and will continue to have effects on influencing the cost-effectiveness of our research, budget levels, personnel numbers, and unit organization. The impacts are far reaching in terms of accomplishing needed harvesting research, coordination with other researchers, and transferring results of research to users.

Let's look at just a few statistics and weigh their importance. The harvesting research units received \$1.6 million in fiscal year 1975, \$2.3 million in fiscal year 1980, and \$2.8 million in fiscal year 1985. This represents 2 percent of the total research allocation. In fiscal year 1985, the harvest of national forest timber sales totaled \$720 million in value. One can argue for a higher level of harvesting research funding. But, one can also argue that of the available harvesting research dollar, priority for expenditure must identify cost efficiency in terms of increasing revenues as a funding priority.

Another statistic has importance to the academic community. Distribution of extramural funding has dropped. In fiscal year 1984 extramural funding for all research to universities was \$7.1 million, which funded 388 projects. However, in fiscal year 1985, funding fell to \$6.6 million and funded 325 projects. This program has importance because of the synergy

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it produces in harvesting research. It also offers opportunities for the Forest Service to direct funds to levels of expertise which it does not employ.

A third statistic shows the growing vitality of the harvesting research work unit accomplishments in publishing results. In fiscal year 1982, the units published 38 articles and in fiscal year 1985, they published 84 articles. This was accomplished with little budget change and greatly surpassed the percentage increase of the entire research system.

So far, in outlining the existing situation, I have focused on budget and economic cause and effect. Harvesting researchers must face and resolve other issues. Management of our forested lands requires satisfaction of a variety of social and political goals, objectives, and needs. Federal land managers work with a bewildering number of laws, regulations, and policies. Harvesting of timber doesn't stop just with the prescription of logging equipment, methods, and controls. Prescriptions result from comprehensive environmental analysis involving a variety of disciplines. Researchers, more and more, involve the use of other research disciplines in developing study plans, conducting research, and sharing in the publication and transfer to users. Private land managers, too, face a trend toward increased regulation. Regulation has progressed from state forest practices acts to county, township, and city regulations and ordinances. Planning and zoning commissions pass on requests to manage vegetation. The pure academic harvesting systems researcher cannot cope with these challenges alone. Other scientists frequently hold the key cards to successful research applications.

In fact, Congress recognized that last year when they recognized three universities as regional centers for wood utilization research. Congress felt that the United States needed to become more competitive in world markets. These universities have developed research programs in cooperation with other academic centers and users to address harvesting and utilization related topics.

Add to this situation other concerns such as international and national competitive forces, balance of payments, growing demands for forest products in the next 15-25 years, worker safety and industrial accident insurance, harvesting training, a work force more aligned with service than development, and unused research on the shelf.

The Forest Service harvesting research work units, academic regional centers, other academic units interested in harvesting research, and the multitude of users have their work cut out for them. Success will require continued emphasis on sharing issues, approaches, and results both regionally and nationally with public and private interests and users.

That is the situation. Let us now review some opportunities which may help make harvesting research work better. We need to do three things: 1) establish the role and scope of the various harvesting research units and their users; 2) broaden and build support for the development and use of harvesting research; and 3) develop an effective information transfer approach.

The Forest Service recently developed an approach for improving systems for exchanging harvesting technology needs and uses. It involved the role and scope of both researcher and user. Problem identification showed that technology existed but with varied knowledge or understanding of its existence or application. It also showed that users ideas were not uniformly sought, heard, or given priority for research projects. A work conference helped teams from each research work unit develop better systems for exchanging harvesting research needs and use of completed technology results. The process provided for identification of national mission-oriented needs which could involve components of more than one research work unit in solving. Leaders of research work units will meet periodically with Forest Service users, universities, and user groups in their work unit areas to develop research priorities and exchange information. Thus, role and scope will evolve from these efforts.

Opportunities exist to develop further linkages. The academic research community can do similar coordinating on a regional basis and participate with Forest Service research work units to identify areas of mutual interest. Although many forestry schools exist, only a few schools specialize in harvesting, industrial engineering of harvesting equipment, or logging engineering. As few as 15 schools provide the national leadership in these areas and include research activities in their program. Logging engineers are a small component of the forest management workforce. Only five research work units exist in the Forest Service. Few equipment manufacturing companies are involved. This is a workable sized group to coordinate a dynamic and creative research program.

The Council on Forest Engineering (COFE) could play a distinct role as a facilitator in making this effort work. With the harvesting and utilization work group from the Society of American Foresters (SAF), COFE can assume a new and challenging role.

This leads us to the second opportunity of building support for harvesting research and use. This year the Senate Appropriations Subcommittee on the Interior was considering a House-passed bill for full Committee action. The money bill contained funds for operation of the Forest Service during fiscal year 1987. Actions of the Subcommittee approved a total of $123 million for forest research, compared to $111 proposed in the Forest Service budget. This included an addition of $6.5 million to keep alive the competitive grants program. The National Forest Products Association (NFPA) supported both of these positions. At both National and State levels, legislative bodies are looking for every way to reduce expenditures. Those who do not participate in this process will, assuredly, not reap the benefits.

Those of you who depend upon and use harvesting research must form the action groups necessary to carry your message. You must identify and target key individuals and groups and then deliver your message. You need to participate in logging conferences, equipment shows, reviews of academic or Federal research programs, environmental group meetings, and a whole host of other contacts with those who control or influence budgets, both public and corporate. Develop contacts with interdisciplinary people and develop harvesting research projects which highlight the multiple benefits achieved through environmentally sound harvesting systems, equipment, and practices. Most of all, do not depend on one or two interest groups, like NFPA, to do your missionary work.

The last, but essential, area of opportunity involves the effective transfer of research between scientist and user and between user and user. The popular buzz word for this is technology transfer. Actually, it is a very personal action by its originator. Scientists, this work sometimes takes years and years to create a research result and you need to take credit for it. You need to grab users like a bible-belt preacher grabs sinners on a Sunday night. Tell them how proud and excited you are about the potential use of your results. Would Lee Iacocca be a household word if he had not had an idea, believed in it and himself, and marketed it to a whole range of users? When users have finally convinced other users of your products merits, you can begin marketing your next product.

Actually, by following seven key steps anyone can develop and market a product.

1. Identify your user's needs and determine the target groups who will use the results. Inform the user of existing scientific results and identify additional needs.
2. Develop a plan of delivery. Involve other essential researchers or contacts you will need to assure a high probability of success. Keep your user informed as you progress. Let the user know what they might use and apply as interim results progress.
3. When done, package the product for quick and easy understanding and application. Dazzle them with believability, not brilliance.
4. Determine how to present the product - published paper, workshop, one-on-one. Generally, it will take a variety of forums to effectively distribute your product.
5. Involve both the user and scientist during the marketing. Let the convert teach. Commitment comes when others see the belief in the convert.
6. Get feedback after a while and follow-up on the feedback. You may need to fine-tune the product after it's breakin period.
7. Evaluate the results of the project, develop corrective action, and share the results with your peers. Then pat yourself on the back and return to the next challenge.

The curious thing about this simple process is that a user can also follow it to explain and get commitment for a research need from a scientist.

Current emphasis on budget control may limit opportunities for expanding harvesting research. However, careful use of this limited money, followed by significant results which generate revenues, contain or reduce costs, and enhance multiple resource values, will improve researcher and user visibility. Both participants need to coordinate research needs across larger geographic boundaries to assure cost efficient return on the research investment. COFE has an opening opportunity to help accomplish these results. COFE members can also help broaden the constituency who passes judgement on the financing, approval, and application of harvesting research. Cooperators who make timely and effective use of harvesting research findings make good supporters. Careful thought by researchers on marketing useful research will assure satisfied customers and a supportive constituency. That concludes my perspective of how I want to see harvesting research work.

Selection, Training and Motivation of the Logging Labor Force[1]

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Abstract: Paper provides a perspective of the logging labor force in the light of current trends in the forest products industry. Regional differences and similarities are briefly addressed. The paper describes a validated selection process and then focuses on what may be workable in the logging industry. The process of developing a "designed" training program is outlined and discussed. The relationships to mechanization are of interest. Design guidelines are provided for incentive systems. Summary discussion will look to near-term prospects for improvements.

Keywords: Designed training, incentives, logging training materials

When loggers get together they tell tall tales (mostly true) about overcoming great adversity in timber conditions, operating conditions, or bureaucratic or regulatory circumstances. They talk about new equipment, new logging systems, and the relative costs and benefits from their trials and tribulations. Now they are even talking about labor force issues. Selection, training, and incentives (motivation) are becoming a part of their discussions.

Economic pressures from poor safety performance, the inability to hire trained people (or even "trainable" workers), more complex equipment and systems, and the potentials of some incentive systems all combine to bring attention to the people in logging. Post recession shifts in the structure of the logging industry in the U.S. make individual workers the focal point for economic viability of small logging firms.

INDUSTRY RE-STRUCTURING AND REGIONAL SIMILARITIES

It is not easy to obtain a composite picture of the U.S. logging labor force. Benchmark collections of statistics such as the Census of Population offer useful information if conditions are relatively stable. However, many profound changes occurred in the early 1980s, and those data will be reflected in the 1990 census (actual data will be available about 1995!). That information is not particularly useful to logging firms facing economic solvency right now.

In the absence of detailed industry studies, observations based on travel and discussions with industry leaders will have to suffice. My observations offered here will make sense to the degree they fit observations in your own region.

Consider a spectrum of logging operations ranging from the large corporate firm to a 1 or 2 person outfit with a single piece of equipment. Figure 1 shows some of the characteristics of the extreme ends of the spectrum relating to type of business organization, business capital availability, level of supervision, human resources, and management talent.

In my judgment, there have been underlying pressures to move the logging industry toward the center of the spectrum for some time. Across the U.S., the number of independent contract logging firms of the type shown in the center of figure 1 is increasing. The recessionary forces of the early 1980s hastened this trend even more. The re-structuring of major corporations away from their own logging activities, market/employment instability for logging services, and the need for flexible and opportunistic business arrangements all favor independent, contract loggers.

Within any region you will still find the full spectrum of logging firms; however, the pressures are toward the middle of the spectrum. In the west, integrated corporations are eliminating their own logging operations. The recessionary period caused considerable "downsizing" of logging firms. In the south, "upsizing" the operation with more equipment and mechanization seemed to make firms more viable. The northeast seems to be continuing the trend toward mid-size contractors. The midwest follows a trend toward slightly larger contractors with increased mechanization.

The success of independent contractors in this size range is due to finding "niches" for their services, keeping equipment costs low, minimizing excess manpower, and keeping supervision and overhead costs to a minimum. The specific size of contractor firm varies with the demand for the type of logging service, timber and terrain conditions, and what firm size can be viable on a year-round basis. Not surprisingly, the size of contractor firms limits the options for dealing with the logging labor force.

CURRENT PRACTICES FOR SELECTION, TRAINING AND MOTIVATION

If it were not such a serious problem, the processes to select, train, and motivate loggers are almost humorous when you hear the anecdotes of what went wrong.

Selection

Selection processes range from placing an ad in the newspaper to phoning the local employment agencies when an entry level position opens up. Selection for more skilled positions might involve moving the person into the job who's supposed to be picking up the job skills while on another job; selecting the person you thought was being trained by the incumbent; using family favoritism, hunting buddies, or some other favoritism; or commonly, selecting the more senior person.

Only the most informal assessments are made for physical abilities, mental abilities, or skills in these approaches. One logger friend recently hired a fellow for a demanding woods job who came with a cracked vertebrae in his neck. Worker's Compensation hearings are skill in process. A brief

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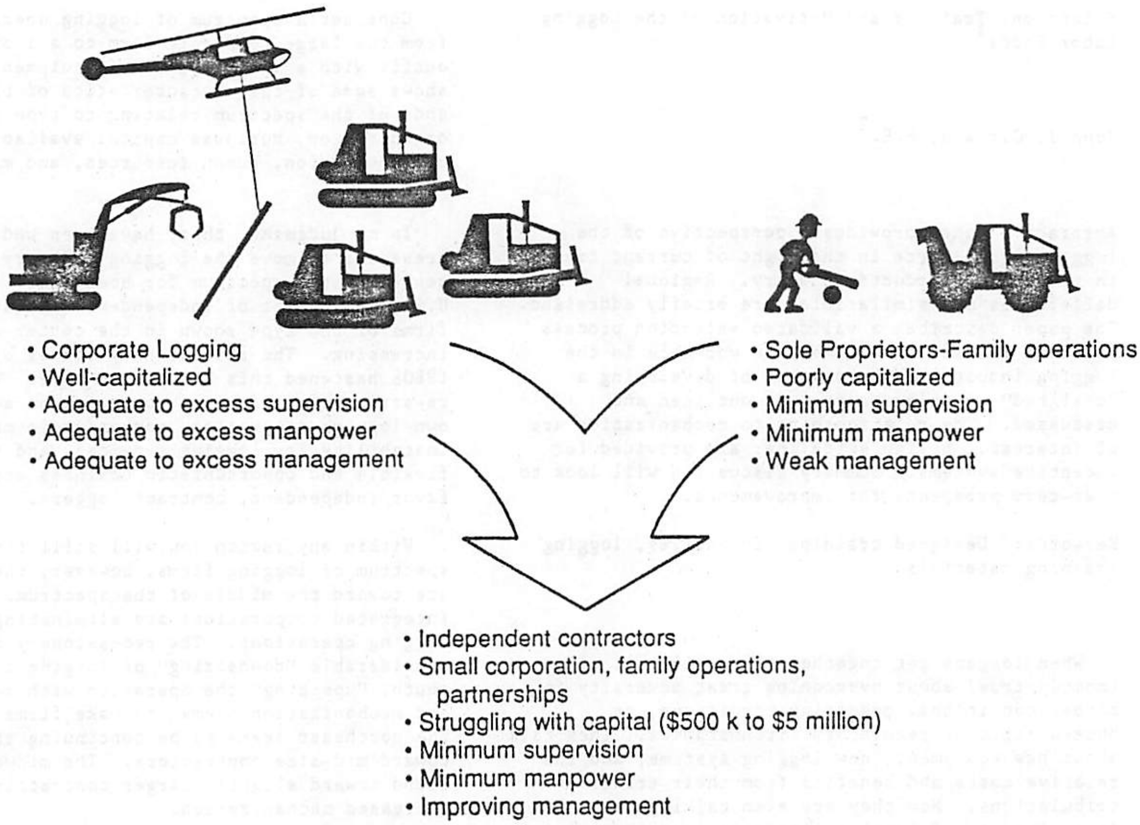

Figure 1--Restructuring of the Logging Industry

background check or phone call to a previous employer would have been invaluable, but production pressures prompted the shortcut.

Training

Some loggers view a trained woodsworker as someone who survives three months on the job without an injury. It's an error to say there is no training taking place in the woods; some very complex tasks (requiring complex skills) could not be accomplished otherwise. It may be more accurate to say there is lots of learning taking place in the absence of much training.

I have earlier characterized three classes of training for the logging industry as formal learning (yes/no, right/wrong rules); informal learning (role models, osmosis); and technical training (designed training efforts). It is worth repeating an earlier description of how these classes apply to logging:

"That loggers learn from 'trials and errors' is evidence of Formal learning at work. Work rules and safety practices are typical of the right-wrong nature of this type of training. Informal learning is most often shown in the characteristic behaviors of loggers, their dress code, their attitudes, their problem solving approaches. Carried to extreme, Informal learning produces a subculture; you and I are probably part of the logging subculture. Technical learning is most often absent in the logging industry. There are few training guides, few training materials, few preparation efforts for trainers, and few evaluation efforts of training effectiveness. From my perspective as an engineer, the lack of Technical learning is akin to building a bridge or complex structure without first designing it. (Garland, 1985)"

It is possible to identify some exemplary training programs across the country, but taking an industry-wide view, there is little technical training compared to other industries. The fact that we are achieving only 40-50% of machine potentials helps document the lack of training. Overseas efforts in Scandanavia, Europe, Australia, New Zealand, and even some developing countries are more advanced than training efforts in the U.S.

Motivation (Incentive Systems)

Most loggers recognize the lack of motivation in their workers, but some of their responses show little understanding of the complex psychological processes surrounding motivation. They respond with:

* "Work harder or I'll fire you!"
* Feedback that is non-specific and threatening.
* Blame on the "attitudes" of the younger workforce.
* Company dinners, Christmas bonuses, softball teams, etc.
* Competition between crews.
* Piece-rate systems of payment.
* Feedback through information systems: goal setting.
* Pay for production systems or contractor parity pricing of services.
* A variety of "experimental" approaches including some true incentive systems for crews, some camp-wide incentive pools, and some human resource development efforts like team building, quality circles, etc.

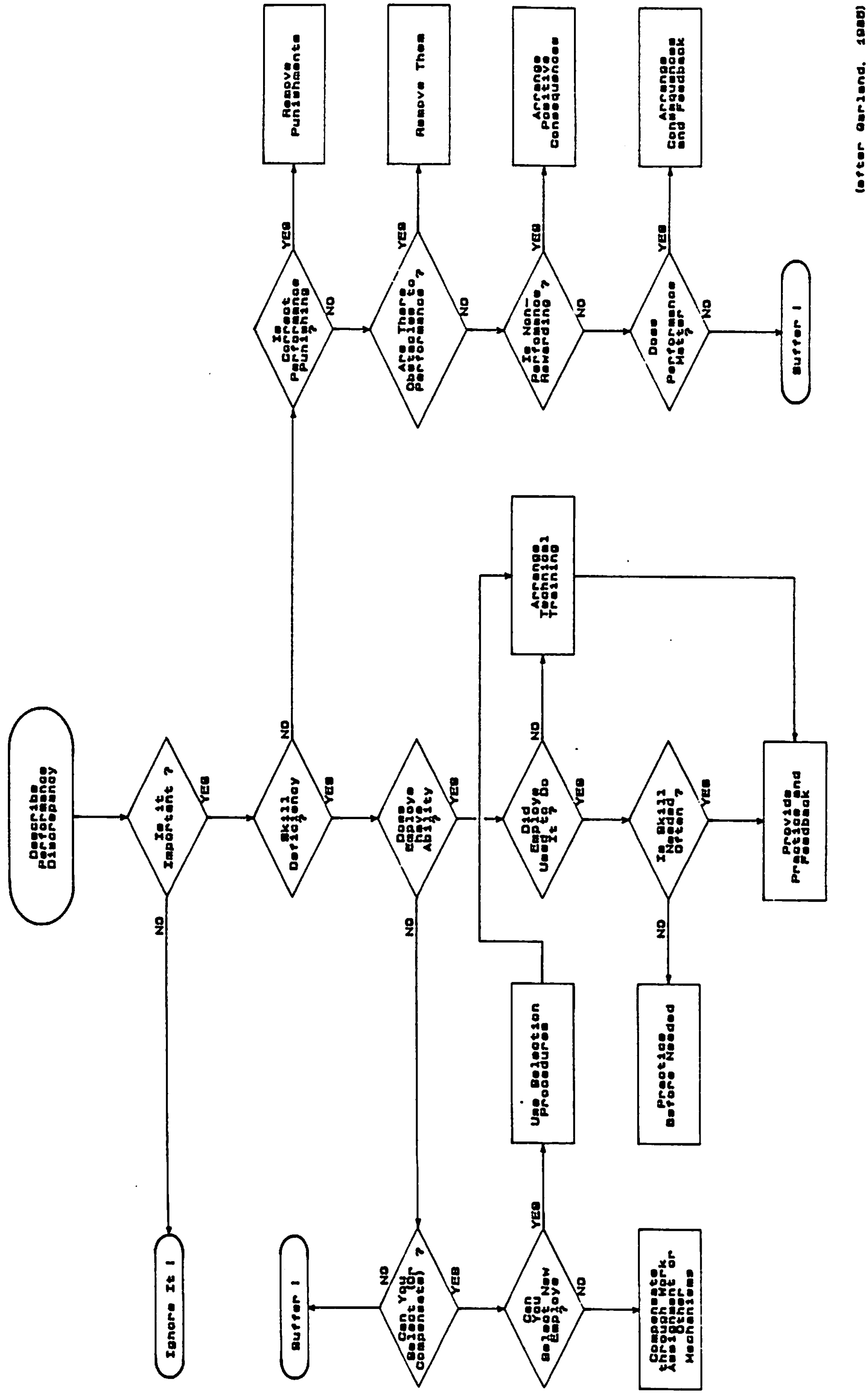

Figure 2--Assessing Performance Discrepancies.

All of the responses above have greater or lesser successes depending on circumstances. When someone reports productivity gains in the 30-40 percent magnitude, the interest in incentives perks up immediately. Some firms adopt the "quick fix" and try to copy someone else's successes without fully realizing the design process necessary to implement incentive systems. More will be said of this later.

Current Practices for Mechanized Harvesting Contractors

The Forest Engineering Department recently surveyed western mechanized harvesting operators on a variety of issues. Two questions were asked about selection and training. Results are shown in tables 1 and 2.

The question on selection (table 1) shows heavy dependence on transfer of operating skills from similar machinery (43 percent). This raises questions about the nature of previous experience and how to evaluate it. Follow-up questions are planned to determine the nature of the skills assessment category (30 percent) checked by some contractors.

The training question (table 2) emphasizes the need to have machine operators be productive while they are gaining skills (40 percent). The nature of past experience contributions to present job skills (21 percent) merits further exploration. The fact that operators are training themselves or learning from other operators can be seen by combining several responses (69 percent). Formal (designed) training efforts are generally lacking (2 percent).

Table 1--Criterion most frequently used by mechanized harvesting contractors to select machine operators.

Primary hiring criterion	Percentage of contractors
Experience on similar machinery	43
Skills assessment	30
Seniority	16
Family membership	9
Other	2
- selects those who seem willing to learn	
- selects those with a high level of motivation	

sample size: n = 81

Table 2--Operator training procedures used in the western United States.

Procedure	Percentage of contractors
"On the job" while occupying job, training by another operator	40
Only hire experienced operators	21
None, they learn by themselves	18
"On the job" prior to assuming job, training by another operator	11
Other (family operations)	8
Formal training effort	2

sample size: n = 87

For both questions, the influence of family involvement in the operations can be seen. Follow-up to the survey is planned for several areas.

PERFORMANCE DISCREPANCIES

Most firms' interests in selection, training, or incentives are not derived from some long term improvement efforts; usually they have a problem. Sometimes there are solutions available before the problem has been analyzed fully. Figure 2 provides an assessment procedure that should precede developing alternative solutions. The review of this chart could prove useful in avoiding the apparent (though incorrect) expedient solutions.

PRELIMINARY ANALYSIS AND LEGAL CONCERNS

A review of legal concerns and some preliminary analysis is needed before undertaking improvement measures in selection, training, and incentive areas. The Equal Employment Opportunity Commission and its state counterparts are concerned with employment decisions which discriminate unfairly against one worker in favor of another. Areas covered include initial screenings, recruitment, actual selection, placement, compensation, training, promotions, and performance appraisals.

In addition, some states have explicit requirements for training in hazardous logging occupations (Workers' Compensation Board, 1982). Oregon requires training in the logging safety code. Meeting legal requirments is largely a matter of keeping decisions related to actual job requirements and eliminating discrimination. How can this be done?

Job/Task Analysis

A job/task analysis defines a job in terms of the component tasks and employe behaviors. Knowledge, skills, and abilities are identified for each logging task by incumbents, supervisors, and/or job experts. The job/task analysis must represent the actual tasks performed or its credibility is subject to challenge.

Preparing a job/task analysis is simply a way of documenting what the job entails. However, there are substantial gains from this process alone when all of the incumbents, supervisors, and managers recognize what the job actually involves.

Behavioral Observation Scales

In any improvement effort you must assess performance differences between people. How can this be done in the logging environment? Output measures like trees per hour, loads per day, etc. may not be comparable across differing operating conditions, machine types, timber, and terrain conditions. Performance appraisal is needed for valid selection procedures as well as to measure training effectiveness.

Behavioral observation scales associate an observable behavior with a key job dimension. The behaviors and job dimensions come out of the job/task analysis through the creative efforts of the incumbents, supervisors, managers and job

Sample Behaviors	0-30% Rarely	30-45% Occas-ionally	45-65% Frequen-tly	65%-85% Usually	85%-95% Almost Always	95%+ Always	Not Applicable
Handles machine smoothly with a minimum of excess movements	☐	☐	☐	☐	☐	☐	☐
Operates within the limits of machine, slope, lifting limits, trafficability, etc.	☐	☐	☐	☐	☐	☐	☐
Builds bunches to help skidding, up to size, location, indexes butts	☐	☐	☐	☐	☐	☐	☐
Uses a plan for felling strips, works with terrain and timber type	☐	☐	☐	☐	☐	☐	☐
Keeps ahead of skidding, can increase production when needed	☐	☐	☐	☐	☐	☐	☐
Maintains safe distance from men, machines, and other operations	☐	☐	☐	☐	☐	☐	☐
Can handle problems when they occur, gets help when needed, informs supervisor and crew when problems occur	☐	☐	☐	☐	☐	☐	☐
Performs start-up inspection, does minor maintenance, makes adjustments, services fluids as required	☐	☐	☐	☐	☐	☐	☐

Figure 3--Sample Behavioral Observation Scale for Performance Appraisal: Felling Machine Operator.

analysts. By using techniques to eliminate ratings bias, some potent appraisal instruments can be developed for logging jobs. See a sample page from the felling machine operator job (fig. 3).

DESIGNED SELECTION

It is assumed that we are interested here in improving selection procedures beyond what is currently used in the industry. Physical capacity for some logging and sawmill jobs has been established and validated selection procedures identified (Scantrino, 1985). For other aspects of woods work, there are less published results available, especially for operators of complex mechanical harvesting equipment. Unpublished results and proprietary experience suggest what might be reasonable approaches to improving selection procedures.

Figure 4 identifies how a designed selection process can be validated. Recall that the job/task analysis is the basis for job content. Using the talent of incumbents, supervisors, and job analysts, the abilities needed for the task are identified. Some are physical: depth perception, perceptual speed, hand-eye-foot coordination, reflexes, finger dexterity, etc. Others are mental: time sharing, visualization, stress tolerance, spatial orientation, etc. Instruments (paper tests and devices) to measure these abilities can be evaluated with the help of psychologists. The most appropriate ones can be selected as candidate instruments.

The measure of the match between the abilities and what is needed in job performance is validity. Job performance of existing operators can be evaluated through behavioral observation scales (fig. 3). If we can administer both the performance appraisal and abilities instruments to a statistical sample of existing operators, we can develop a correlation matrix. This shows the relationship of abilities to performance.

The next step is to select from the abilities instruments, the ones that best meet needs of practicability and validity. Not all instruments need to be used as the basis for selection. You also need to establish a cutoff score that makes sense for the task and likely pool of applicants.

This description is an ideal one but it has been accomplished for a logging job (loader operator). However, the results remain proprietary. A similar project might be undertaken by logging industry associations or a consortium of firms interested in better selection of machine operators. Given some average machine operating costs and rates, it is possible to estimate the value of selection strategies for machine operators.

There are always costs associated with establishing a selection system, however, what opportunities are lost by placing a $400,000 asset in the clumsy hands of your wife's uncle's cousin?

DESIGNED TRAINING

On the surface, training in logging tasks seems a straightforward procedure. However, loggers readily admit they don't know how to be trainers or they view their small firms as unsuitable for training. There is a definable process that can help loggers better train their workers.

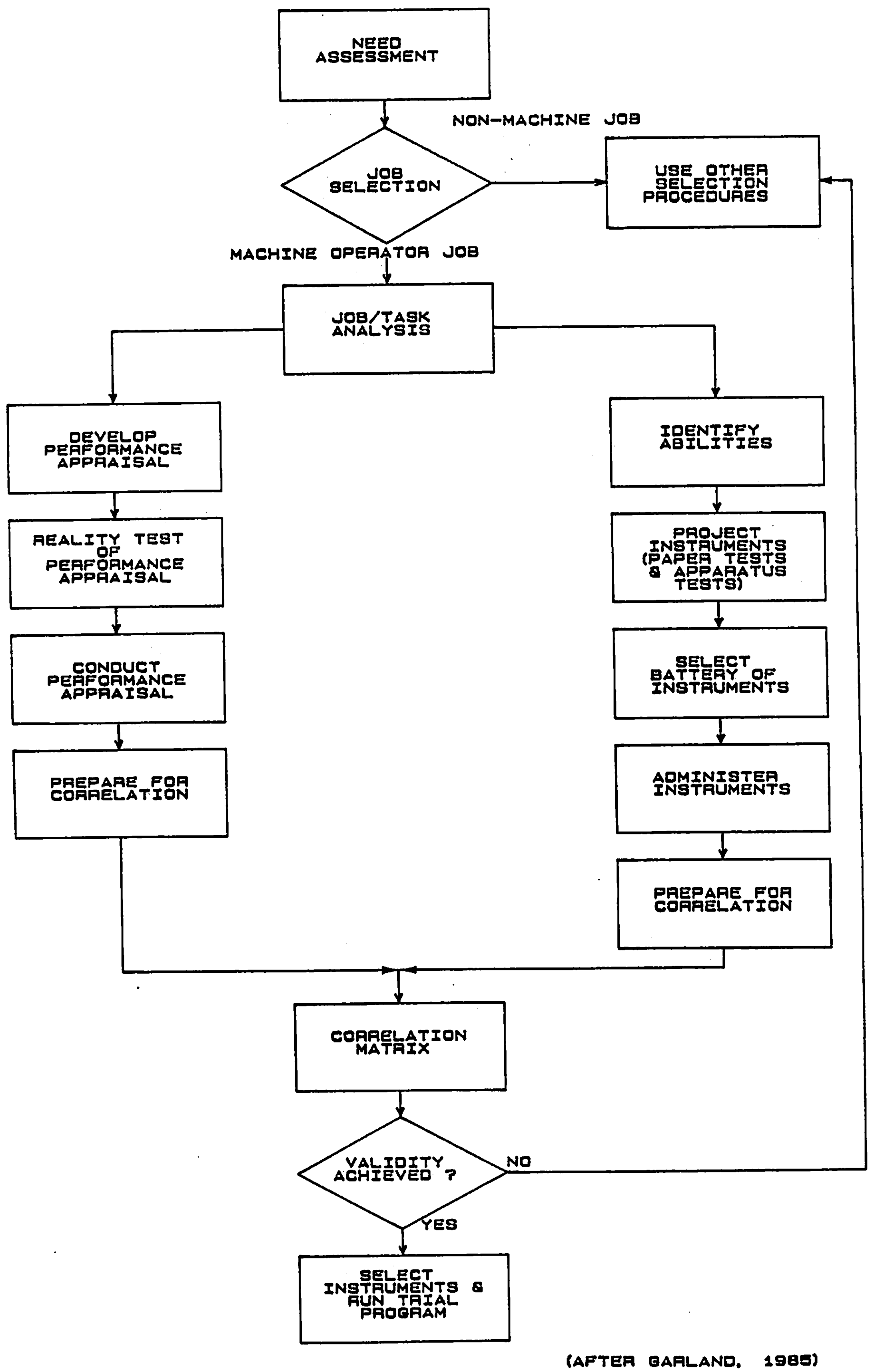

Figure 4--Flowchart of a Selection/Validation Effort.

Process of Training Design

The process of designing training can be briefly outlined here, but good examples of training efforts show the process more effectively.

Training objectives come from the job/task analysis developed earlier. Objectives break the job into bite-sized tasks that are comprehensible to trainees. If you can isolate Principles associated with each task, they can trigger the trainee's memory for more detailed training received earlier. It takes some skill to develop the Content and Presentation of training. However, if some loggers who are demonstrating a technique would simply slow down their movements, the trainees could get the sequence correct and go for speed later.

Training needs some Feedback-Coaching activities that are effective. The best advice is to place yourself in the position of the person being trained. How would you respond to a vulgar tongue-lashing? There also is need for Performance Assessment during training. Recall the performance appraisal using behavioral observation scales? These devices also serve to measure training effectiveness.

Finally, you need Training Materials to help do the logging training. Unfortuntately, these materials are largely lacking and serve as a formidable obstacle to training within the logging industry.

Types of Training

There are several types of training to consider for the logging industry. I have earlier identified them and now repeat them here for completeness (Garland, 1985). Decisions need to be made on where the most pressing needs are within the firm for the types of training needed.

* Entry level training - Safety statistics point to the lack of training associated with this group. And, in many operations, the entry level positions determine the pace of operations or are the source of production bottlenecks.

* Integrated job sequence training - We presume a job progression in logging, but do little to provide training needed for workers to occupy successively more skilled positions.

* Machine operator training - Few firms begin with fundamental principles and build to a high level of operator proficiency and machine productivity in the logging system.

* "Whole concept" training - Jobs are often viewed as isolated activities and the impacts of job performance on downstream functions are not apparent to workers. Workers learn by errors when they foul up subsequent operations.

* Crew productivity training - Tasks that require crew coordination and cooperation need to have training on specific techniques and principles of productivity to achieve the potential of the operation.

Removing Obstacles - An Example

The lack of training materials has been earlier identified as an obstacle to logging firms. I have tried to partially eliminate this obstacle for firms in the west with the production of ten plastic-coated training cards for logging.

Figure 5 shows one of these cards with both the front and back content for "The Meaning of 'In the Clear'" card. A listing of the ten cards is shown below:

1. Using cards to train for safe and effective logging techniques
2. Orienting new employes
3. Skidding machine operations
4. Rigging crew hazards
5. Safe and effective chainsaw use
6. Hazards at the landing
7. The meaning of "in the clear"
8. Chokersetting techniques
9. Basic felling techniques
10. Stump selection and notching

The process of developing the cards followed the designed training process above. I worked with a firm whose management, supervisors, and job incumbents conducted the task analyses that underlie the training content. The fourteen members of this group had 240 years of logging experience.

The cards are distributed through the Forestry Media Center at Oregon State University. In addition, the Oregon Logging Conference provided funding for the mass production of the cards and will make them available at their equipment show and conference next February. A variety of other organizations from insurance companies to industry associations will likely use them with their clients and members.

INTERACTIONS BETWEEN SELECTION AND TRAINING

It is useful to more fully understand how selection and training systems work together. Figure 6 shows how selection and training systems serve as screens impacting both the quality and quantity of woodsworkers for particular jobs.

At the highest level of selection and training, some number of applicants (5 for example) enter the process. Selection removes some two and lack of success in training removes another one. The firm is left with two employes who are likely to be successful in their job performance.

If only a selection system is used with the current training practices, one of the screens is removed. Two applicants may be rejected, but the quality of the employes going through training is variable.

Another approach is to use selection as a screening measure to accumulate information on a selection system. This puts the burden on training to help eliminate unsuccessful employes. If a well-designed training system is in place, it can serve this selection function quite well. Job candidates, who are performing poorly in training and receive this in feedback/coaching activities, often choose other work or other jobs on their own without following through the training period.

At the current level of industry selection and training, there is little screening effects and a wide variation in employe performance.

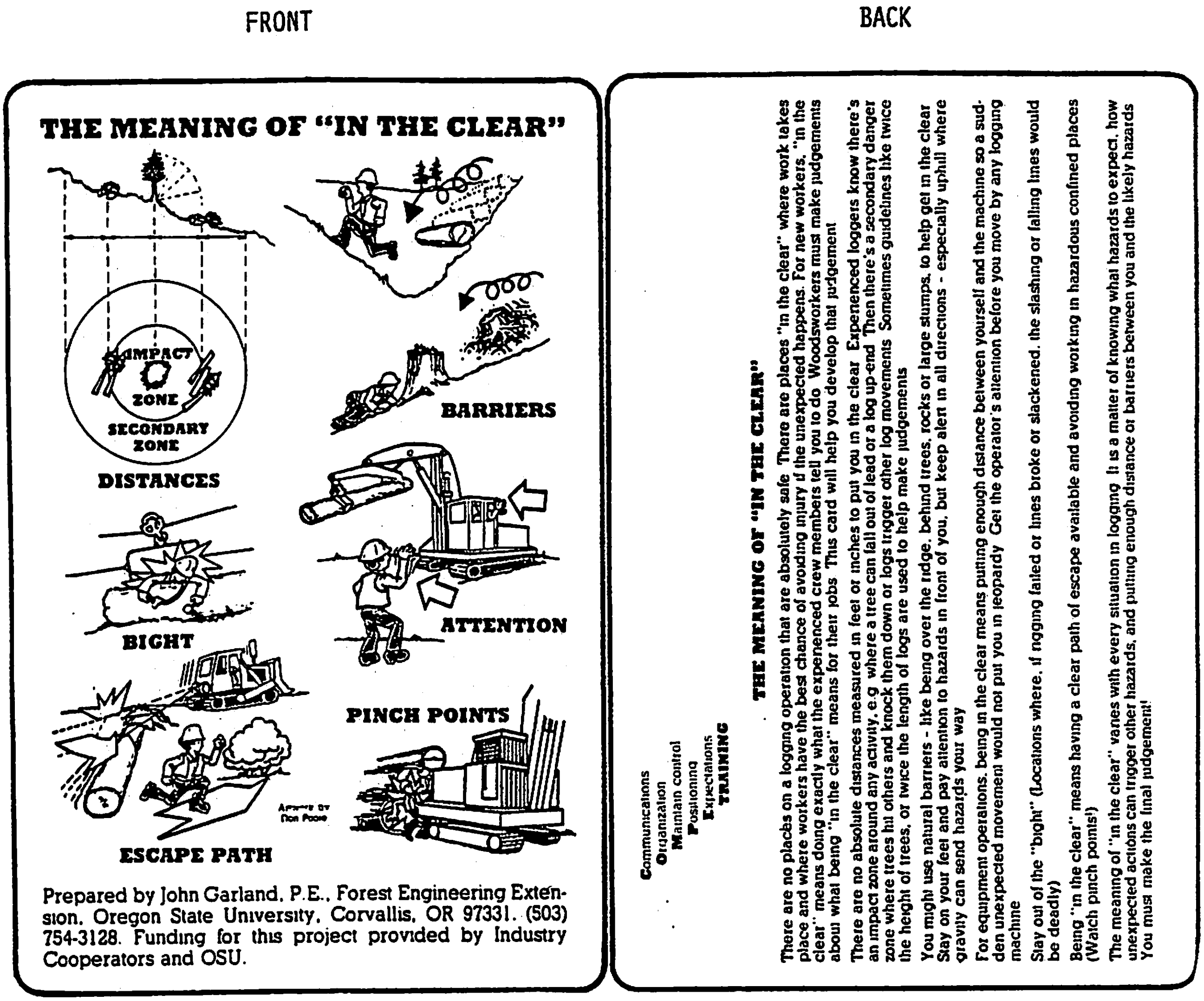

Figure 5—Sample Training Card

If we assume the gains for each of these descriptions to be related to the full selection and training approach (100%), I can estimate the relative gains of the other approaches. The second approach (selection system with current training) would achieve 65 percent of the potential. The third approach (selection system for information only and designed training) might yield 80 percent of the available gains. Current practices of selection and training only reach about 50 percent of the potential of the logging labor force.

DESIGNED INCENTIVE (MOTIVATION) SYSTEMS

Not all incentive systems in logging go through a conscious design process. Payment by the piece or unit volume is a conceptually simple (and motivating) approach. For some small firms (and of course partnerships), ownership or viability of the firm itself provides strong motivation for success. However, as firms increase in size and payment systems become complex, a designed incentive system is likely to be more effective. Also, there may be legal obligations associated with employing workers that need to be taken into account.

Range of Programs

Most actions by management or supervision are not neutral in their effects on motivation. They either provide positive motivation or they punish correct performance, provide obstacles, or reinforce non-performance. With this grim thought in mind, you can review the list of current efforts in motivating the logging labor force.

It is not possible here to outline all of the incentive programs in logging. However, I can list some pre-conditions to implementing incentive programs, and I can further list some design criteria for assessing incentive schemes. The magnitude and distribution of gains due to incentives are important considerations. Finally, for incentive systems to be effective, there will likely need to be some changes in the way logging managers and supervisors do their jobs.

Pre-Conditions for Incentive Programs

I have observed most of these conditions in place before incentive programs were established and became effective. First, there was management

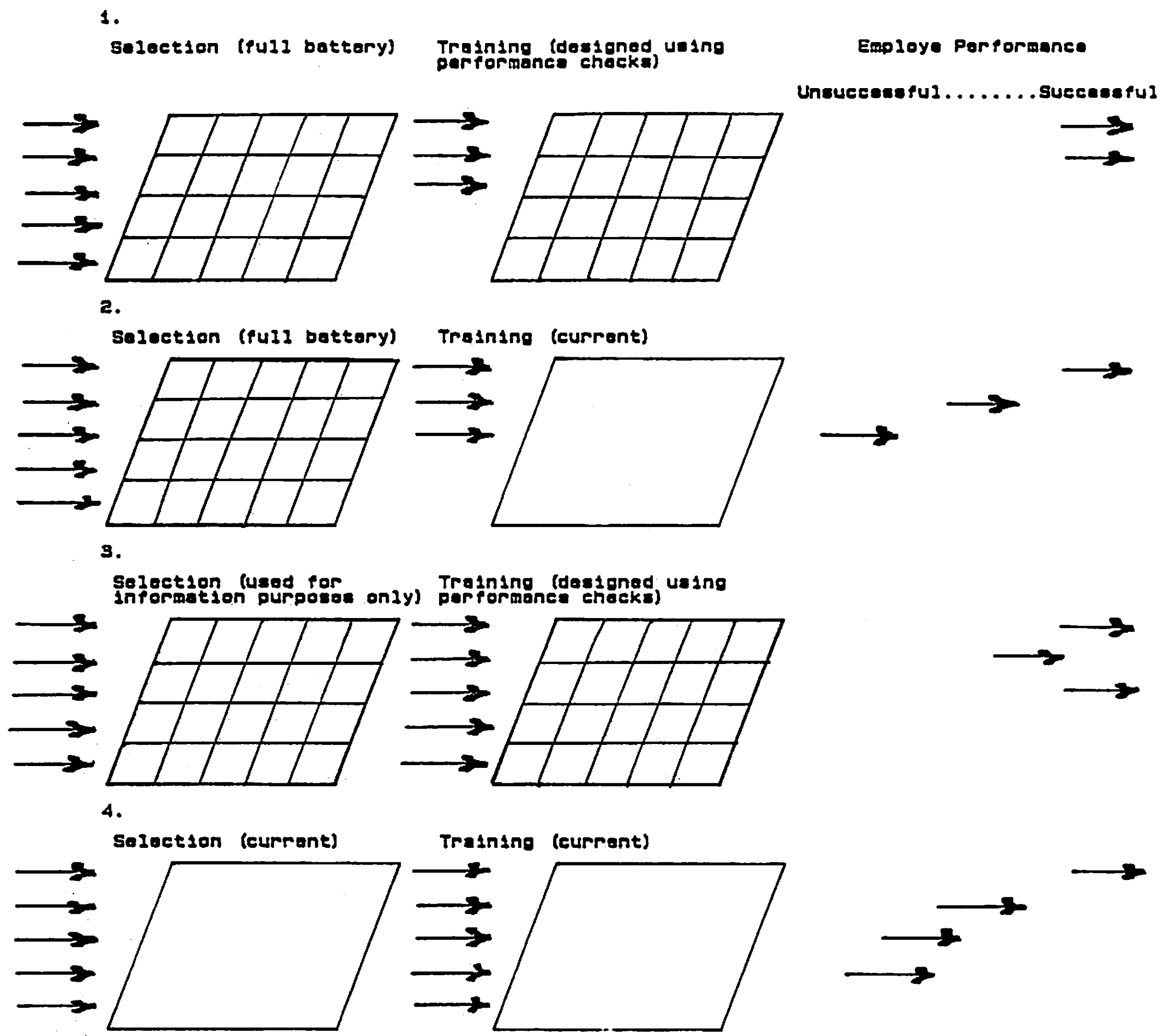

Figure 6--The Interaction of Selection and Training.

pressure and commitment to make an incentive program work. Usually there was a single individual or a small group of advocates willing to put in the energy to make the system function in the logging environment. Second, the firm had a good handle on selection and training of workers. In the absence of trained workers, you could expect mistakes to be made even faster than usual.

Third, there needs to be reasonable stability of work. Workers quickly perceive that the harder they work, the less work is available to them. There must be a match of crew size and composition to production levels. Fourth, there must be employe/management trust. Past adversarial relations will taint the flexible processes needed to work out the disagreements that are certain to arise.

Finally, successful incentive efforts have a win/win philosophy. Punishments are reduced or eliminated, and the incentive system is relatively free from capricious manipulation. A major benefit of incentive systems is that company goals and the goals of individual workers are brought into alignment.

Design Criteria

In addition to the pre-conditions above, there are some design criteria to consider in developing incentive systems. Because of the number of these, only a few brief comments are possible. Also, the order presented is unrelated to their importance.

* Time Delays Cannot Be a Factor: The time-gap between performance and reward must be as short as practical. Year-end bonuses may not be motivating at all.

* Clear Links Between Actions and Results: Workers need to know what they did to achieve positive results, and how their actions lead to no gains. Remove the mystery of results.

* No Arbitrary Caps on Benefits: If workers bump up against arbitrary caps on incentive gains, they will only produce to that level and overall opportunities will be lost.

* Resolve Equity Issues: Workers know the relationship between effort and results. If inequities exist, they must be removed or the chances for gain (or loss) equal for everyone.

Supervisors are especially important problems if worker pay greatly exceeds their salaries.

* Short versus Long Run: Using incentive systems to cream logging chances or run equipment into junk will not make the firm viable. Environmental performance is especially significant to long run consequences.

* Sound Base for Comparison: Many systems rely on historical records, production estimates, or the opinion of knowledgeable people to set a basis for measuring productivity gains. If the base is in error, the incentive system is doomed.

* Realize Administrative Resources and Costs: Substantial administrative resources are needed for some incentive systems, especially those that rely on information feedback to help improve productive behaviors.

* Select Size of Incentive Unit: Some analysis is needed before the size of the incentive unit is selected. Individuals, crews, departments, and camps have all been tried. Generally, smaller is better.

* Adjustments During Program Life: Once installed, incentive systems need frequent maintenance and periodic review and reforms to match current conditions.

* Displaced Workers: If incentive systems work, you may need fewer workers. Some forethought is needed to handle this humanely, effectively, and legally.

* Trust Relationship Essential: How can management/employe trust remain strong or improve over the course of installing and using incentives?

Magnitude of Gains

Gains from incentive systems can be very high. Michie (1983) reports gains as high as 39 percent. I also know of crews that have worked eight months under an incentive system and never received a bonus no matter how hard they tried. (Is this an incentive system?)

How the gains are distributed between workers and company is another important issue. Fifty-fifty splits to 80-20 percent splits are in use at present. How should gains be distributed? What if a guaranteed base wage is involved? These questions merit further research.

In my judgment, at least some of the early gains (10-15 percent) may be attributed to slack in the system (everyone pushes a bit harder). Another source of early gains is the "Hawthorne Effect." Workers respond to nearly any management interest in their work activities. However, gains beyond 15 percent or so will likely be achieved by doing some things differently: efficient, smaller crews; better machine utilization; better system production balances; improved cost control; and better people/task selection as well as training.

Recall the pre-conditions for incentive systems. If the firm is lacking these elements, some of the gains will be directed toward making the incentive system work rather than taking advantage of opportunities.

Changes for Management and Supervisors

When incentive systems work in logging there are substantial changes to management and supervision. For first-line supervisors, there is less need for egos and having the crew idle while a decision is made where to put the landing. Workers won't stand for it; delays cost them as well as the company. Supervisors may spend more time coaching workers, removing obstacles, and training the crew how to improve productivity rather than "giving orders." Managers may have difficulty implementing the incentive system, resolving equity issues, and coping with support demands placed on them by logging crews.

Traditional management functions and legal obligations are changed but certainly not eliminated with incentive systems. Worker health and safety, environmental performance, responses to upper management, timber supply and demand, quality issues, etc. are not magically resolved with incentives.

Some workers, crews, and supervisors may have difficulty in the transition to an incentive system. If you can't blame management for your lack of success or you can't throw your hard hat on the ground to scare the crew, then some new work practices and supervision styles will be needed. One supervisor told me he thought it would take the "fun" out of logging, but instead he said he actually was spending more time on the important things.

PROSPECTS FOR THE NEAR TERM

By the near term, I mean the next five years or so. Periods longer than that require a crystal ball.

Selection

If wages, benefits, and work conditions in logging were more attractive, there would be pressures on firms to select the best applicants from the pool. The truth is that logging firms often face the choice of picking from the low end of the spectrum. This means that selection systems will be matched to the needs of the small firms.

Selection systems might improve to help eliminate problems, e.g., chronic injury cases, and a few larger firms may experiment with strength testing. Drug testing may become a part of the industry as various insurers recognize there may be a relationship to drugs with fatalities and severe injuries.

As mechanization increases, there will be greater need to identify the physical and mental abilities of machine operators. Experience and training can only build on the abilities already present in operators. An industry association or consortium of firms needs to take the leadership for operator selection. Such leadership is presently lacking.

Training

I believe the industry will see an increase in logger training from entry level training with a safety emphasis to crew productivity training. The needs are becoming recognized by a number of associations, trade journals, some large firms, insurance companies, and the academic and governmental sectors.

A limiting factor will be the availability of suitable training materials and efforts to "train the trainers" in logging firms. These limiting factors could be turned into driving forces if the industry as a whole could generate resources to hasten the production of materials and support efforts to help develop trainers. Ironically, other countries with more directed efforts may move faster than the amorphous North American logging industry.

Incentive (Motivation) Systems

Trends are for increasing use of incentive systems in logging. Most of the current systems will continue and expand. Research is underway at Oregon State to document and examine some of the incentive systems used in the west. One project is aimed at finding out how an incentive system can be developed and made workable within small contract logging firms. Incentive systems based on information will follow the trend of increasing use of small computers in logging.

In the west, those large corporate firms with logging divisions will expand the use of "pay-for-production" or contractor parity incentive systems. Recent union negotiations and contracts adopt incentive systems with support coming from both unions and companies. Expansion of these types of systems is likely for some larger, independent loggers and mid-size forestry firms. Lack of information is one of the limiting factors to wider adoption of incentive systems.

Relation to Other Industry Trends

After nearly fifteen years of stressing the importance of the logging labor force, I am gratified to see the increasing interest in selection, training, and motivation. However, there is still an absence of combined effort within the logging industry to help firms realize the potentials. In fact, when the cyclical downturns occur in the forest products industry, these are the types of programs most quickly cut out. Nonetheless, once a critical mass of common thinking evolves on selection, training, and motivation, the industry can make quicker progress. I enlist your support in this effort!

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In-Woods Weighing Systems for Southern Logging[1]

Robert M. Shaffer and Joseph F. McNeel[2]

Abstract: Southern logging contractors need to maximize log truck payload without exceeding legal weight limits to operate efficiently. On-board electronic scales, loader-mounted scales, and portable weighing pads are discussed as possible tools to help achieve this goal.

Keywords: on-board scales, loader-mounted scales, portable weighing pads

Over two-thirds of the South's pulpwood requirements are delivered to the final destination by truck (American Pulpwood Association 1984). Almost every load of wood or logs is trucked at some point during the transition from stump to mill.

Trucking is often the most expensive part of a timber harvesting operation, running as high as 50 percent of the total logging cost. Southern loggers hauling timber are faced with high equipment costs, low profit margins, and strict government regulations. Whether or not a logger stays in business often depends on the efficiency of the trucking phase of his operation.

Since the Surface Transportation Assistance Act was passed in 1974, truck weight laws have become increasingly restrictive in most southern states. Log trucks are often targeted for weighing by mobile Highway Department crews using portable scales on the less-traveled secondary roads. Trucks are checked for individual axle and tandem weights, as well as the gross weight allowance. Overweight fines are usually expensive, often costing a logger several weeks' profit.

Maximizing the legal payload on every trip to the mill is one of the most effective ways to reduce trucking cost (Beardsell 1986). However, this is easier said than done for a logger loading his trucks at a remote woods landing. Accurately estimating the weight of a load of logs or pulpwood is difficult under the best circumstances, even for the most experienced logger. Unfortunately, trees vary greatly in terms of size, shape, density, and center of gravity. The weight of an individual log can vary as much as several hundred pounds, depending on its length, diameter, species, where it was cut, and even the time of year. Axle weights depend upon the exact placement of the log on the truck, and even things like mud and the amount of fuel in the tanks can affect the truck's weight distribution.

So the logger is caught in a serious dilemma--he needs to load each truck to its maximum payload, but he'd better not exceed the legal limit or he may face an overweight fine. A recent study at three paper mills by researchers at Virginia Tech found that, in their attempt to avoid overweight fines, many loggers were regularly underloading their trucks, costing them several thousand dollars per year in lost revenue (Beardsell 1986).

A potential solution to this problem has evolved in recent years due to advances in technology. Electronic and hydraulic weighing devices are now available to the logger that can provide an accurate estimate of his truck's weight. The three major systems that show promise for southern loggers are on-board truck scales, loader-mounted scales, and portable weighing pads.

ON-BOARD SCALES

Electronic on-board scales have been around for several years but are a relatively new concept for southern loggers. An on-board scale system consists of three components: load cells, an indicator, and a cable to connect the two. The load cell (fig. 1) consists of strain gauges mounted within a high-strength steel bar. For an on-board system, load cells are installed at the primary load-bearing points on the tractor and trailer--usually at the tractor's fifth-wheel mounting brackets (fig. 2) and at the trailer's equalizer hangers on each side of the rear tandem (fig. 3). As the trailer is loaded, electric current passing through the strain gauges is altered due to the very slight bending of the load cells. Although you can't see this bending with the naked eye, it is precisely measured by the amount of resistance met by the electric current. The electric impulse is then fed through the cable to a digital indicator (fig. 4) in the cab, where it is converted to a weight reading. Most on-board systems can display net or gross, axle or tandem, as well as total vehicle weight.

Case studies of two loggers using on-board scales were recently conducted in Georgia and Virginia (Shaffer 1986). The Georgia logging contractor cooperating in the study delivered an average of 1200 tons of pine tree-length per week to two mill locations. His average haul distance was 40 miles. Load weight data was collected from the logger over an 18-month period. During the final 6 months of the study period, his trucks were equipped with on-board scales. Using the scales,

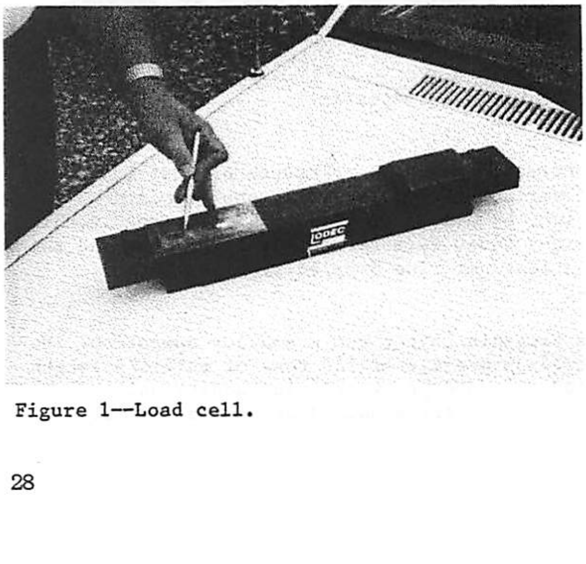

Figure 1--Load cell.

[1] Presented at the 9th Annual Council on Forest Engineering Meeting, Mobile, AL, September 30-October 2, 1986.

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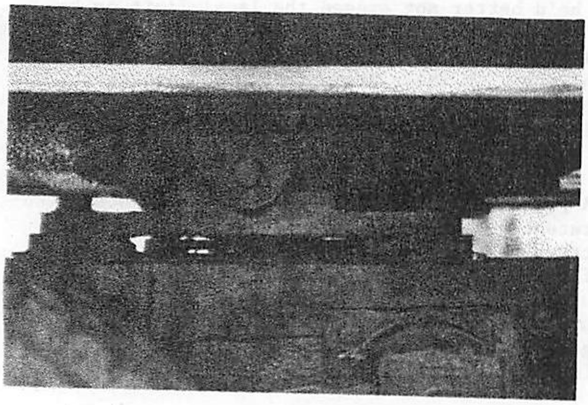

Figure 2--Load cell mounted at tractor's fifth wheel.

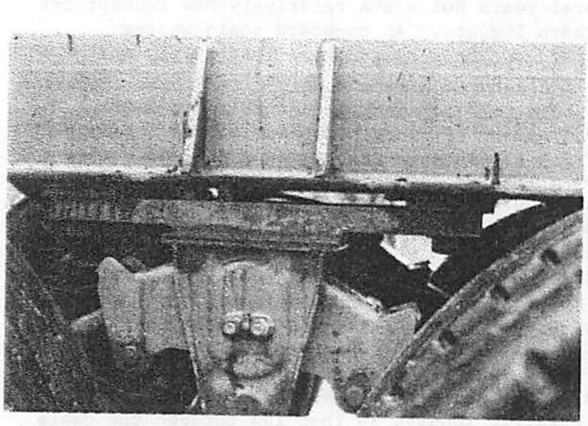

Figure 3--Load cell mounted on rear tandem.

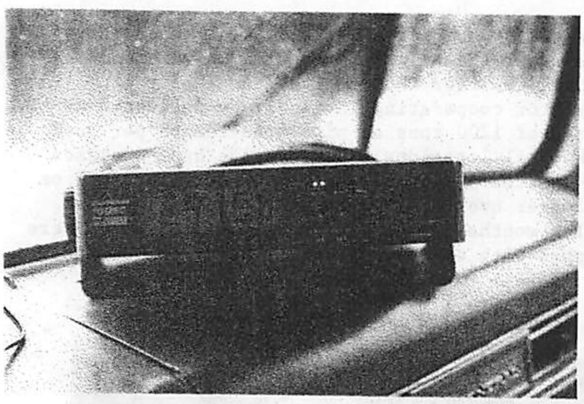

Figure 4--Digital indicator.

the contractor was able to reduce his net load weight variance, as measured by the standard variation, by 0.52 tons (fig. 5). As a result, his overweight fines were reduced by 38 percent and the average cost per fine dropped from $92.69 to $57.64.

The Virginia logger ran a smaller operation. He delivered an average of 130 tons of multiple-length hardwood pulpwood per week, plus additional sawlogs. His average haul distance was 80 miles.

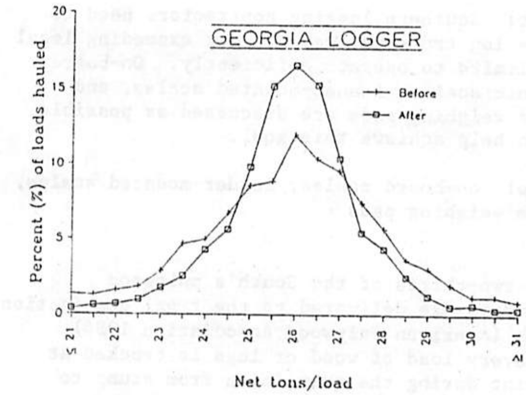

Figure 5--Comparison of net load weight distribution before and after scale installation, Georgia logger.

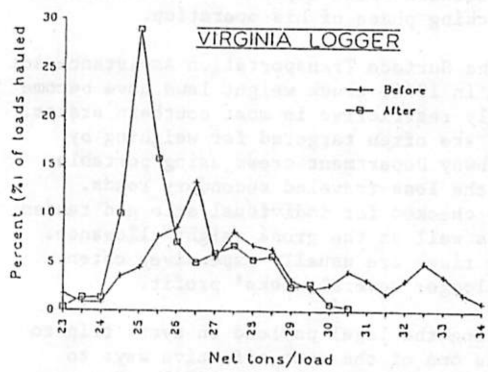

Figure 6--Comparison of net load weight distribution before and after scale installation, Virginia logger.

This contractor provided load weight data for a two-year period, and his truck was equipped with on-board scales during the second year. The scales enabled this logger to reduce his net load weight variance by 1.14 tons (fig. 6). This increased control over load weights allowed him to discontinue a costly practice of hauling pulpwood at night to avoid the state weighing crews. In addition, data collected comparing the weights recorded by the on-board scales with the certified mill scales show the on-board scales to be within 98 percent accurate.

Thus, it appears that on-board scale systems offer southern loggers the advantage of a fast, accurate readout for individual axle and tandem weights, as well as gross vehicle weight, under typical woods-landing conditions. A set of on-board scales currently costs about $4500 installed, so outfitting a large fleet of log trucks can be expensive, and recalibrating units when tractors are pulling several different trailers can also be a problem. Even so, the relatively few southern loggers who have purchased on-board scales to date are almost unanimous in their praise of the system, and many claim to have recovered their investment in a very short time.

LOADER-MOUNTED SCALES

Loader-mounted weighing systems offer an interesting alternative to on-board scales. However, these systems are newer and less tested under southern logging conditions. One loader-mounted system measures the weight of the logs through the increase in hydraulic pressure as the logs are lifted. The system was originally designed for front-end loaders but has recently been adapted for use on knuckle-boom loaders with some success.

In this system, a pressure transducer is connected to the loader's stick boom hydraulic cylinder by a small hydraulic line. When the boom is operated to lift the logs, the transducer senses the pressure increase and converts it to an electronic impulse. This impulse is then transmitted by a cable to a computerized indicator in the loader cab, where it is converted to a digital weight reading. Most indicators have the ability to accumulate the individual grapple load weights into a running total as the trailer is being loaded.

In order to attain the necessary accuracy with a hydraulic loader-mounted system, the logs must be weighed with the boom in the same relative position each time. Some systems have a switch that is automatically activated and records the weight as the boom simply passes through the prescribed position, while other systems call for the loader operator to manually trigger the weight recording when he moves the boom into the proper weighing posture. In some cases, this could reduce loader productivity.

Manufacturers report accuracy within 2 percent of the total load weight when hydraulic-sensing loader-mounted weighing systems are properly used. System cost is currently around $6000. Loader-mounted systems provide an estimate of the net vehicle payload only, so they might not meet the needs of a logger operating in an area where individual axle and tandem weights are strictly enforced. In addition, the jury still seems to be out regarding the reliability of these systems. However, they offer the potential of a low-cost alternative for a logger operating several trucks in a situation where gross vehicle weight is his major concern.

PORTABLE WEIGHING PADS

A third system that offers some potential for logging is portable weighing pads. Portable pads have been used in agricultural applications for many years but are a new concept in logging. Modern portable weighing pads use electronic load cells, similar to those in on-board scales, but weigh only one axle or tandem at a time. The load cells are usually connected to a digital indicator that can be placed at a convenient location for the truck driver to read from the cab. Since portable pads provide a reading of individual axle or tandem weights only, gross vehicle weight must be computed manually. In addition, since weighing is done after loading is completed, required load adjustments may cause production delays. Typical pads weigh about 1000 pounds and can be easily transported from one logging site to the next. However, care must be taken to construct a suitable bed for the pad to rest on at each weighing location. About 12 inches of crushed stone on a firm and level site provides a good base for the pad and ensures accurate weight readings. Portable weighing pads currently start at about $4000. They would appear to be perhaps best suited for logging operations on large tracts where the pads, along with a back-up loader to make weight adjustments, could be set up on a main exit haul road where they would only have to be moved infrequently.

Southern logging contractors should examine the variance of their net load weights, the frequency and cost of overweight fines, and the cost associated with any operational measures taken to avoid fines when considering an investment in an in-woods weighing system. The benefits gained from any of the weighing systems described here will vary from one operation to another, depending upon the logger's specific situation. In-woods weighing may offer a tool that could improve the efficiency of many southern logging operations.

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GEOTEXTILE MYTHOLOGY IN FOREST ROAD CONSTRUCTION: Design Considerations[1]

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Abstract

Forest engineers are understandably confused about just what a geotextile does in forest roads built on soft subgrades, and how to go about selecting the proper geotextiles for given projects. Manufacturer's literature is often confusing, because of the multiplicity of design assumptions and approaches. The current paper addresses these problems, by presenting the results of approximately 1/3 scale tests performed on model road sections, in a 2.5 metre square by 1.5 metre deep soil testing bin. The test results indicate that rather than acting as reinforcement, the geotextiles really only served as separators, suggesting that less expensive, lighter - weight geotextiles would be adequate in forest road construction on thin fills. This conclusion is confirmed by a mathematical treatment of the "reinforcement" mechanism in thin fills.

Keywords: reinforcement, separation, thin fills, road stiffness, rheological model

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IF A MAP of the occurrence of muskeg is superimposed over a map of the areal distribution of timber reserves in Canada, it is evident that Canadian forest engineers come up against the problem of building roads over muskeg very often. Geotextiles present new solutions to the problem, but a great deal of "mythology" has arisen around them, leaving engineers understandably confused.

The use of geotextiles in road construction has mushroomed. Since the first recorded use of a cotton fabric in road construction in 1936 (Christopher and Holtz, 1985), through the initial use of synthetics in the early 1970's, geotextile manufacturers in Canada and the US have approached an annual total production of 150 square kilometres. The synthetics have been employed in countless road construction, erosion control, embankment stabilization and retaining wall projects, are being used for such things as snow fencing and silt control fences, and even figured in the recent Falklands hostilities.

However, despite, or maybe because of such rapid development, the typical engineer is still left with little to go on when carrying out the design of roads using geotextiles. There are few comprehensive design methods yet, and one is often stuck using literature produced by individual manufacturers for specific products.

In a study where the same field data was input to six different design methods, (Knappe, 1986), it was found that the recommended road base thicknesses for a geotextile - reinforced road over peat ranged from 0.2 m to 1.7 m. Obviously, some of the methods proposed were downright inapplicable, but the dilemma is, which ones?

Research is currently underway at the Department of Forest Engineering, University of New Brunswick, to attempt to derive an "all encompassing" design approach, one applicable to all types of geotextiles, which will allow comparison of one fabric to another, and to predict the performance of the road once constructed.

Before discussing the research, it is worthwhile to first examine what is expected of the geotextile in the road structure. This is where one encounters the mythology, in this author's opinion.

Geotextile Functions in Unpaved Roads

It is commonly held that the geotextile serves two functions in the road structure, separation and reinforcement. It is easily demonstrated that the geotextile keeps the gravel of the road base from punching into the soft subgrade soil, and keeps the soft subgrade soil from impregnating the gravel, impairing its strength and bearing capacity.

In addition, it is proposed by many that the geotextile reinforces the road structure. It is thought that the fabric develops a membrane action (similar to the support the canvas of a trampoline gives a gymnast), through the generation of tensile forces in the fabric. The friction on the top surface of the geotextile, due to the surcharge of the road base gravel, together with the friction (or cohesion) developed on the bottom face of the geotextile are thought to anchor the geotextile (Figure 1). The vertical component of the tension force in the anchored fabric augments the subgrade soil's resistance to compression, therefore reinforcing the road structure.

Problems

There are a number of problems with this theory.

To begin, the thickness of the typical forest road structure is usually relatively small. Although thick fills, upon which much of the

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[1]Presented at the 9th Annual Council on Forest Engineering Meeting, Mobile, AL, September 29 - October 2, 1986.

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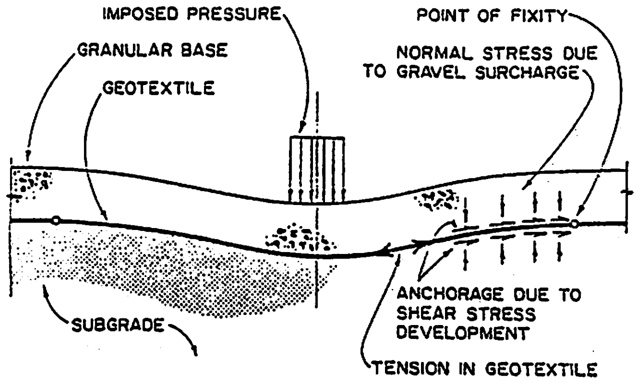

Figure 1. Assumed load support mechanism.

reported research has been done, can indeed be reinforced by a deep geotextile layer, the typical forest road does not present these conditions. The thin fill of the forest road structure can develop very little friction between it and the geotextile, on the upper surface of the fabric.

In many cases, no friction at all is developed between the gravel and the geotextile (Jarrett and Bathurst, 1985), as the fill ends up "going along for the ride" on the geotextile (Figure 2). With no relative movement between the geotextile and the gravel, no shear resistance can be developed.

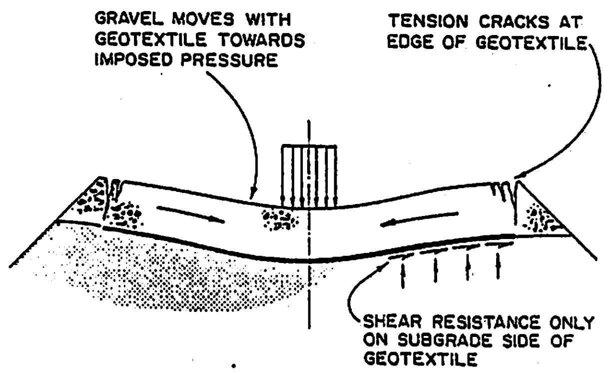

Figure 2. Observed load support mechanism.

The subgrade usually cannot supply much restraint either. The reason for using a geotextile in the first place is usually to overcome the problems associated with a soft compressible soil. Since such soils generally have a concomitant poor shear strength, the resultant shear resistance developed on the bottom face of the geotextile is also usually low (Addo, 1986, Small, 1985).

As a result, very little restraint can be offered to the geotextile. With little restraint, it can develop little tensile force, and therefore contribute very little additional vertical load resistance to the overall road structure.

One last consideration adds to this. Road structures are built with horizontal layers, including the geotextile layer. How can a horizontal geotextile be expected to develop much vertical load resistance, without undue settlement first?

Therein lies the myth: because of the actual field conditions into which the geotextile is placed, it is not likely to generate the "reinforcement" a design engineer is led to believe it will.

The Research Program

The basic hypothesis of the research was that if a geotextile indeed reinforces the road section, a stiffer geotextile, that is, one with a higher modulus, would have a greater reinforcing effect than one with a lower modulus. Also, if the geotextile is completely restrained only a short distance from the point of load application, it should have a much greater reinforcing effect than if it is completely unrestrained only a short distance from the load.

Two sets of laboratory model tests were carried out, in an effort to gather the necessary data under well controlled conditions. A relatively small number of tests were performed at approximately 1/3 scale, in a steel bin 2.5 m square by 1.5 m high (Douglas and Kelly, 1986). A small box 1.3 m long, by 0.7 m high, by 0.3 m deep was used to perform similar tests (Bessey, 1985). Its smaller size allowed a greater number of tests to be carried out, but the test results could not necessarily be scaled up to full scale directly. However, the results were useful in establishing trends.

In both cases, artificial sphagnum peat beds were produced by first mixing bales of horticultural peat at very high water content, and then draining it off through the bottom, until a constant water content was obtained, following a method established by Jarrett (1984). The average peat water content ranged from approximately 500 percent to 1000 percent for subgrades prepared in the large bin (Figure 3). Since mixing and draining were done before the commencement of each load test, the consistency of the peat beds from one test to the next was a concern.

There was a general progressive increase in the average drained water content of the peat as the water content was cycled (Figure 3). However, as will be shown later, the peat stiffness was not particularly sensitive to the water content, and it was concluded that peat beds with satisfactory consistency were produced from one test to the next.

Following the production of the "reconstituted" peat bed in either the small box or the large bin, model road sections were built by placing a sheet of geotextile on the peat surface, and covering it with crushed gravel to the required depth.

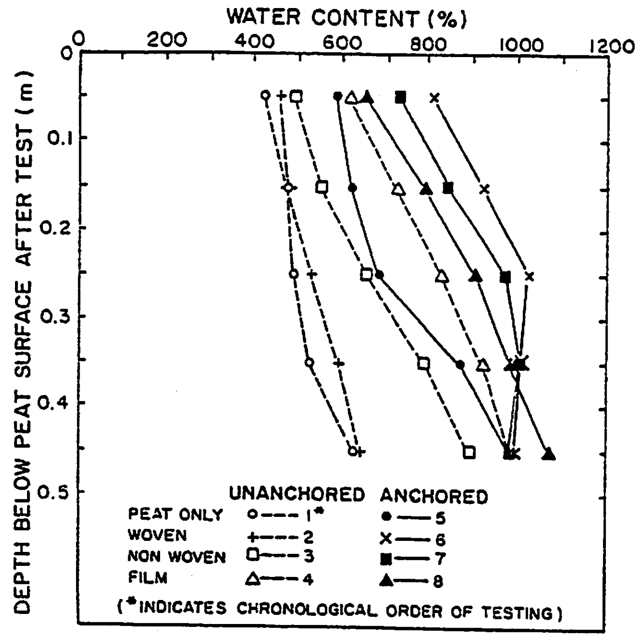

Figure 3. Peat water contents, large bin.

Two geotextiles were used: Mirafi P 500, a woven polypropylene material (to be called "woven" in the rest of this paper) and P 350, a nonwoven polyester material ("nonwoven"). The woven and nonwoven geotextiles had reported respective unit weights of 160 g/m² and 400 g/m², and respective grab strengths of 890 N and 880 N (Mirafi, undated). In addition, 0.102 mm thick polyethylene film commonly used as a vapour barrier in house construction was used. The results of wide strip tension tests carried out on these "fabrics" are given in Table 1.

Table 1

GEOTEXTILE TENSION TEST RESULTS
(after Douglas et al, 1985)

Fabric	Warp or Weft	Width (mm)	Tensile Modulus (kN/m)	Failure Load (kN/m)	Failure Strain (pct)
woven	warp	100	90	24	30
		200	88	24	32
	weft	100	123	27	23
		200	119	27	24
non-woven	warp	100	47	18	43
		200	45	18	43
	weft	100	26	14	56
		200	27	14	53
film	weft	100	6.9	0.83	19
		200	12.	0.85	19

Note Depending upon the length of the specimen, strain rate was 10 or 13 percent per minute.
Results are averaged over the following length to width (L/W) ratios:
for W = 100 mm, L/W = {0.75, 1.0, 1.5, 2.0}
for W = 200 mm, L/W = {0.375, 0.5, 0.75, 1.0}

With the load tests in the box or bin inducing plane strain in the geotextile in the weft (cross machine) direction, it is seen that the operative wide strip tensile modulus and strength of the woven geotextile were approximately 4.5 times and twice that of the nonwoven material, respectively. The polyethylene film was indeed very weak and extensible by comparison.

Crushed limestone with particle sizes ranging from 19 mm to 4.76 mm, and a uniformity coefficient of 1.43, was used for the uncompacted gravel layer.

As had been mentioned earlier, the peat stiffness was relatively insensitive to the as-tested water content. It was tested in two ways.

Five 300 mm diameter plate load tests carried out on a peat bed prepared in the bin in the usual manner prior to the beginning of all tests in the bin yielded an average subgrade modulus of 190 kN/m³. Some 13 months and over 10 wetting and drying cycles after the start of the testing program, two more similar plate load tests yielded a subgrade modulus of 200 kN/m³.

At intervals throughout the testing program, strip load tests inducing plane strain in the peat were performed, using a 250 mm wide beam spanning the full length of the test bin. These tests gave plane strain moduli of subgrade reaction of 170 and 145 kN/m³. Figure 4 indicates the close match of the strip load tests performed on the peat surface in the bin.

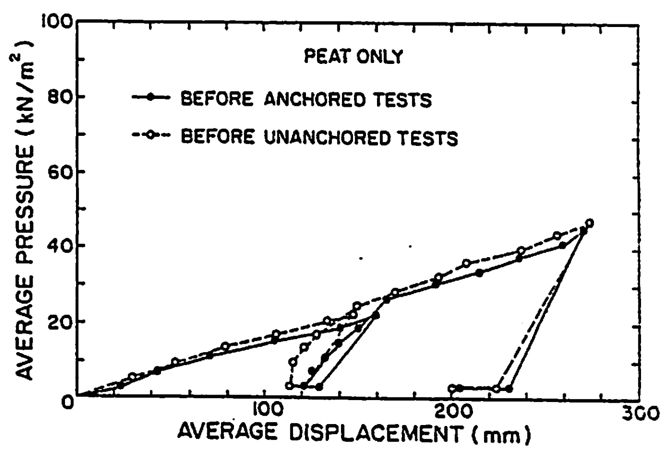

Figure 4. Load tests on peat surface.

With what was considered to be the satisfactory production of sufficiently consistent peat beds, the effects of the geotextile modulus and anchorage of the geotextile were investigated with a series of plane strain inducing strip load tests using 250 mm and 75 mm wide load beams in the bin and small box respectively. Anchorage was effected in the large bin using the arrangement shown in Figure 5. A completely

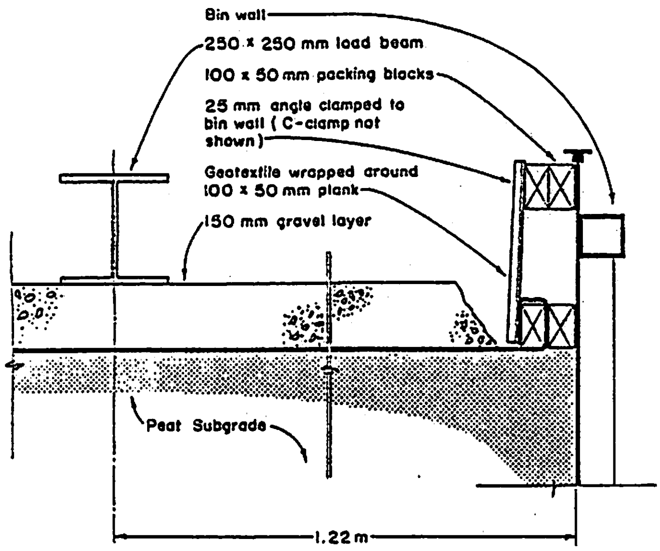

Figure 5. Large bin test arrangement.

<u>unanchored</u> arrangement was achieved when desired by simply omitting the clamping detail, and leaving the edge of the geotextile free. No anchored tests were performed in the small box.

Figures 6 to 9 inclusive show the results of these tests, where the gravel thickness to loaded strip width ratio (H/B) was 0.6. Figure 6 is for the anchored tests only, whereas anchored and unanchored tests are summarized in Figures 7 to 9, and in Table 2.

Test Observations

The overall initial road section stiffness may be defined as the initial slope of the pressure - displacement curve. This stiffness is an indication to the design engineer of how deep a rut (average displacement, in Figures 6 to 9) will form, for a given wheel load (average applied pressure), on the first pass of the wheel.

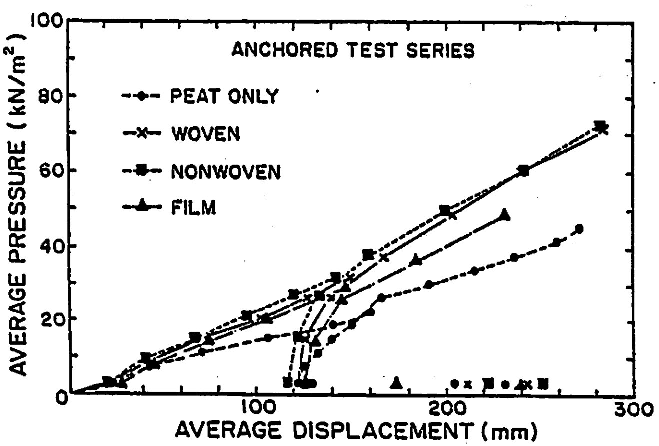

Figure 6. Anchored test results.

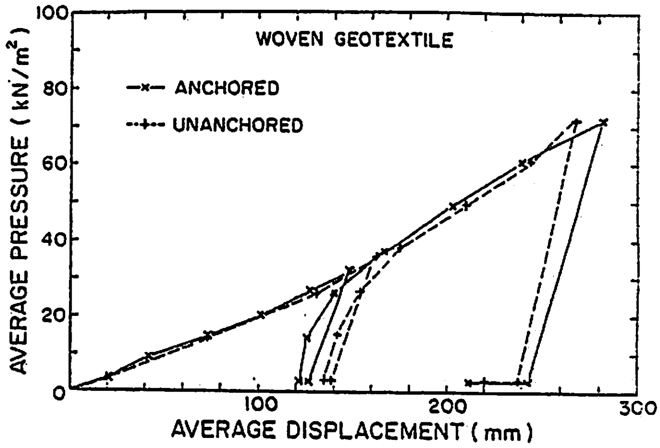

Figure 7. Test results, woven geotextile. H/B = 0.6.

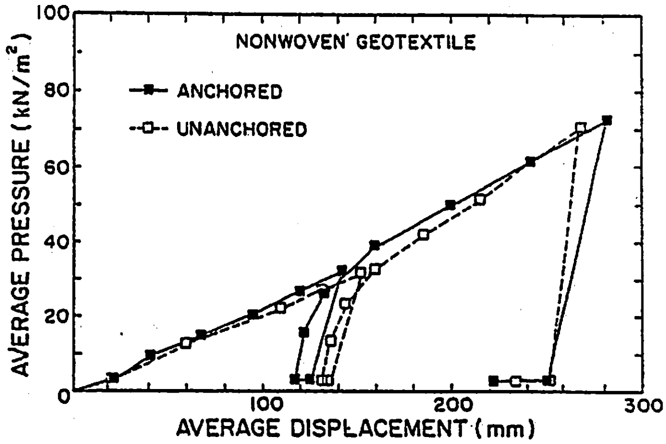

Figure 8. Test results, nonwoven geotextile. H/B = 0.6.

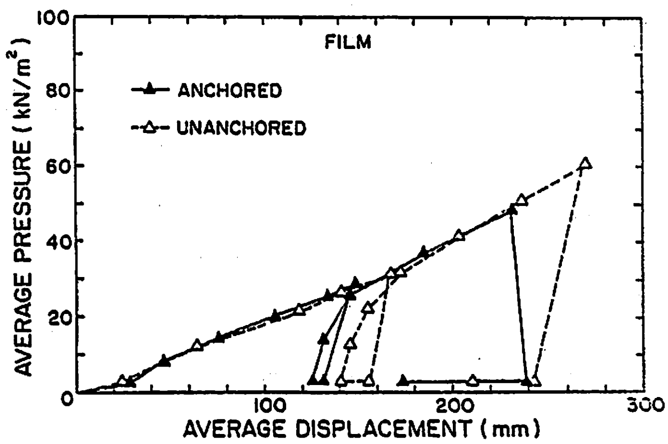

Figure 9. Test results, polyethylene film. H/B = 0.6.

Figure 6 demonstrates that there was very little increase in the initial stiffness over that of the peat subgrade alone, when a geotextile "reinforced" gravel layer, with H/B = 0.6, was placed on the peat. Table 2 (columns ii and iv) indicates that the increase in stiffness was relatively small:

approximately 20 percent for the unanchored road sections, and approximately 50 percent for the anchored sections. The performance of the extensible polyethylene film was not much worse than that of the geotextiles.

Table 2

MODEL ROAD SECTION STIFFNESSES (after Douglas and Kelly, 1986)

Col:	i	ii= i/a	iii	iv= iii/b	v= iii/i
Test Config	Unanchored Stiffness (kN/m^3)		Anchored Stiffness (kN/m^3)		
peat only	170 (a)	--	145 (b)	--	0.85
woven	205	1.21	210	1.45	1.02
non-woven	205	1.21	220	1.52	1.07
film	185	1.09	190	1.31	1.03

NOTE
1. Stiffness defined as initial slope of average pressure vs average displacement curve.
2. Gravel thickness = 150 mm and H/B = 0.6, where applicable.

Figures 7 to 9 show that there was very little difference in the performance of the road sections when only the anchorage detail was changed. The measured stiffnesses were virtually identical. Given that there is evidence that the stiffnesses of the peat beds produced had a variation of as much as ±8 percent of their average (Table 2, "peat only" row), it may have been that small improvements in the anchored section stiffnesses were masked by small decreases in stiffnesses of the underlying peat beds.

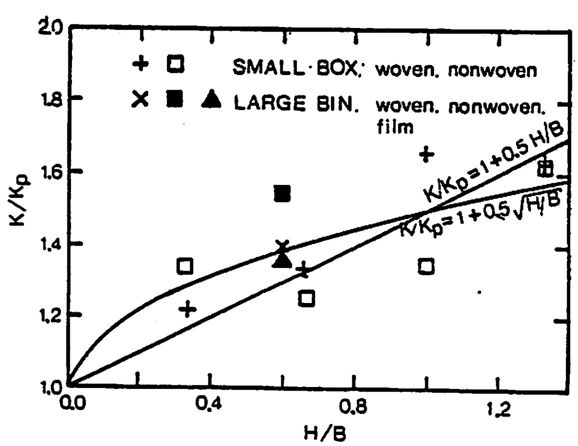

Figure 10. Nondimensional test results.

However, it is clear that:
1. no dramatic increase in overall road section stiffness due to the addition of a geotextile was observed during the tests,
2. the improvements in stiffness which could be attributed to the anchorage detail were small enough to be within the precision of the tests, and
3. none of these small increases in initial road section stiffness appeared to depend upon the geotextile modulus, within the range of geotextile moduli tested.

Rheological Model

Figure 10 serves as a summary of the test data collected in the small box and large bin to date. Simple regression analysis yields the following two equations, which fit the data:

$$K/K_p = 1.0 + 0.5 \cdot H/B \quad \ldots [1]$$

and

$$K/K_p = 1.0 + 0.5 \cdot \sqrt{H/B} \quad \ldots [2]$$

where:
- K = slope of the pressure - displacement curve for the model road section $[F/L^3]$
- K_p = slope of the pressure - displacement curve for the artificially produced peat subgrade alone $[F/L^3]$
- H = the thickness of the gravel base in the model road section [L]
- B = the width of the loaded strip [L]

The fact that the coefficients of both Equations 1 and 2 are identical is coincidental. Given the spread in the data, either equation would be acceptable in describing the data.

In classical soil mechanics, subgrades have been characterized by the Winkler model: the soil bed is modelled as a bed of discrete springs, like the typical bedroom box spring (Figure 11a). For such a system, the relationship between the applied pressure and the resultant displacement is:

$$p = k \cdot w \quad \ldots [3]$$

where:
- w = vertical displacement [L]
- p = applied pressure $[F/L^2]$
- k = spring stiffness, or "subgrade modulus" $[F/L^3]$

This equation can be used to describe the behaviour of the peat.

The geotextile might be idealized as a membrane, with resistance to in-plane tensions, but no resistance to bending or shear. Further, the gravel might be idealized as a shear layer, with resistance to shear forces, but no resistance to bending.

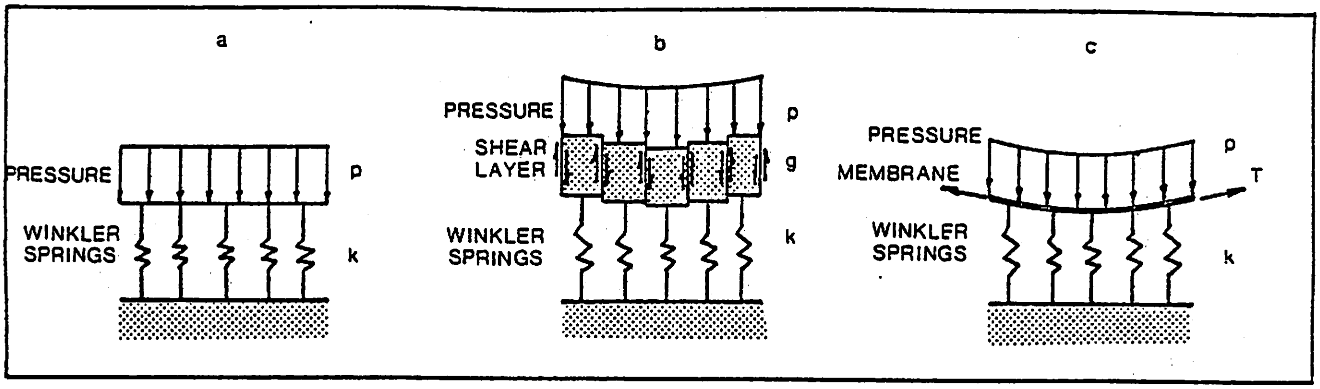

Figure 11. (a) Winkler, (b) Pasternak, and (c) Filonenko - Borodich models.

The combination of these models in pairs results in two well known physical models (Kerr, 1964). Pasternak combined the Winkler subgrade with a shear layer (Figure 11b), resulting in the following governing differential equation:

$$p = k \cdot w + g \cdot \frac{d^2w}{dx^2} \qquad \dots [4]$$

where:
g = ratio of shear force to shear displacement [F/L]

Note that if G is the modulus of rigidity (shear modulus) in classical elastic theory, then $g = G \cdot H$.

Filonenko and Borodich (Kerr, 1964) combined a membrane with a Winkler subgrade (Figure 11c), and found:

$$p = k \cdot w + T \cdot \frac{d^2w}{dx^2} \qquad \dots [5]$$

where:
T = membrane tension [F/L]

If these models are combined (into a Pasternak - Filonenko - Borodich model!), and the vertical equilibrium of the resultant element of the road section (Figure 12) is examined, the result is:

$$p = k \cdot w + (g + T) \cdot \frac{d^2w}{dx^2} \qquad \dots [6]$$

with all variables as defined previously. Outside the loaded strip, the applied pressure is zero:

$$0 = k \cdot w + (g + T) \cdot \frac{d^2w}{dx^2} \qquad \dots [7]$$

Solving Equation 7, a homogeneous, linear, second order differential equation, is outside the scope of this paper, but the solution leads to:

$$\frac{p}{kw} = 1 + 2 \cdot \left[\frac{G}{kB} \cdot \frac{H}{B} + \frac{T}{kB^2} \right]^{0.5} \qquad \dots [8]$$

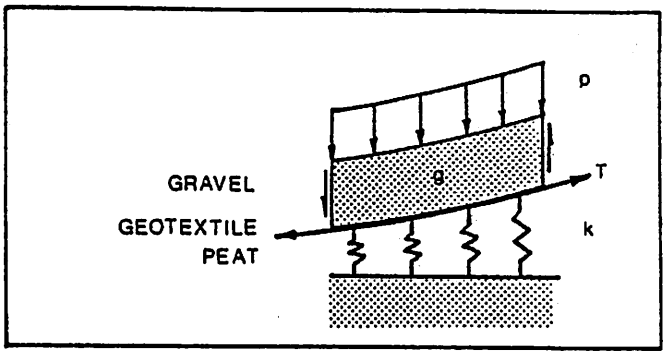

Figure 12. Combined model.

Recognizing that p/w is the initial slope of the pressure - displacement curve for the road section, called K in Equation 2, and that k is the subgrade modulus for the peat, earlier called K_p, the required substitutions can be made to compare Equation 2 and Equation 8. Further, if on the basis of the experimental evidence it is assumed that the relative contribution of the membrane action of the geotextile (T/kB^2) is very small compared to the contributions of the shear layer (the gravel) and the subgrade (the peat), Equation 8 reduces to:

$$\frac{K}{K_p} = 1 + 2 \cdot \left[\frac{G}{K_p B} \cdot \frac{H}{B} \right]^{0.5} \qquad \dots [9]$$

Equation 2 can be further rearranged to produce:

$$\frac{K}{K_p} = 1 + 2 \cdot \left[\frac{1}{16} \cdot \frac{H}{B} \right]^{0.5} \quad \ldots [10]$$

Equations 9 and 10, one representing a theoretical approach to the modelling of the road section behaviour, and one simply fit to experimental data, both have the same form. For the experimental data, curve fitting indicates that the best fit from regression gives $G/K_pB = 1/16$. Under other circumstances (different subgrade modulus K_p, gravel shear modulus G, and/or loaded strip or tire-width B), the value of this nondimensional term will be different.

If a sensitivity analysis is carried out on the original rheological model equation (Addo, 1986), Equation 8, it is seen that the stiffness ratio K/K_p rises dramatically for very small values of membrane tension T or gravel shear modulus G. Since the experimental stiffness ratios (columns ii and iv of Table 2) were small, it is apparent that the Equation 8 implies little contribution to road stiffness being made by the gravel and the fabric.

A Design Approach

On the basis of the above experimental program and mathematical considerations, an approach to the design of forest roads employing geotextiles built on soft subgrades can be put forth. At the outset, it must be recognized that these design problems can be divided into two classes, each requiring very different treatment.

Thick Fills

If the project involves the construction of a thick fill - an embankment - on a soft subgrade, where the fill thickness is much greater than the wheel width, then the design problem is one where dead loads control. If a geotextile is required, it will need to be one capable of reinforcing the embankment. The design of such a project is outside the scope of this paper, but may be accomplished with established methods (Christopher and Holtz, 1985).

Thin Fills

If, however, the project involves a thin fill, where the fill thickness is of the same order as th wheel width, on a soft subgrade, often the case in forest road construction, then live loads control. Traditionally, brushmats, corduroy, or fascine mattresses have been used for this class of problem. Because of economics, and a more predictable resultant structure, geotextiles are now also employed.

For this class of problem, the design must address both the bearing capacity of the road structure, and its working load behaviour.

The design fill thickness must be the greater of the two calculated from these two considerations. The required fill thickness for bearing capacity can be determined with classical soil mechanics theory.

The initial rut depth resulting from the first pass of the wheel is a measure of the working load response, which, it is proposed, may be estimated by Equations 8 or 9. With a specified maximum rut depth, these equations can be reworked to determine the required gravel thickness.

After the calculation of the controlling gravel fill thickness, the following step would be to select the geotextile. On the basis of the experimental work presented here, one would ignore the reinforcement function, and rather select the geotextile for its survivability during construction and in service, and its separation and filtration properties. Established designs for these functions are available (Christopher and Holtz, 1985).

When a Thin Fill Becomes a Thick Fill

It is worth noting here that in forest applications, thin fills have a habit of later becoming thick fills, as the requirements of the road change with time. If there is indeed a chance that at some future date a thick fill will be built on what starts life as a thin fill, then the requirement for a true reinforcing geotextile must be addressed in the initial design.

Limitations, Conclusions

The assumptions and limitations of the above hypothetical design approach should be reiterated.

It is based on the assumption that a moving wheel load can be legitimately modelled by a strip load exerting an equal pressure on the road surface. The approach assumes, on the basis of model testing, that the modulus of the geotextile does not appreciably affect the initial road section stiffness. Further, it has been based on the validity of modelling the road section components through a combination of the Pasternak and Filonenko - Borodich rheological models. The experimental evidence indicates that this is a reasonable approach to take.

Most importantly, the development of the hypothetical design approach is based entirely on model tests, performed at small scale and approximately 1/3 scale. The trends observed during the model tests seem well established, and give credence to the design approach proposed. However, the possible effects of scale cannot be investigated until full scale testing has been carried out. Those faced with the design of prototype forest roads on thin fills are urged to first test trial sections as input to their designs.

The testing of geogrids, and experiments using full scale road sections and cyclic loading, will be priorities in the future geotextiles research programme at the Department of Forest Engineering at UNB. To date, it has been encouraging to be able to shed some light on what this author considers to be some of the mythology of geotextiles, to allow forest road designers to more confidently design geotextile "reinforced" roads.

Acknowledgements

The author wishes to acknowledge the financial support of the Canadian Natural Sciences and Engineering Research Council, and the Canadian Forest Service. Geotextile specimens were donated by Dominion Textiles, Woodstock, Ontario. The ongoing geotextile research program at UNB benefitted from the enthusiastic support of graduate student R. Cormier, and undergraduate research assistants M. Kelly and P. Jofriet.

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Reduced Tire Pressure on Forest Service Roads through Central Tire Inflation Systems[1]

Ed Gililland and William Ryburn[2]

Abstract: Recent developments in tire designs, and central tire inflation (CTI) systems, allow vehicle drivers to vary the inflation pressure of a vehicle's tires while the vehicle is in motion. Preliminary test results indicate tire pressure reductions on forest roads have substantial potential for reducing road construction, road maintenance and timber haul costs.

BACKGROUND

The Forest Service has undertaken a study to look at the effect of tire inflation pressure on log-truck performance and forest roads, and the implications it may have on road construction, road maintenance and timber hauling costs. The study centers on the central tire inflation (CTI) technology for controlling tire pressures. Recent developments in tire designs (radials and military tires with bead locks) and CTI systems innovated by the military allow a driver to automatically and uniformly vary the inflation pressure of a truck's tires from inside the cab while the truck is moving.

There is an inherent conflict between the requirements for a good off-road vehicle and a good highway vehicle. A CTI system may be a useful component for narrowing this gap by conforming tire inflation pressure to the type of road surface and operating conditions. A CTI system provides the means to lower a truck's tire pressure on an unpaved road and then to automatically return the tires to a higher highway pressure when the truck reaches a paved road. At the lower inflation pressures, the tire's print is greatly increased and the load is applied over a substantially larger area. Preliminary proof-of-concept tests indicates that longer tire imprints may result in reduced forest road construction, surfacing, and maintenance requirements. This longer tire print will also dampen and greatly reduce drive-train shocks, decrease truck operational and maintenance costs, and may increase driver comfort and tire life.

In the summer of 1984, the Forest Service's San Dimas Equipment Development Center conducted this proof-of-concept testing using a typical western 18-wheel logging truck operating over a forest road. The truck operated with radial tires at 24 psi (as compared to a recommended pressure of 100 psi) for a period of over a month. The test showed that a logging truck can safely and smoothly handle heavy timber loads with low pressure tires, that forest roads surfacing wear is less with low pressure tires, and that low pressure tires can heal a deteriorated road. Additional benefits noted include reduced operator fatigue and decreased truck maintenance because of the reduced vibration.

Central Tire Inflation Systems (CTI) are mechanical systems which allow the vehicle driver to adjust his tire pressure while in motion. By utilizing these systems a truck could be operated at a tire pressure appropriate for the speed and strength of the road section being negotiated. The radial tires in use today can be much more effectively used by adjusting the pressure to match the load and speed of operation. Thus a radial tire commonly operated at 110 psi on high speed paved roads when fully loaded might be operated at pressures as low as 45 psi when loaded if speeds do not exceed 20 mph and as low as 20 psi when empty and speeds are below 20 mph. CTI systems would allow this variation in pressure.

The questions remaining to be answered are:

° What tire pressure is appropriate for various road surface material types and strengths

° What economic changes will occur with reductions in tire pressure

° What changes should occur in road design methods to accomodate lower tire pressure

While the preliminary work has convinced the Army to equip their latest 5-ton trucks with CTI systems, and has indicated there are tremendous benefits from the use of lower tire pressure, no adequate quantification has been done.

In order to answer the questions, begin the job of quantification, and encourage implementation of CTI in the logging industry and by other vehicle users, the Forest Service has established a two part test program. There will be structured tests conducted on test courses where variables can be controlled and quantification of effects can be documented. There will also be unstructured field tests which will demonstrate the technology and subjectively evaluate the effectiveness as well as the operational problems of the use of CTI (or lowered tire pressure) in actual field conditions. Some measurements will be made to correlate the unstructured tests to the structured tests. However, this will be limited.

UNSTRUCTURED TEST PROGRAM

The unstructured test program currently consists of field tests in Idaho, Washington, and here in Alabama.

The Alabama test will utilize two CTI equipped 10-wheel log trucks in a pulpwood operation this fall. These trucks will be tested in two different phases; an accelerated loop-test operation and an actual timber harvesting operation. The two trucks will be instrumented to obtain data on inflation pressure, travel speed, and ride quality while trucks operate in designated tests strips. Road profile measurements will be made on road roughness, rutting, washboarding, and surface density/moisture.

The Washington test will utilize one CTI equipped 10-yard dump truck and five more 10-yard dump trucks

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[1]Presented at the 9th Annual Council on Forest Engineering Meeting, Mobile, AL, September 29-October 2, 1986.

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that will have the tire pressure adjusted at an airing station. The trucks will be used to haul aggregate for a road surfacing project on the Olympic Peninsula in January, February, and March of 1987.

The Idaho test will utilize four 18-wheel western log trucks in a timber sale operation. The tire pressure will be adjusted at airing stations.

All these tests will be on native or aggregate surfaced roads since the tire pressures to be used are below current Tire and Rim Associated approved standards and therefore operations on public highways will be prohibited. The effect on truck handling, driver fatigue, truck maintenance, tire damage or wear, road maintenance, road compaction, road roughness, surfacing loss, dusting, washboarding, trafficability in wet conditions, and truck gradability will be evaluated by engineering personnel and truck drivers. Measurements will be taken to determine shock and vibration to drivers, fuel consumption, vehicle speeds at test sections, road roughness, dusting, washboard propagation, soil compaction, and round trip times as the vehicles are operated at different tire pressures.

STRUCTURED TEST PROGRAM

While the unstructured tests will provide valuable information, the main thrust of the program will be the structured tests. The structured test is presently divided into two parts. It is felt that additional work may be desired after these two parts are completed.

HODGES TESTS

One part of the structured test program is currently under contract to Hodges Transportation Inc. in Carson City Nevada. Hodges has one of the largest privately owned automotive test facilities in the nation. Two 18-wheel log trucks will be operated on parallel tracks each day on a constructed course. One truck will be operated at the normal tire pressure of 105 psi. The other truck will be operated with tire deflections of 21 percent. This requires 54 psi for front tires, 41 psi for driving axle tires and 38 psi for trailer axled tires. In the evenings the trucks will be operated on a paved road with both trucks at 105 psi to simulate off-highway to on-highway tire pressure adjustments. After 1000 passes on the course the test will be repeated with empty trucks. The low tire pressure truck will remain at 21 percent deflection so tire pressures will be lowered to the 20 to 25 psi range.

The tires will be run at constant deflection on the low pressure truck rather than at constant pressure because it is desired to keep the spring rate of the tires constant. This should keep the dynamic loading experienced by the truck and the road constant. It also allows better evaluation of the tire performance, because tire performance is more appropriately a function of deflection rather than pressure.

The primary emphasis of this test will be to quantify the effect of tire pressure (deflection) on trucks and tires. Effects on road surfacing materials will also be measured. At the conclusion of this test it is planned that the Goodyear Tire Company, Michelin Tire Corporation, and Rubber Manufacturers Association (who are cooperating in this test) will propose and support an interim standard for adoption by the Tire and Rim Association to allow operation of these tires at the pressure (deflections) tested for the appropriate speeds. The tests are designed to provide the necessary data for this standard, data which is not now available and previously has been considered unimportant because of the trend toward higher and higher tire pressures.

Measurements will be made of the stresses experienced by various truck components to quantify the effect tire pressure has on the repair costs and life of the trucks. These measurements will be correlated to extensive data bases compiled by the U.S. Army in their test program on truck repair cost and life.

Measurements will be made of the forces and vibration experienced by the driver and correlated to similar U.S. Army data bases used to predict driver fatigue and injury.

Measurements of fuel use and vehicle speed will be taken to quantify these effects.

Tires will be carefully monitored and tested for wear, heat build-up, hysterisis, and damage. Tire company technicians will be involved in the test. Additional tests will be performeed by the tire companies at test completion.

Measurements will be made of aggregate loss and/or movement in the curved track segments.

For the double chip seal sections and the 2-inch hot mix sections, rutting, shoving, cracking, and aggregate loss will be measured.

If adequate deterioration of the thin pavements is not seen with dry conditions the subgrade will be flooded to simulate spring thaw conditions.

Records will be kept of road maintenance required in each track (high pressure and low pressure) to maintain a constant ton-mile delivery rate. Any time the ton-mile delivery (speed) begins to drop off because of road roughness, that section will be maintained.

Comparison will be made between the test track, tires, and trucks operated at high tire deflections (low pressure) versus those run at normal operating pressures.

WATERWAYS EXPERIMENT STATION TEST

The second part of the structured test will be conducted at the U.S. Army Corps of Engineers Waterways Experiment Station (WES) in Vicksburg, Mississippi. The test course is to be built under a contract currently being advertised. The course should be completed this fall with surfacing to be done next spring (1987). Once the planned structured test is completed this test course will be available to all Federal Agencies and Cooperators for test work required in the future.

The course will consist of two parallel tracks with 90', 110' and 335' radius curves, straight sections, level sections, and sections with grades of 12 percent. The course will accommodate 8 to 12 test segments with various surfacing types, curvature, and grade.

When course construction is complete, a contract for the test work and data analysis will be advertised. Road surface compaction, rutting, shoving, washboarding, aggregate loss, pavement cracking, dusting, and maintenance requirements will be measured for each surfacing type and each tire deflection and load condition.

The primary goal of the testing on the WES course will be to quantify the effect of the tire pressure (deflection) on road surface deterioration and design requirements. While most of the effort will be directed toward that effort, additional measurements will be made of truck and tire parameters to adequately correlate the data gathered to other test data from the unstructured tests and Hodges tests.

RESULTS

At the conclusion of the test program the following results are expected to be complete:

- An interim tire standard to allow lower tire operating pressure (higher deflections).

- A listing of operational problems encountered in field use and an action plan to mitigate or resolve them.

- A guideline for analyzing the economic tradeoffs of lowered tire pressure in various situations (economic model).

- Recommendations for revising road structural section design methods (for thin pavements and aggregates) to account for dynamic loading variations encountered with varying tire pressures (deflections).

The interim tire standard should be a direct result of the Hodges test. The tire manufactures have indicated that this test is necessary only to validate engineering analysis, and barring my unexpected results, an interim standard can be processed quickly.

The listing of operational problems will be compiled from all tests. It will include suggestions and parameters given by engineers, loggers, and truckers involved with the test. This will be used to help guide the future development of CTI systems as well as operational criteria for use of the systems in the logging industry.

The economic model will be primarily used by the Forest Service to evaluate individual timber sales for CTI requirements. The results of the fuel economy, tire life, round trip time, truck maintenance and repair cost, and driver fatigue and injury studies will be used to develop cost ranges of timber haul costs as a function of road surfacing type, alignment, and tire deflection. Road maintenance rates will be established for each surfacing type as a function of tire deflection.

The surfacing requirements for the model will be based on modifications of the Road Surface Design and Management System (SDMS) developed by the Forest Service. Preliminary calculations indicate surface thickness reductions of 40 percent can be expected if tire pressures are reduced from 110 psi to 40 psi. The tests at Hodges and WES are designed to verify the performance of surfacing designed by this method. If adequate correlation is shown to exist, this method will be used initially for the economic model.

One of the more important objectives of the structured tests is the work that will be done at Hodges and WES to develop recommendations for revising road structural section design methods for a more permanent basis. All testing done in this program will include material classification for surfacing and subgrade to determine gradation, Atterberg limits, proctor values, and "R" values. The different materials used will be evaluated for their ability to withstand the dynamic loading imposed by the tires at different pressures. This should provide an adequate starting point for adjusting surfacing depths for varying tire pressure. However, as we look at the effect of tire pressure on roads we must begin to look at road design differently than we have in the past. We have always considered the way the load was applied to our road as a constant. We design for an estimated number of 18 kip axle loads (load repetitions). We have not been overly concerned with the way the loads are applied to the surfacing but more with number of times a given load is applied. As we begin to look at the effect of variations in tire pressure have on road surfacing we are required to look more closely at how the forces are transmitted from the vehicle to the road.

There are four separate loading methods that become apparent when closely observing the tire's interaction with the road on a moving vehicle. One loading method is the static weight of the load applied vertically to the surface over the area of the tire ccontact patch. Work done by Dr. Tielking and Dr. Litton at Texas A &M show that even this loading is not as simple as often considered since the load distribution is not consistant over the entire contact patch but is actually close to zero at many areas in that patch depending on tire construction and design. Other areas within the contact patch experience extremely high stresses.

The second type loading seen is the horizontal sheer force imparted by the drive tires as they pull the truck along the road. Much of the washboarding observed in testing to date has actually been caused by the cyclic nature of the loading applied by the drive tires. They sink low enough to gain sufficient traction to pull the weight of the truck then start to release and rebound when that traction finally develops only to start to slip and begin once again to sink low enough to regain traction. This cycling has been shown to start road washboarding and to accelerate existing washboarding.

The third type of dynamic loading is the force imparted horizontally by the steering tires and other tires as they "swipe" around a curve or as a truck maneuvers from a straight course. Unless the tire imparts some horizontal force to the road the truck will maintain a straight line. This shear stress is the cause of accelerated road deterioration in curves and "maneuvering" areas.

The fourth type of loading is impact loading. There are many reasons a truck does not maintain a smooth constant loading on the road. Road roughness, traction hop, boogie hop (cyclic occillation of tandem axels) and other factors cause the loading experienced by the road surface to be impact loading rather than static loading. Tests done for the U.S. Military show that when dynamic loads are measured, the truck and the road often experience forces 5-10 times the static forces of a stationary truck.

In order to identify and quantify the dynamic forces involved in the road-tire-truck system interaction, trucks will be thoroughly instrumented for the tests at Hodges and WES. Three dimensional force and acceleration measurements will be taken to quantify the force applied to the truck components and transmitted to the road surface. By instrumenting the truck, the actual forces can be measured. Effects of surfacing material type and tire pressure can readily be determined.

Since the entire system must be energy accountable, measurements of energy input and dissipation will be made. By determining the energy input to the engine and measuring losses through the vehicle, the amount of energy that is being consumed at the tire road interface can then be determined. This energy must be used to propel the truck or be wasted into tire or road deterioration. By calculating the wasted energy, the energy invested in road deterioration can be determined. This will be used to evaluate the effectiveness of various tire pressures on different surface types to reduce deterioration. This will also be used to help design surface materials to reduce wasting energy into road deterioration.

By adequately identifying the forces and energy inputs involved in the truck-tire-road system, a better picture will emerge of the design methods appropriate for road surfacing materials. In the future we should be able to design a road surfacing to handle both the compressive forces as well as the sheer forces that can be expected from the dynamic loading of the vehicles moving over it rather than simply designing for an estimated number of repetitions of a static load.

These tests will provide only a small sample and be limited to one type of truck. They will probably not be statistically valid to base an entire road design system on. However, they will give us the starting point to define what dynamic loads are involved and how much slip (waste) energy is acceptable. From this a clear course should be defined to establish an adequate road design and management system.

CONCLUSION

While the focus of this discussion has been on the upcoming structured and unstructured tests to validate and quantify the use of a CTI system, the vehicle, and the tires, the overall focus remains on the vehicle's effect on the road. Controlling factors for the vehicle's effect on the road are tire contact length, tire/road contact pressure, and wheel loads.

Therefore, the ultimate goal must be to develop a system which will allow vehicles to be operated economically over forest roads and county and state highways at the appropriate tire contact length and pressure for the strength of the road segment being traveled. Adjustment of the tire pressure by use of a Central Tire Inflation System is only the means to that end.

CTI systems are not commercially available at this time. However, the potential benefits demonstrated to date, combined with the interest exhibited by numerous public agencies, equipment manufacturers, associations, universities, and vehicle operators all indicate it is only a matter of time before CTI systems become commercially available.

Techniques For The Assessment And Control Of Log Value Recovery In The New Zealand Forest Harvesting Industry[1]

Glen Murphy and Alastair Twaddle[2]

Abstract: The need to control value recovery in the New Zealand forest harvesting industry is evident from recent research carried out in this area. Up to 40 percent or more of the standing value of a tree may be lost through poor harvesting practices. Suitable techniques for the assessment and control of log value recovery combine log value optimization routines, such as the New Zealand developed AVIS system, with statistical quality control techniques, such as Shewart or geometric moving average control charts and double-sampling. It is recommended that further research is required to identify the most economically suitable sampling procedure (in terms of sampling frequency and sample size) and value control techniques for the New Zealand forest harvesting industry.

Keywords: New Zealand, harvesting, quality control, control charts, value recovery, AVIS.

THE PROFIT EQUATION

The objective for both the government and private forestry sectors in New Zealand is to make a profit. Traditionally the New Zealand forest harvesting industry has been primarily concerned with the costs of extracting and manufacturing trees into logs and the total volume recovered. New Zealand was not alone in the attitude "to increase profits, increase volume recovery and reduce costs" (usually by increasing productivity). A perusal of the forest harvesting literature of many countries, including the United States of America (USA), reveals that costs and volume recovery are the factors most discussed and by implication the factors which should be controlled to maximize profits. Profit equations have another key component however - value. For example,

Profit = Volume x (Unit Values - Unit Costs).

The value component often seems to be relegated to last place in importance. However, in New Zealand, since the time span between felling and delivery at a mill is measured in weeks, log values are known with relative certainty (compared with some parts of the USA). Therefore the value component should receive more consideration. Only recently has the New Zealand forest industry become concerned with the amount of value recovered from the forests.

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[1]Presented at the 9th Annual Council on Forest Engineering Meeting, Mobile, AL, September 29-October 2, 1985.

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IMPORTANCE OF CONTROLLING VALUE RECOVERY

By the time a tree is felled, extracted, manufactured into log lengths, and loaded on a truck in New Zealand up to 40 percent or more of its standing value can be lost through poor harvesting techniques (Murphy, 1983). Table 1 shows a breakdown of these value losses as determined from field studies in New Zealand (Murphy, 1982, 1984; Geerts and Twaddle, 1984). The similar levels of loss found in American literature (Craig, 1982; Pease, 1982; Garland, 1985) indicate that felling breakage, high stumps, breakage during extraction, and damage during loading operations are sources of value loss about which logging managers in any country should be concerned.

In New Zealand and elsewhere, the area with the greatest potential for minimizing the large amount of value loss is the log-manufacturing phase. This fact is not only newly discovered however. In 1913 R.C. Bryant wrote in his textbook on American logging practices, "Log-makers frequently do not give sufficient attention to securing quality as well as quantity ... A system by which timber is cut for quality as well as quantity means an increase in the percentage of the higher grades, more timber per acre and prolonged life to the operation [through greater profits]". More recently, Steve Conway (1976) wrote about American logging practices, "In the past (and even to a certain extent today), logs were cut without regard to end use. ... Least cost was, and unfortunately still is in all too many cases, the main objective. ... Failure to cut for end use can result in the loss of millions of dollars to the [forest] industry every year".

Ensuring that the maximum value is obtained from each tree during the log manufacturing phase is not an easy task for any person. Figure 1 gives an indication of the decision-making problems a log-manufacturer is confronted with when trying to optimize the total value of a stem. Tree length, taper, defects, branching, sweep, and other quality characteristics must be made to optimally match allowable log specifications and market prices.

TABLE 1--Sources of value loss in harvesting operations

Source	Value loss (pct. of potential value)
Thinning damage	1 - 2
Felling breakage in the top portion of the tree	4 - 7*
High stumps and butt damage	4 - 5
Extraction breakage and damage	1 - 2
Log manufacturing	10 - 25

*Felling breakage can be double these losses on steep broken terrain.

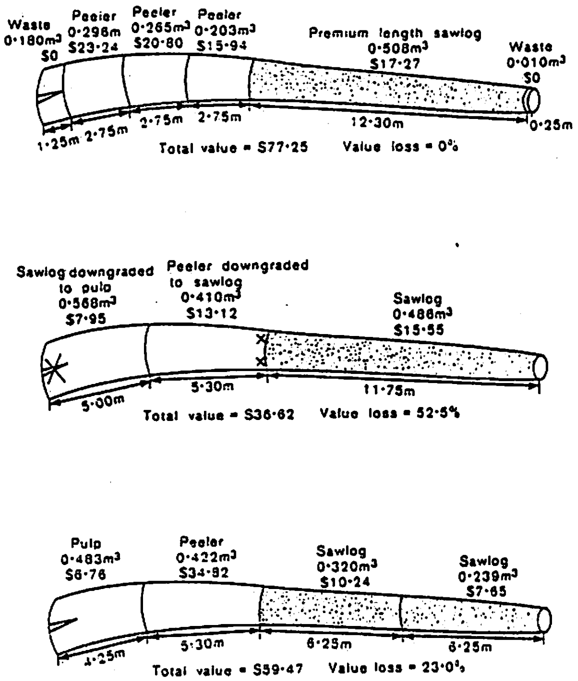

Figure 1--Optimal cutting pattern (upper) and sub-optimal cutting patterns in which logs do not (middle) and do (lower) meet specifications.

The same tree, cut into logs in a sub-optimal way, can produce some logs that are out of specification and in need of re-grading and re-manufacturing, incurring further loss. (Some discussion of methods to control out-of-specification logs has occurred in New Zealand (Twaddle, 1986a, 1986b).) This type of sub-optimal log-manufacturing is easier for a logging supervisor to recognize than the type where the sub-optimal pattern produces logs that meet specifications, but is not the best cutting pattern for the tree as a whole.

DETERMINING THE BEST OR OPTIMUM PERFORMANCE

Determining the optimal cutting pattern for each and every different tree is a significant problem in controlling value recovery. Optimising the value recovery for trees is often done by two techniques: linear programming and/or dynamic programming. Pnevmaticos and Mann (1972) were the first authors to propose the use of dynamic programming for optimizing log value recovery. They believe that dynamic programming is the better of the two techniques since it "can incorporate deterministic and probabilistic elements, can handle both linear and non-linear functions, and the solution yields a policy for all possible conditions". They describe an algorithm for manufacturing logs which were all one grade. Briggs (1977) and Dykstra (1984) describe a similar algorithm. Several papers presented at a KWF-IUFRO meeting held in Germany in 1979 discussed other algorithms suitable for dynamic programming analysis of logs (e.g., Geerts, 1979). Sessions and Layton (1986) have proposed this as a network problem.

In New Zealand, several value optimizing packages have been developed (Deadman and Goulding, 1979; Eng and Daellenback, 1985; Geerts and Twaddle, 1984), all of which incorporate dynamic programming algorithms. Of these packages, the AVIS package developed by Geerts and Twaddle (1984) is the most applicable to the forest harvesting industry and could readily be turned into the heart of an effective value recovery control system.

THE AVIS SYSTEM

AVIS is an acronym for Assessment of Value by Individual Stems. As the name implies it is an value audit system based on individual trees rather than on stands. It compares, stem-by-stem, the log-making decisions made during harvesting operations with an optimal solution calculated by a dynamic programming algorithm. AVIS can assess the level of value loss through sub-optimal log-making and detect the patterns in worker cutting decisions and the type of defects they tend to overlook. It can also be used for quantifying other sources of value loss such as felling breakage, thinning damage, and high stumps. In addition, AVIS has potential as an education aid for illustrating how different cutting patterns affect stem value and the effect of changing products and product specifications (Threadgill and Twaddle, in press).

AVIS comprises a field procedure for gathering of stem data, and a set of eight computer application programs for analysing these data. The field procedure consists of two segments. The first is a dimension and quality cruise on felled trees to establish the size and quality parameters of a stem. The second is the log outturn cruise which measures the actual output from a stem when it is manufactured into logs.

During the first cruise, an AVIS field form is completed for each piece of a single tree . Data is recorded on such peripheral features as a tree code, stump height, and diameter breast height; on dimension features such as tree taper and length; and on quality features such as defect and quality codes, lengths, and cut zones for sweep. The log cruise is a record of the logs produced from each measured stem, recorded in their sequence along the stem. It represents the achieved solution for log manufacture, rather than the solution produced by the dynamic programming algorithm within the body of the AVIS computer program.

The "AVIS System User's Guide" describes in detail the set of computer programs for analyzing the field data. The eight programs require about 300 K for storage and are written in VAX-11 FORTRAN. The optimizing routine uses the stem dimension and quality characteristics, log specifications, and prices to determine the best way to cut a stem to its maximize total value.

The computer output of the optimal cutting pattern and value for a typical piece is shown in figure 2. Figure 3 gives the actual cutting strategy from the large end, with its associated value. At first glance it appears that the log-manufacturer has somehow found a better solution than the optimal AVIS solution for this piece. However, the "LOG UPGRADING" section to

OPTIMAL CUTTING STRATEGY FROM THE LARGE END

NUMBER CUT	SED	ACTUAL LENGTH	CUM. LENGTH	SEQ. No.	TYPE NAME ASSORTMENT	VOLUME(UB)	VALUE($)
1	471	0.50	0.50	76	waste	0.09	0.00
2	412	5.20	5.70	10	PRUNED sawlog	0.78	66.13
3	305	12.20	17.90	27	UNPRUNED sawlog 'L'	1.31	81.33
4	259	5.80	23.70	75	Pulpwood	0.37	3.70
REST	233	2.50	26.20	75	Pulpwood	0.12	1.16
					TOTAL	2.66	152.32

Figure 2--Optimal cutting pattern

the right of the actual solution shows exactly where the logs in this piece do not conform to the log specification rules (log upgrading does not occur on all pieces). The type of information presented in figure 3 would be of great help to a log value quality control manager.

STATISTICAL QUALITY CONTROL

The AVIS system has been used successfully in several research projects in New Zealand (Geerts and Twaddle, 1985) each involving measurement of several hundred trees. Although the results were valuable to the harvesting organizations involved, the procedure would not be entirely suitable for a quality control management program without some modification. The modification would probably include the use of statistical techniques to allow a reduction in the number of trees measured and, as a result, a reduction in the cost of quality control.

Statistical techniques, with respect to log value control, have only rarely been used in the forest harvesting industry of New Zealand. Some of the reasons for this fact have been the problems of large variability in the raw material and market requirements, and the lack of a suitable technique for establishing a standard or base. From the harvesting end, little can be done about raw material and market variability, but the AVIS system could be used now to provide a suitable standard. Although statistical quality control techniques have yet to be combined with the AVIS system, some possibilities can be conjectured.

$\bar{X}$ and R control-charts

Statistical control-charts have been used by a wide range of industries for a long time because they are effective and are relatively easily understood by both management and the employees. They provide a means of documenting and communicating performance relative to defined standards. Craig (1955) writes "The real heart of statistical quality control is process control. And for process control the control chart is a remarkably well designed and effective instrument".

When dealing with a quality characteristic that is variable (e.g., percentage of value lost), it is a standard practice to control both the mean value of the quality characteristic and its variability. An $\bar{X}$ chart is usually used to control the mean quality level. Performance variability can be controlled by either a standard deviation control chart (S chart) or a range control chart (R chart). The R chart is more widely used since it is easier for the workers and management to understand. Furthermore, it is almost as efficient as an S chart at low levels of sampling intensity. $\bar{X}$ and R charts are discussed in detail in many quality control texts (e.g., Montgomery, 1985).

The hypothetical charts in figures 4 and 5 show how $\bar{X}$ and R charts could be used for controlling log value recovery. Since the control limits on the $\bar{X}$ chart depend on and are made meaningful by the performance variability, it is best to begin with the R chart when setting up $\bar{X}$ and R control charts. Value loss is calculated as follows:

$$\text{Value loss (percent)} = \frac{100\ (\text{Optimal \$ value} - \text{Actual \$ value})}{\text{Optimal \$ value}}$$

The R chart in figure 4 is based on samples of five stems (industry uses samples of 4-6 stems). Each point on the chart is the difference, or range, between the stems with the highest percentage value loss and the lowest percentage value loss. When the operation was in control the mean range was c. 17 percent, which is the centre-line for the R chart. The upper and lower limits of most control charts are chosen so that, if the operation is in control, nearly all of the sample points will fall between them.

In this example, there is only an upper control limit, and less than one sample in 500 should fall above it if the operation is in control. That samples fall above this limit (marked as asterisks) suggest that it is very likely that the log-making

CUTTING STRATEGY SKIDS FROM THE LARGE END

NUMBER CUT	SED	ACTUAL LENGTH	CUM. LENGTH	SEQ. No.	TYPE NAME ASSORTMENT	VOLUME(UB)	VALUE($)	[Diam. (cm) < SED	> SED	> SED	LOG UPGRADING Qual (m^3) QUALITY & VOLUME	Len (m) < MIN	> MAX]
1	477	0.25	0.25	76	waste	0.04	0.00						
2	413	5.31	5.56	1	Peeler	0.80	76.41*						
3	350	8.60	14.16	26	UNPRUNED sawlog 'S'	1.01	63.28				S 0.05		0.C
4	299	4.54	18.70	66	'L2' sawlog	0.38	13.73*	0.1					
5	260	4.90	23.60	72	'S3' sawlog	0.31	7.71*				L 0.01 R 0.19	0.1	
					TOTAL	2.54	161.13*						

Figure 3--Actual cutting pattern

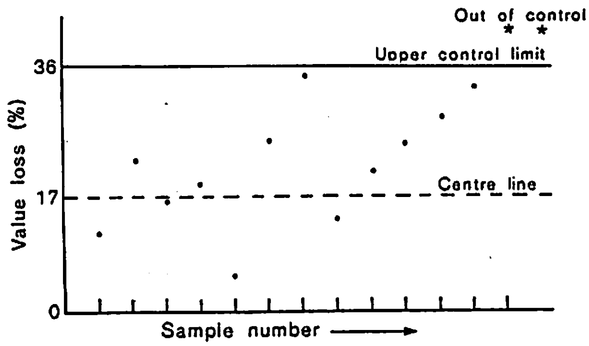

Figure 4--R chart for controlling variability in value loss

operation is out of control at these points. At such a time, the logging supervisor would need to intervene. The five points immediately to the left of the first asterisk indicate a run where the operation may have been gradually getting out of control. Nelson (1985) and Montgomery (1985) describe methods for analyzing patterns on control charts which help to identify such runs at early stages.

The centre-line of the $\bar{X}$ chart in figure 5 (i.e., 10 percent) is the mean of the sample means ($\bar{\bar{X}}$) when a hypothetical operation is in control. Ideally management would hope for 0 percent loss, but the cost of achieving perfection in any industry is often greater than the return. In addition changing market conditions which result in varying product specifications and values mean that the log-maker is continually operating on a new learning curve for optimal recovery patterns. It is thus unlikely that 0 percent value loss will be achieved often.

According to the example in figure 5 the logging supervisor would be prepared to accept an average loss of 19 percent for a sample of five stems without getting unduly concerned because the upper control limit is at c. 20 percent. A supervisor would know it is very unlikely that the value recovery operation is in control if average losses were 25-30 percent.

Under a value control system based on X and R control charts each log-maker would be sampled frequently - possibly once a week.

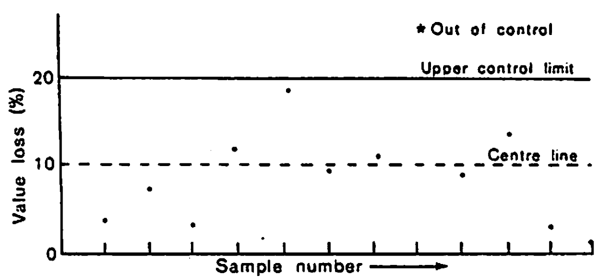

Figure 5--$\bar{X}$ Chart for controlling average value loss

Double-Sampling Techniques

Although a small sample of trees may be adequate for determining whether the value recovery operation is out of control, it may not be adequate for identifying how and why it is out of control. In forest mensuration, double-sampling techniques are often used to reduce the overall sample size required. Similarly, if the statistical quality control procedures indicate that the operation is out of control, an additional sample could be taken to identify sources of value loss. Research is required in this area to identify what the original and additional sample sizes should be for value control in the forest harvesting industry.

A warning should be passed on from people using statistical quality control techniques in the sawmilling industry. Martin (1982) writes "The power of statistical quality control is useless - even counterproductive - if there are variations [in the operation] that can easily be detected by the naked eye from across the mill and that are the result of ... negligence". In other words, if a system is out of control, first get it into control and then use statistical quality control techniques to keep it there. A commitment by management to quality control and the provision of proper rules and tools are often the first steps needed for bringing a value recovery operation into control (Conway, 1976).

THE FUTURE

The New Zealand Forest Service is currently adapting the software of the AVIS program for use in a robust, handheld portable micro-computer. Similar developments are underway in both Canada and Sweden[1]. Such a tool would be a valuable aid in both training log-makers and auditing their output. One could envisage a value control system with a market feedback mechanism whereby the prices driving the decisions about individual trees are influenced by the aggregate supply and demand of logs. Periodically (e.g., once per week), the log-makers would transfer the log product information they had gathered on their hand-held micro-computers onto a mini-computer or main-frame computer. The larger computer would then summarize the information from all of the log-makers and combine it with the current market information to calculate updated product prices. These updated prices would then be reloaded into the hand-held micro-computers for use by the log-makers during the next period. Such a value control system would negate some of the criticism of single stem dynamic programming models (Ramalingam, unpubl. report[2]; Bare et al., 1979) as opposed to whole stand linear programming models where constraints can be imposed on the number and types of logs produced from a stem.

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[1]International Energy Agency/Forest Agreement CPC-9 Project. Proceedings of a workshop held in Rotorua, New Zealand, 1986.

[2]A branch and bound approach to the tree bucking problem. A paper presented at the 1976 Joint National Meeting of ORSA/TIMS. Philadelphia, Pennsylvania, 1976.

We believe that statistical quality control techniques will be needed to complement the use of hand held micro-computers if a value control system is to be effective in the future.

CONCLUSIONS

The need to control value recovery in the New Zealand forest harvesting industry is strongly evident from recent research carried out in this area. Significant value loss can occur, which inturn could have a great impact on the profitability of both the domestic and export-oriented forest industry. Combining the AVIS system with statistical quality control techniques should provide an acceptable basis for a good value recovery control program. The AVIS system can be used to:

- help train log-makers in value recovery techniques,
- define optimum performance,
- analyze performance in economic terms,
- help identify sources of value loss.

Statistical quality control techniques can be used to:

- monitor performance on a regular basis,
- provide frequent and timely feedbck,
- document performance.

Further experience and research is required, however, to identify the most suitable sampling procedures (in terms of sampling frequency and sample size) and value control techniques for the New Zealand forest harvesting industry.

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Optimizing Productivity, Costs, and Products Through Complete Harvest Planning[1]

Michael B Lambert[2]

Abstract: A method was needed to analyze the economical potential of a radically different harvesting system before some of the equipment was fabricated. Simulation software was prepared that models the production rates and costs of all activities in a harvest operation; it was based on the size and number of trees in the stand and on the capacities of the equipment and the crews involved. The simulation model allows planners to observe and evaluate the effects of different variables on the efficiency, economics, and yield of the harvest activities.

Keywords: logging, modeling, simulation

Overall productivity and cost per unit of production can be improved by thoroughly planning the harvest operation. Such planning requires consideration of all aspects of the harvest from start to finish--from sale preparation to reforestation. This task is complex, so fully understanding and quantifying the effect that interacting harvesting activities may have on each other and on the harvest in terms of production rates, costs, and products is difficult.

This paper presents methodology for analyzing (both individually and collectively) the aggregate logging activities that comprise a total harvest, so that the operation is economical and efficient. An organized approach has been devised and used with supporting software that considers ownership costs, operating costs, and production rates for each activity; equipment capacities; numbers of people and machines; timber stand characteristics; terrain and environmental features; equipment reliability and production queues that affect delays and idle time; commuting distances and travel methods; log weights, preferred log lengths, and bucking strategies; transport distances; and the costs of road construction, slash treatment, and reforestation. The method also helps the planner estimate the total cost of operations and the time required to complete each phase.

Besides the productive costs (such as dollars per ton), the software used for the new methodology calculates such things as total weight and volume of merchantable wood in a stand, the number of logs (categorized by diameter and length) that could be harvested, the number of turns required, and woody biomass remaining after harvest.

Advance simulation of harvest-strategy alternatives and sensitivity studies, using the described method, will assist planners in selecting the best combination of timber operations for optimum harvesting. As desired, planners can decide to maximize productivity or to minimize costs; they can make the best of given limitations, maximize use of certain equipment capacities, or weigh alternatives for reasonable compromises of any of several objectives.

THE PLANNER'S PLIGHT

Many harvest-planning jobs are routine. Often, the harvest being planned is adjacent to or similar to an existing harvest. Planning for these jobs is straightforward. Rules of thumb, regional averages, and standard company practices will give acceptable results. Planning becomes more difficult, though, when some drastic change is anticipated that is beyond the planner's experience: a new species, a very large or unusually small sale, an unfamiliar location or mill specification, or perhaps the introduction of new, untried equipment.

Several important questions invariably face the planner about the suitability of certain harvesting systems, future market trends, and general business issues, but sooner or later an answer is needed to the ubiquitous bottom line: How much will it cost?

Sometimes the planner is asked to use a sharper pencil in the face of tight competition, austerity programs, marginal timber quality, or pending outlays of investment capital. For these occasions, a rigorous treatment of costs, productivity, and product yields is warranted.

HOW THIS WHOLE THING GOT STARTED

The Assignment

In 1981, I received an assignment: analyze the technical and economic feasibility of logging with large airships, develop methods for estimating the weight of logs and trees, and prepare for field trials of a developmental airship (Heli-Stat).

The Heli-Stat was then being designed and fabricated for logging 50,000 pound loads over distances up to 6 miles. The prototype airship, which was a combination of four surplus helicopters and an aerostat (helium blimp), crashed in July 1986 during a test flight.

Although the Heli-Stat has been lost and with it the anticipated testing opportunities, the preparations have resulted in harvest simulation modeling that is applicable to other harvest planning.

The Real Needs

The Yarding Vehicle

The analysis assignment required a full understanding of the operating characteristics of the new yarding vehicle so that its place in the operation could be appreciated. How fast it could bring its large loads to the landing from various distances and how much fuel would be required for different flight profiles were questions that had to be answered. At the outset, expressing the airborne flight performance and fuel requirements of the new airship in mathematical terms appeared necessary (Lambert 1981).

[1]Presented at the 9th Annual Council on Forest Engineering Meeting, Mobile, AL, 1 Oct 1986.

[2]Mechanical Engineer, USDA Forest Service, Pacific Northwest Research Station, Portland, OR.

Even if the field trials could have been completed by actually logging six or seven units, the test data would have reflected only case-study information for particular sites. Many questions would have remained about the effects of many variables on performance and costs. What if the yarding distance had been different? What if the wind had been different during yarding? What effect did test-imposed delays have? Could the cycle time be improved with different load assembly and load pickup methods? Would alternate methods have been cost effective?

Future Yarding Vehicles

In the analysis assignment was an inherent requirement to project beyond the limitations of the existing test vehicle into the realm of an improved version of it or another logging airship with much different airborne performance or hourly cost features. The Heli-Stat was intended to be a proof-of-concept demonstrator, built at minimum cost with Government surplus materials. The question of future use of large airships for logging necessarily must include development and investment costs that would be very different if surplus equipment were not used.

Performance and cost figures would be affected if the design configuration were different. Other questions arise. What would be the effect of larger engines? Different rotor diameters? Different drag coefficients? (Drag is greatly influenced by aerostat shape and external structure design.) And what if the payload were different?

Preparing Loads for Yarding

Loads must be carefully prepared to match the carrying capacity of the yarding vehicle for maximum efficiency. Large equipment, especially airborne equipment is expensive to own and to operate. Trips with underweight payloads and operating delays must be minimized. However, the penalties of overloads must also be considered. Overloads strain equipment, and expensive procedures must be followed to recover from loads that unexpectedly exceed lift capacities.

Planners and analysts need to know how much effort can be directed into preparing loads for yarding without exceeding the limits of practical cost-effectiveness.

Handling Loads at the Landing

Material handling at the landing deserves careful thought. The arriving log loads are dropped at intervals depending on the yarding distance, the flight path, the weather conditions, and the load preparation activities. The landing size or the speed of production of the various transfer, sorting, and loading activities, or both, must be adequate to use the airborne equipment most economically.

Again, for analysis, an understanding of the relative costs and production rates is required. Extra equipment and crews to move materials are costly, and construction of larger landings to accommodate queues of unprocessed logs is also expensive. Where, then, is the optimum tradeoff for least total cost?

Interrelations of Harvesting Activities

Expanded yarding capabilities cannot be introduced by a large airship or any other radically new equipment without affecting other activities that support the yarding operation. New requirements are added as well as new possibilities. With great changes, planners have a more complicated job. Activities cannot be planned and carried out without considering how they complement other activities and how they contribute to total productivity and cost.

Longer yarding distances require loads that more closely match the most efficient load-carrying capacity of the yarder. This means that more effort can be directed toward estimating log weights and preparing loads of the proper weight.

Larger lifting capacity means that less bucking and limbing must be done at the stump. Required bucking may be more effectively done on the landing after yarding long logs or whole trees. Extra revenue for chips and fuel and easier slash treatment may compensate for the increased marginal costs of yarding whole trees.

The prospect of better fuel economy provided by helium carrying part of the load may mean that yarding to multiple landings or to one very large landing that is farther away from the unit, because of lower construction cost, could be advantageous.

Expensive road construction costs in steep terrain may suggest longer yarding distances in lieu of closer roads and longer truck hauls.

Theories are easy to express but can be expensive to demonstrate. The planner's task is to understand the interrelations among harvest activities. Good planning in the office can save time and money in the woods. How will a change in one operation affect the productivity of later operations? And more importantly, how will changes affect the final cost and products of the harvest?

Timber harvest planners need mathematical models of the critical components of harvesting to assist them in suggesting improvements for productivity, costs, and product selection.

METHODOLOGY

Rising to the Need

LOGPAC (for Logging Productivity and Costs) was conceived to mathematically organize the many variables in timber harvesting and, thus, improve presentation of analysis results. The results of a complex analysis cannot be communicated for uniform understanding without a clear description of how each variable was considered in the analysis. As the structure and modular nature of LOGPAC were being established, we realized that LOGPAC could be used in planning for other applications as well as for meeting the immediate needs of Heli-Stat planning and analysis.

Two important functions can be accomplished with the model: (1) the performance of an aerial vehicle with specified size, shape, and power can be simulated before it is built, and (2) the productivity and costs of logging under different plans can be compared whether the yarding is done by cable, helicopter, or airship.

A principal advantage of LOGPAC over other planning and accounting methods for aerial logging is that productivity and costs are calculated based on the logs being handled, on a specific site, under the environmental conditions at hand, and by people and machines whose performance is quantified. Productivity and costs are not based on average values.

Structure

LOGPAC considers each harvest activity individually and in detail. First, the production rate is determined. Then, the cost of the activity is calculated, based on ownership and operating costs (Mifflin 1980) and on the total time required to complete the activity on the particular harvest unit being considered. As the simulation proceeds, each activity passes the correct form of the material being handled on to the following activity. For example, standing trees enter the felling subroutine. The trees are progressively changed into felled trees; bucked logs; assembled loads; rebucked, trimmed, sorted and loaded logs; and so forth.

Production Rate

The method of calculating production rate is based on the best algorithm (arithmetical expression) available for the activity being considered. Algorithms may come from prior observed operations in the form of regression equations, constant values, or simple, logical relationships that effectively represent actual production rates of that activity within normal bounds of the significant variables. Ideally, the algorithm will have been validated by comparison to actual experience in similar conditions before use. Limits and ranges of validation should be made known to the planner so that each algorithm will be used appropriately.

Costs

The method of calculating ownership cost is based on capital investment, salvage values, depreciation, interest rates, taxes, license, insurance, and storage of all equipment used for the activity.

Operating cost is the sum of all consumables (fuel, oil, lube), repairs, maintenance, wages, supervision, and overhead incurred by the activity.

Costs are included for move in, move out, relocation, refueling, commuting, and other incidental costs of completing each activity.

Time

Operational time includes productive time and nonproductive time, as long as the equipment and workers performing the activity are in the woods and dedicated to completion of the activity. Delays caused by planned maintenance or by unscheduled downtime due to equipment failures (reliability), weather, etc. are all included as operational time.

The productive time required to complete the activity depends on the production rate of the equipment and workers assigned and on the quantity of trees and logs processed by the activity.

Minimum Crew

The minimum crew is defined as the least number of workers and equipment that can accomplish work on the activity. For example, a felling crew is one worker and one chainsaw. A loading crew may be one rubber-tired, front-end loader and one driver. The analyst or planner can use multiples of any minimum crew to find the effect on production rates and costs. Also, the amount of time a crew is actually dedicated to an activity is indicated by an application fraction (a number between 0 and 1). This helps the planner track idle time and shared costs if a crew is assigned to more than one activity. For example, the same person could work on the landing as a choker chaser and a knot bumper.

Internal Links

Because LOGPAC first considers each activity individually and later sums the results, a consistent set of values must be used for uniformity and comparison. Each activity may require specific starting values based on the variables in the algorithm used for production rate calculations; but, for reporting results, each activity uses two standardized values--tons and dollars. Production rates are then expressed in tons per hour, and machine rates are expressed in dollars per hour.

One rate divided by the other rate gives the productive cost--dollars per ton. This value is of extreme interest in the search for the least costly method of harvest. For comparison to other planning methods, the bottom line ($/ton) may be converted to a more frequently used term such as: $/MBF (dollars per thousand board feet of finished lumber). For studies of material handling by aerial logging systems, however, weight units (tons) have advantages over finished lumber volume units (board feet), because lift capacities are limited by actual weight at the time of handling, and because green trees and logs contain water that affects weight during the harvest.

Sequence of Simulation

Stand Information

Simulation of harvest systems with LOGPAC begins with a description of the stand to be harvested. This infotmation comes from a standard timber cruise as numbers of trees and their heights by diameter classes and species.

Felling Activity

The time and cost of felling can be calculated by using a description of the numbers and sizes of trees, terrain characteristics, and values for other variables that may be required by the felling production algorithm, and the number of felling crews used (provided by the planner). Some planner choices can be made here. Is this conventional chain saw felling? Is it uphill felling? Are feller bunchers to be used? How many machines or fallers? The planner should always ask, "Are the correct algorithms in place for the selected felling operation?"

Weight Estimation

LOGPAC estimates the weight of tree boles, logs, and crowns, based on actual stand measurements of green density, diameter, and bark thickness. The applicable data must be taken and inserted into the weight estimating subroutine before simulation. Applicable data may already be available or new sample-weight data may be taken for improved confidence according to procedures such as those established by Waddell and others (in press).

The weight-estimating subroutine prepares a table of the product inventory expected from the harvest unit based on the given cruise data, sample weight data, preferred bucking lengths, bucking strategy, and maximum lift capacity of the yarding and handling equipment. This product table can be used by the planner to estimate the quantities of logs, by size (not grade), that will be produced for sale. The planner may want to refer to this table in subsequent simulation runs to observe what effects changes in constraints (stand data, preferred lengths, bucking strategy, equipment capacities) might have on the product mix.

Load-Preparation Activities

The production rates, time for completion, and costs for each activity in load preparation are individually calculated much like the calculations for the felling activity are figured. Activities such as bucking, the weight-estimating process, log tagging, machine prebunching, and/or choker setting are usually included here.

Yarding

The time and costs of yarding are calculated based on the planner's description of the flight paths from the harvest unit to the landing(s), previously described airborne performance capabilities, weather data, and several other factors. Because of the relative impact of the cost of yarding activities on the total cost of harvest, a more detailed cost-accounting system is used for this activity. It is based on the same principles that are used for the other activities, but it is more rigorous to match its complexity. Data on capital investment, depreciation, and other costs are provided by the planner for each piece of support equipment in the yarding system, whether ground based or airborne. Each piece of equipment is itemized separately. Wages for pilots, mechanics, and other workers are listed individually. Different machine rates are charged for flying, idling, or standing by, depending on fuel consumption rates, how many workers are drawing pay, and so on.

Fuel used and time to complete a turn are calculated by equations of motion and aerodynamic pinciples. The forces, inertias, accelerations, and velocities of flight are simulated for each maneuver of the yarding vehicle as it completes its turn cycle.

With this itemized cost-accounting and engineering approach to yarding dynamics, the planner can observe the relative effects of various delays, different-length work days, actual support equipment costs, longer refueling times, larger on-board fuel tanks, reduced aerodynamic drag, and other interesting items.

Landing Activities

Individual material-handling processes on the landing are individual activities for production rate and cost calculations. Each activity is discrete but also part of the whole material-flow process. Material flow through each activity is affected by the production rate of that process and also by the production rates of the preceding and following activities. All this is driven by the arrival times and size of the loads delivered to the landing by the yarder. If an activity at the landing has no material to process, the activity is idle. If space to transfer material into a following activity is lacking, a bottleneck develops, and the delivering activity is forced to accept a delay. Delays can eventually work back to the drop zone and cause expensive hovering delays for the yarder, which may require extra trips back to the service landing. The planner can use information about bottlenecks to suggest extra equipment or workers or perhaps a larger or more distant landing.

Totaling The Results

After all activities have been simulated, LOGPAC sums the results to show the total cost. Other important values are calculated and accumulated for printing, according to the detail selected by the planner. A typical final report displays the critical input variables for each activity. It then shows the production rate, time to completion, cost, and cost per ton of each activity. Finally, the bottom line is printed, which reflects the aggregated productive cost--in dollars per ton.

Modular Construction

Each algorithm of LOGPAC that performs a calculation can be (1) used as is, (2) bypassed with a known or externally calculated value, or (3) replaced with a more applicable or current algorithm.

This modular-construction attribute of LOGPAC enhances its applicability to new harvest areas and processes. A planner can incorporate the best information available for each and every activity under consideration. If information is lacking, it can be added as soon as it becomes known and validated. Or, a range of inserted values can be used on successive runs to observe the sensitivity of the logging system to that item.

How to Use LOGPAC

Select Activities

Because LOGPAC can analyze a range of activities on a range of harvest sites, subroutines for many activities are included that are not used for every analysis. The planner who uses the simulation model must be familiar with the particular logging systems and individual activities that are simulated. The planner's first task is to select and identify the exact combination of activities that comprise the harvest system to be analyzed.

Evaluate Algorithms

The planner next evaluates the applicability of the production-rate algorithms for the selected activities. This is done by referring to the written description prepared for each item. A regression equation for the time required to fell old-growth Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) in southwest Washington may be acceptable for the same species in northwest Oregon but not for lodgepole pine (Pinus contorta Dougl. ex Loud.) east of the Cascades. As necessary, the planner chooses the best algorithm available (noting possible inaccuracies), modifies or substitutes if possible, or bypasses the calculation by entering a known value from another source.

Prepare Data-Entry File

After the activities are selected, values for the required variables must be collected and organized into the order required by the algorithms for the selected activities. Depending on the software and computer used, this step can be done interactively or by building a separate data file for use in batch mode. Preparing file-building routines to aid interactive data entry may be desirable.

Sometimes lengthy reports that fully describe the productivity and costs of all aspects of the harvest are of interest. At other times, only specific items need to be highlighted. The planner should set the appropriate flags in the data-entry file to produce the desired reports from the simulation.

Run, Observe, Change Entries, Rerun, and Compare

When the data-entry file is complete, the planner allows the computer to do the hard part--and then studies the results. For comparison and optimization, the planner may change certain data-entry values while holding other values constant, rerun the simulation with the altered data, and compare the results to previous runs. By repeated use of this process, the planner can select the best combinations of equipment and workers to minimize costs, speed production, deliver certain product mixes, or optimize some combination of all of these variables.

STATUS OF THE SOFTWARE

LOGPAC is currently running on an IBM mainframe. It has been used by the Forest Service to analyze several aerial-logging vehicles and various applications. In its current form, the model can be used for variations of harvesting systems that use helicopters or aerostat/helicopter hybrid-type yarding vehicles. Models of aerodynamic performance are available for helicopters commonly used in logging and for hybrids with one, two, or four helicopter rotors.

Productivity submodels for various common and specialized load-preparation methods and landing activities are available. Many, but not all, of the productivity algorithms have been validated.

ORIGIN OF SUBMODELS

Weight Estimation

The ability to estimate the weight of trees and logs in the given timber stand according to the constraints of preferred length and maximum weight per log (provided by the planner) forms the foundation of LOGPAC. Simulation of the number of workers needed and production rates for all activities are based on the number and sizes of logs that enter the material handling processes.

Research under my direction on the Wind River Experimental Forest, Gifford Pinchot National Forest, Washington, in 1981-82 has produced methods of estimating tree and log cubic volume and developed related tools and computing capability to support methods of estimating weight in the field (Pong and others 1986, Waddell and others 1984).

Productivity Estimates

Data for the productivity algorithms contained in LOGPAC have been assembled from various sources. Data from literature and information from other scientists were assembled as appropriate. Individual field trials were conducted to supply information on activities for which data were lacking. Several cooperators assisted, including: Intermountain Research Station and the Pacific Southwest and Pacific Northwest Regions of the Forest Service, Montana State University, University of California, and Oregon State University. Technical assistance with aerodynamic computer modeling came from a private aerospace firm.

Cost Tabulation

Ownership and operating costs are calculated by a standardized subroutine patterned after Mifflin (1980). Yarding costs are calculated by a more extensive subroutine called HECON[3].

VALIDATION

The data in most of the productivity algorithms have been validated during logging operations between May 1981 and November 1983.

The most recent validation trial was planned as a dress rehearsal for the Heli-Stat in the Rogue River National Forest, Oregon, in late 1983. The yarding vehicle was a Sikorsky S-64E helicopter. Data were collected for the successful validation of the airborne performance model. The trial also built confidence in the validity of the model for airships that combine an aerostat with one or more helicopters. Tests in the Gifford Pinchot National Forest in 1982 and the Mount Hood National Forest, Oregon, in 1983 (Waddell and others, in press) validated the log-weight estimating methods developed in 1981-82. Other validation studies included load assembly and load factors in the El Dorado National Forest, California (Hartsough and others 1983, 1985); load assembly methods for small timber in the Gallatin (Montana) and Clearwater (Idaho) National Forests (Gibson and others 1984); landing operations in the Rogue River National

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[3]Unpublished study by Michael B Lambert; data on file, U.S. Dept. of Agric. For. Service, PNW Res. Sta., Portland, OR.

Forest, Oregon[4] and on land owned by St. Regis Paper Company near North Bend, Washington (Gerstkemper 1982); and production rates for the Spyder (mechanical load preparation machine for steep slopes) in the Olympic (Washington) and Rogue River (Oregon) National Forests[5].

EPILOGUE

The preceding described a methodology to meet a special need for a tool to analyze the concept of logging with large airships. The tool is in use for that purpose. The features and capabilities of the methodology offer new possibilities in harvest planning. Software has been prepared and used as an initial embodiment of the methodology. Space here does not allow presentation of all the logic or even a description of all the activities that are included in the initial software. Yet, if the methodology is to be widely applied, many additional or improved productivity algorithms will eventually be added. What is needed is more use of the simulation methodology by planners who can refine its contents. Performance models for various types of cable and even ground-based yarding systems need to be inserted so that comparisons of a wider range of harvesting alternatives can be made. Subroutines for construction costs of roads and landings should be added as well as for costs for secondary transportation and reforestation. These items must currently be handled by the planner externally to the model. Incorporation of existing digital terrain modeling softwware would be advantageous, especially with added road construction and cable yarding subroutines.

This paper has focused on methodology rather than software because different users of the concept may prefer to model on different levels of precision and complexity to suit their needs. Reinstallation of the code onto smaller computers may be preferred. I am willing to help anyone who wants to use this approach to harvest planning.

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[4]Unpublished studies by Michael B Lambert; data on file, U.S. Dept. of Agric. For. Service, PNW Res. Sta., Portland, OR.

[5]Unpublished studies by Michael B Lambert, Dennis Caird, Donald Nearhood, and Paul Clemens; data on file, U.S. Dept. of Agric. For. Service, PNW Res. Sta., Portland, OR.

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Mechanized Harvesting and Processing in Mountainous Terrain of Western Montana: A Case Study[1]

Michael J. Gonsior[2]

Abstract: This presentation summarizes some of the results of a study of mechanized harvesting in a variety of terrain, stand, and climatic conditions in Western Montana. Included in the array of systems studied was a steep terrain feller-buncher, a couple of delimber-buckers, a chipper, and a debarker. Study results comprise availability as well as productivity of the various systems, and the influence thereon of tree size, ground slope, and other factors. Obstacles to extending mechanized harvesting and processing into steep terrain are identified and discussed.

Keywords: Logging, productivity, availability

STUDY OBJECTIVES AND METHODS

The principal objective of our study was to determine if mechanized multiproduct recovery systems could be used in so-called second growth stands in steep terrain. If so, the acreage available for management with such systems in the Intermountain West might be substantially increased. Otherwise, only relatively gentle terrain affords such opportunities.

The modus operandi was to fell and bunch trees with a Timbco,[3] then skid them downslope with an FMC grapple skidder to a Hahn Harvester. Trees large enough to produce sawlogs or plywood peelers were delimbed and bucked by the Hahn, and a companion loader decked the logs or loaded them onto trucks. Smaller trees--down to 3 inches diameter at breast height (dbh)--and the residual upper portions of the larger trees were delimbed and topped at about 2-inch diameter. The delimbed portions (called pulp boles) were decked by the loader, and residual limbs and tops were piled separately by the Hahn system's infeed operator. Subsequently a Morbark Model 18, served by a rubber-tired grapple skidder, chipped the pulp boles and attempted to chip the limbs and tops.

As the name implies, the pulp boles were intended to become feedstock for Champion International Corporation's pulp mill near Missoula, MT (since purchased by Stone Container Corporation). Accordingly, partial debarking was attempted by the Hahn system operators. Further, the limbs and tops were to have been chipped to provide hog fuel for the mill's boilers. Unfortunately, the resulting pulp chips failed to satisfy extant quality standards, because of excessive bark content, so all the intended pulp chips ended up as hog fuel. Moreover, the problems encountered in trying to chip the limbs and tops were deemed insurmountable. Nevertheless, even though we recognized early in the study that the original goals could not be met, we decided to continue for part of the study duration with the procedures as originally planned because the information gained might be useful in other circumstances where either (1) chip quality standards might not be so high or (2) instead of in-woods chipping, hauling delimbed boles from the woods might be desirable.

During the latter part of the study, utilization standards were relaxed to conventional sawlog and plywood peeler specifications, and attempts to use residues and smaller trees were abandoned. This enabled determination of the effects of utilization standard, in combination with season, on the Timbco and Hahn systems' performance.

During the early, close utilization phase of the study, we harvested 13 units totaling about 140 acres, with slopes up to 60 percent and stand densities ranging from 180 to 610 and averaging about 380 stems per acre (larger than 3 inches dbh). Two units were clearcut and the rest had residual stand densities of under 50 trees per acre.

During the latter, conventional utilization phase, we harvested 10 units totaling about 200 acres, with slopes up to 55 percent and stand densities ranging from 55 to 280 and averaging about 165 stems per acre (larger than 3 inches dbh). Some units were clearcut, and the residual stand densities in the remainder were under 50 trees per acre. The Timbco was assisted by sawyers with chainsaws in some of the units, partly to fell trees larger than the Timbco could handle but also to assist during periods when the Timbco was incapacitated.

Gross data were collected by the machine operators, unit by unit and day by day, consisting of total trees cut or processed, total yield of products (if applicable), total time, and unscheduled downtime (UDT) as well as reasons therefor. More detailed "time and motion" data were collected by observers, consisting of times for activities such as fell and bunch cycles, position-to-position moves, and maintenance or repair operations, along with associated data such as species, dbh, and resulting products.

RESULTS

Timbco System Performance

We monitored the Timbco system from August 8, 1984, until February 7, 1985, a period comprising 6 months or 184 calendar days. Excluding Saturdays, Sundays, and holidays, there were 122 "scheduled" workdays; but only during 89 days, including five weekend days, was work performed with the Timbco. Thus, the Timbco system was at least partly available a little less than half the

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[3]The use of trade or firm names in this paper is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

calendar days (89/184) or three-fourths (89/122) the scheduled workdays. The system was idle during the remaining workdays due to major mechanical breakdowns, exceedingly cold weather, or other reasons not always attributable to the Timbco itself. This is comparable to the availability reported by McMorland (1985).

During the 89 days when the Timbco system was operated, workday lengths ranged between 0.5 and 22.5 hours (excluding lunch periods) and averaged about 8 hours. Based on time and motion studies that accounted for about half these hours, approximately 70 percent was spent in the basic productive function--about 48 percent for felling and bunching while stationary, and about 22 percent for moving from position to position (PP and PP-CC) or strip to strip (SS and SS-CC). (The nomenclature PP-CC and SS-CC will be defined shortly.) The remaining 30 percent of time not utilized for the basic productive function was approximately distributed as follows: 20 percent for unscheduled downtime (UDT), 5 percent for scheduled downtime (SDT), and 5 percent for a combination of commuting (COM) and ancillary activities (AA). These are average percentages for the entire study; later it will be shown how activity distributions were affected by slope and utilization specifications.

Figure 1 summarizes the Timbco's basic felling and bunching productivity for one-, two-, three-, and four-tree cycles. Noteworthy, apart from the obvious advantage of accumulating trees during the felling and bunching operation, was the gradual increase in mean time per tree with increasing dbh up to about 14 inches, beyond which there was a substantial increase in mean time per tree with increasing dbh in one-tree cycles. Virtually all the multiple-tree cycle data represented in figure 1 were obtained during the close utilization phase.

The mean time per tree vs. dbh relationships shown in figure 1 are only for trees felled and bunched while the Timbco was stationary. The activities called PP-CC and SS-CC entailed cutting and carrying one or more trees in the process of moving from position to position or from strip to strip; such trees were not included in the basic productivity data. About 8.7 percent of all trees tallied in the time and motion study were accounted for in PP-CC or SS-CC activities (about 4.4 percent in the close utilization units and about 22.6 percent in the conventional utilization units). Therefore, if the relationships reported herein are used as a basis for predicting productivity, then some additional production occurring during position-to-position and strip-to-strip moves must be anticipated.

While figure 1 shows productivity improvement due to accumulation during the felling and bunching activity, judgment must be used in estimating the proportions of trees that will be cut during one-tree and multiple-tree cycles. For example, in the conventional utilization phase, over 99 percent of the observed trees were cut in single-tree cycles, requiring a mean time of about 30.2 seconds per tree. However, during the close utilization phase, less than half the observed trees were cut in single-tree cycles, for which the mean time was about 24.2 seconds per tree. For all observed trees cut during the close utilization phase, the mean time was about 19.8 seconds per tree because over half were cut in multiple-tree cycles requiring a mean time of only about 16.2 seconds per tree.

To discern the effects of ground slope on performance, the time and motion data were stratified into three slope classes: (1) <15 percent, (2) 15-35 percent, and (3) >35 percent. The bar charts of figure 2 show how activity distributions varied by slope class in both the close and conventional utilization phases of the study, suggesting that the proportion of time spent in the basic productive activity of felling and bunching decreases somewhat with increasing slope.

As terrain steepens, it seems reasonable to expect an increase in the proportion of basic productive time for position-to-position and strip-to-strip movements. Figure 2 supports such expectations. Even if movement speed is unaffected by slope, the Timbco must move greater distances per unit area as slopes increase. Moreover, the operators in our study cut only in the uphill direction on steeper terrain, so more time was spent in strip-to-strip (SS, SS-CC) movement as slopes increased.

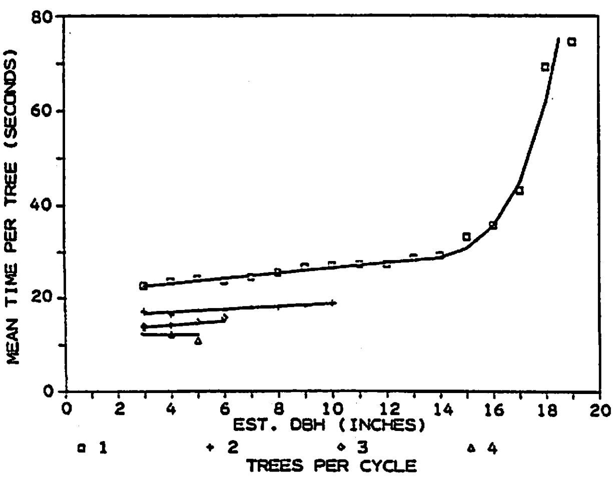

Figure 1--Mean fell and bunch time per tree vs. estimated dbh for 1, 2, 3, and 4 trees per cycle, Timbco system.

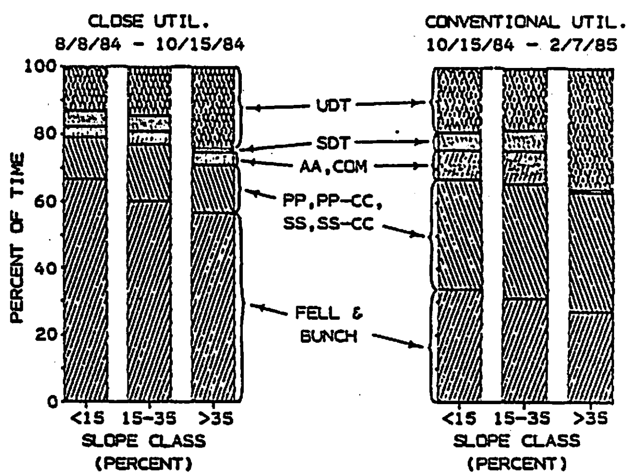

Figure 2--Activity distributions (percent of observed time) for Timbco in three slope classes, comparing close and conventional utilization.

The lower productive time in the conventional utilization bar charts of figure 2, compared with close utilization, may have been due to the more adverse winter weather conditions and an associated increase in UDT. However, the lower proportion of productive time spent in felling and bunching in the conventional utilization units mainly was due to spending more time moving among the larger, more widely dispersed trees. In close utilization, the feller-buncher spent a smaller proportion of its time moving from position to position, and a greater proportion felling and bunching, because there were more trees per unit area to be cut.

Basic productivity--the relationship between mean time per tree and dbh for felling and bunching --seemed not to be affected consistently by slope or utilization standard. Of course, the mean time per tree for felling and bunching was considerably smaller in close utilization circumstances, not only because of smaller average tree size but also because of greater opportunity to use the accumulator.

According to the preceding, for close utilization on moderate slopes, we estimate (from fig. 2) that about 60 percent of the time was spent in the basic fell and bunch activity. With a mean time per tree of about 19.8 seconds, this resulted in a basic production rate of 109.1 trees per hour (0.6 x 3,600 sec. per hour ÷ 19.8 sec. per tree). In addition, with 4.4 percent of the trees cut during position-to-position or strip-to-strip moves, the resulting production rate was 109.1 ÷ 0.956 = 114.1 trees per hour, or about 913 trees in an 8-hour day.

In contrast, for conventional utilization on moderate slopes, we estimate (from fig. 2) that only about 30 percent of the time was spent in the basic fell and bunch activity. With a mean time per tree of about 30.2 seconds, this resulted in a basic production rate of 35.8 trees per hour (0.3 x 3,600 sec. per hour ÷ 30.2 sec. per tree). In addition, with 22.6 percent of the trees cut during position-to-position or strip-to-strip moves, the resulting production rate was 35.8 ÷ 0.774 = 46.3 trees per hour, or about 370 trees in an 8-hour day.

Incidentally, Stokes and Lanford (1985) derived production rates between 111 and 147 trees per productive machine hour (PMH) from their studies of loblolly pine thinning with a Timbco, based on a mean dbh of about 6 inches. Assuming an average of 0.75 PMH per scheduled hour, the corresponding production rates would range between about 83 and 110 trees per scheduled hour. This compares reasonably well with the results we obtained during the close utilization phase of our study; and it is likely that production rates would have been improved if the machine Stokes and Lanford studied had been equipped with an accumulating shear head.

Lastly, although figures 1 and 2 fairly represent the Timbco system's mean performance in our study, it should be recognized that data from many circumstances are aggregated therein, and variations from stand to stand are not shown. For example, in one virtual clearcutting situation in the close utilization phase of our study, when stand density was approximately doubled (from 246 to 485 stems per acre)--yet slope, tree size distribution, and all other factors remained sensibly unchanged--then gross productivity increased by about 25 percent: from about 100 to 125 trees per hour. In part this was due to a lower proportion of time spent moving from position to position or strip to strip in the denser stand and, correspondingly, more time spent in the basic felling and bunching activity. It also was partly attributable to the fact that a higher proportion of the trees were cut in multiple-stem cycles in the denser stand. Moreover, the basic production rates were higher in the denser stand (23.3, 16.7, 14, and 11.4 seconds per tree in the denser stand vs. 26.5, 18.6, 14.8, and 13.9 seconds per tree in the other stand, for one-, two-, three-, and four-tree cycles, respectively). Consequently, the combination of lower mean time per tree (for a given dbh and a given number of trees per cycle) with a higher proportion of multiple-tree cycles resulted in an overall mean time per tree of only about 18 seconds in the denser stand, compared with about 21 seconds per tree in the other stand. Thus, in concurrence with Stokes and Lanford (1985), we found that stand density as well as tree size affected the Timbco system's productivity.

Hahn System Performance

Based on time and motion study observations that accounted for about half the time and trees tallied by the Hahn's operators, about 50 percent of its time was spent in the basic tree-processing (delimbing, bucking, and topping) function. About 15 percent of the time was attributed to UDT, another 15 percent was spent in the ancillary activity of clearing and piling limbs and tops, and about 10 percent was lost due to delays caused by running out of trees and waiting for the skidders to deliver more. The remaining 10 percent of the time was attributed to other delays, SDT, and system relocation. Differences in activity distributions between the close and conventional utilization phases of the study were deemed inconsequential.

Figure 3(A) shows the relationships between mean delimbing and bucking time per tree and estimated dbh, for single-tree cycles, in both the close and conventional utilization phases. The increase in time with increasing dbh corresponded with the increase in mean number of logs per tree as tree size increased, reflecting the extra time required for careful length measurement and adjustment when cutting sawlogs and plywood peelers. The consistently greater times in the close utilization phase at least partly were due to the added time for delimbing the tops to make pulp boles. (Data scatter above about 18 inches dbh may be attributed to small numbers of observations in the close utilization phase.)

Figure 3(B) shows the relationships between mean time per tree and mean estimated dbh for multiple-stem as well as single-stem cycles in the close utilization phase of the study. Obviously, delimbing more than one stem per cycle reduced the mean time per stem. Moreover, multiple-stem processing usually entailed the production of pulp boles only, so there was correspondingly less sensitivity to tree size.

Overall, the Hahn system's productivity was reasonably well matched with the Timbco's, averaging about 900 trees per workday in the close utilization phase and about 310 trees per workday in the conventional utilization phase. Workday lengths averaged about 8.5 hours.

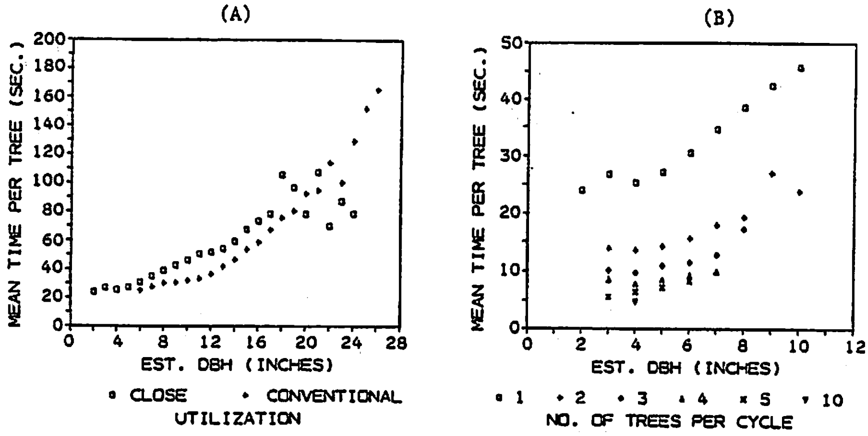

Figure 3--Mean processing time per tree vs. estimated dbh, Hahn Harvester system, (A) one-tree cycles only, comparing close and conventional utilization, and (B) single- and multiple-tree cycles, close utilization only.

Chipping System Performance

Based on time and motion studies that accounted for about a fourth the time and van loads tallied by the chipping system operators, only about 45 percent of the time was spent in the basic chipping operation. Another 15 percent of the time was idle due to running out of wood during the chipping operation and waiting for the skidder to deliver more. About 5 percent of the time was delay due to being out of empty vans and waiting for another to arrive. The remaining 35 percent of the time was about equally distributed among (1) UDT, (2) SDT, and (3) ancillary activities (AA) or system moves (PP, COM).

Table 1 shows the mean total and net van filling times for 40-foot and 45-foot vans, as well as mean numbers of skidder turns per van load, based on the time and motion study observations. The difference between total and net fill time mainly was due to running out of wood and waiting for the skidder to deliver more. An average of about 8 van loads per nominal 9-hour workday were produced. If delays due to running out of wood while chipping could have been eliminated, the production rate might have averaged about 10 van loads per day.

Chipping of two van loads of limbs and tops required mean total and net times of about 3.5 and 2.5 hours, respectively, and an average of 35 skidder turns per van load. The skidder had difficulty extracting the debris from the piles left by the Hahn system, and its grapple-loads were "short on substance and long on air." The chipper infeed rate was correspondingly low. Moreover, the chipper became plugged with badly oriented limb fragments. In short, production of hog fuel from limbs and tops turned out to be impracticable with this type of system.

Of course, given that the pulp bole chips became hog fuel anyway, it would have been more sensible to bypass the Hahn system altogether and chip the small trees and tops of the larger trees for hog fuel without first delimbing them. This would have increased the hog fuel yield and probably would have reduced total cost per unit of hog fuel, even though chipping cost might have been somewhat higher. Reasons for proceeding otherwise were provided earlier.

Table 1--Chipping production, delimbed pulp boles.

Van length	Mean fill time		Mean skidder turns
	Total	Net	per van load
Feet	Minutes		
40	39.4	30.2	9.9
45	43.6	32.6	10.3

In addition to the problems of restricted landing size in mountainous terrain, negotiating narrow, winding roads with chip vans is difficult. In one of our study circumstances, the road had to be widened in a few locations. Even then, only the shorter 40-foot vans could be used.

Harricana System Performance

The initial study objectives emphasized steep terrain harvesting. However, we found that the Hahn Harvester was compatible only with relatively large, flat landings. Unless the steep terrain immediately adjoined relatively flat terrain, the opportunities for using the Hahn were limited. Indeed, some of our intended harvest units were abandoned because it was deemed infeasible to employ the Hahn system on narrow roads in steep terrain.

One system that seems more flexible, and better adapted to working in the confinement of narrow roads in steep terrain, is the slide-boom delimber. An opportunity to study one made by Harricana arose in January and February of 1985.

Figure 4(A) shows the activity distribution for the Harricana, based on time and motion studies that accounted for over 80 percent of the trial period. It reflects a slightly higher proportion of time devoted to the basic processing function (PROC) than exhibited by the Hahn system, largely because there were no delays due to running out of wood as experienced by the Hahn. The proportion of time attributable to PP, AA, and COM was slightly less than that observed for the Hahn system; and virtually all of this was for position-to-position moves. Unlike the Hahn, the Harricana deposited the limbs and tops where the operator desired, requiring no interruptions to clear and pile debris. Instead, it moved frequently from deck to deck. Delays (DEL)--mainly caused by log trucks and other traffic for which the Harricana had to move aside--accounted for 4.1 percent of the time.

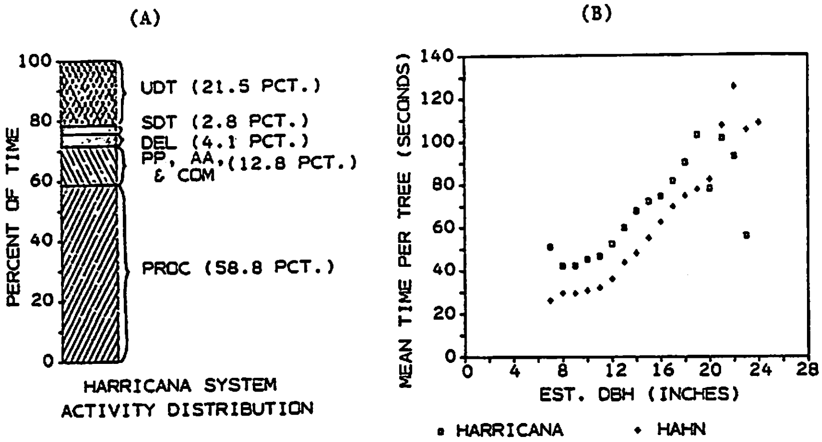

Figure 4--(A) Activity distribution (percent of observed time) for Harricana and (B) mean processing time per tree vs. estimated dbh for Harricana, with comparable data from Hahn system.

Figure 4(B) shows mean processing time (PROC) per tree vs. estimated dbh for the Harricana, and contrasts it with comparable data from the Hahn system study. It should be noted that the Harricana processed single trees only and produced only sawlogs and peelers, no pulp boles. Virtually all the trees were Douglas fir, and most were relatively limb-free because limbs tend to break off readily during skidding in cold weather. Whether the Harricana could delimb and top several stems simultaneously to make "pulp boles," as was done by the Hahn system, was not investigated.

It also should be noted that the Harricana operator had no prior experience with such a machine. Thus, improvement in productivity with additional experience might be expected. For example, Folkema and Lavoie (1978) reported a mean time per tree of under 30 seconds, for trees averaging 7.7 cubic feet in volume, with an early prototype run by an operator with 3 months experience.

Virtually all of the data represented in figure 4 were acquired in relatively gentle terrain, in which the Hahn system could have operated as well. However, during one brief period, the Harricana operated on a narrow road along a steep hillside, immediately below which trees had been decked as though by a skyline system. Results from this trial indicated that performance was virtually the same as in gentle terrain.

Debarking System Performance

The aforementioned inability to satisfy pulp chip quality standards heightened our interest in the potential for in-woods debarking. Though not originally incorporated in the study plans, an opportunity arose to study the performance of a portable debarking system during a brief period of only about 15 hours distributed over 4 days in January 1985.

The system consisted of a Morbark 2250 debarker, a hydraulic loader, and a grapple skidder. The skidder delivered bunches of whole trees to the infeed end of the debarker and roughly delimbed them with its blade. A sawyer topped the stems and removed any remaining limbs with a chainsaw. The sawyer also bucked the crooked stems into shorter, relatively straight segments when necessary. The loader placed the delimbed pieces on the debarker's infeed conveyor. The limbs and tops were gathered by the grapple skidder and taken to a chipper for conversion into hog fuel. The skidder also occasionally pushed bark away from the debarker into waste piles.

Figure 5(A) shows the proportion of observed time spent in various activities. Availability of the system was high. Only 5.4 percent of the time was attributed to UDT, over half of which was caused by a hose leak on the loader. However, 29.4 percent of the time was idle due to running out of trees (OT) and other delays. Thus, only 65.2 percent of the time was attributed to the basic debarking function. Of this, only about 60 percent (39 percent of total time) was attributed to debarking per se while the remaining 40 percent (26.2 percent of total time) was attributed to gaps between the pieces (GAPS).

We originally anticipated that feed rate while debarking would be inversely proportional to stem diameter. Correspondingly, the lengths and end diameters of the pieces were estimated. Based thereon, the mean diameter for each piece was calculated, and the aggregates of debarking times and lengths for all stems within each mean diameter class were used to deduce mean feed rates. Figure 5(B) shows the relationship between these feed rates (expressed reciprocally in seconds per foot) and mean diameters; and it only weakly supports original expectations.

Use of figure 5(B) must be tempered with judgment because it excludes unusual debarking cycles, such as those with reversals to achieve better quality. Represented in the figure are about 85 percent of all the observed pieces, with a mean length of about 30.8 feet and mean debarking time of about 16.5 seconds (about 0.54 seconds per foot). The mean time for the other 15 percent of observed pieces was about 19.5 seconds; so the overall mean was about 17 seconds per piece. Combining this mean production rate with the 39 percent utilization level from figure 5(A) yields an estimate of 82.6 pieces per hour (0.39 x 3,600 sec. per hour ÷ 17 sec. per piece), or about 660 pieces per 8-hour day. This translates into a daily production rate of under 660 trees, because some trees must be cut into shorter pieces. If the 24.5 percent of time in figure 5(A) attributable to being out of trees could be eliminated, then the production rate might be increased to over 1,000 pieces per 8-hour day.

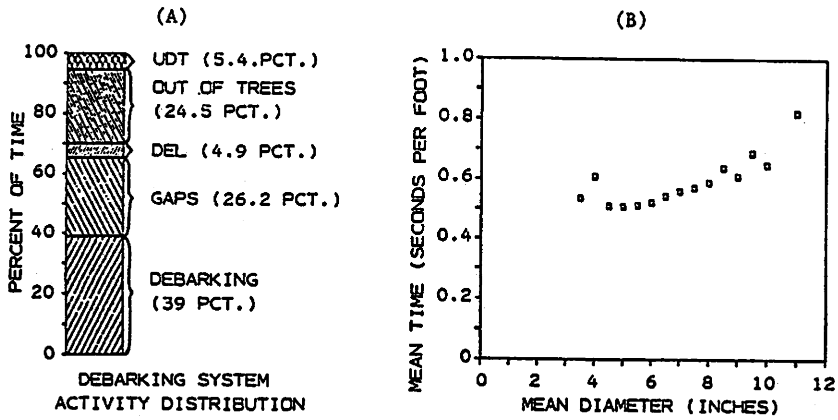

Figure 5--(A) Activity distribution (percent of observed time) and (B) mean debarking time per unit length vs. mean of end diameters, Morbark portable debarking system.

As with the Hahn Harvester and Morbark chipping systems, substantial landings are needed for setup and operation of the debarking system described herein. Accordingly, operation in circumstances characterized by narrow, winding roads in steep terrain is difficult.

DISCUSSION AND CONCLUSIONS

Although the Timbco can harvest timber on slopes up to 60 percent and travel in a direction perpendicular to the contours on even steeper ground, it cannot so readily maneuver parallel to the contours on such terrain. Moreover, despite its impressive climbing abilities, it cannot negotiate certain road cuts. Deal (1983) noted this problem in his report on the Kockums 880 in the mountains of North Carolina. Thus, gaining access to otherwise operable terrain from many mountain roads is problematic. Even if occasional access locations can be provided, the only feasible means of reaching much of the terrain above road cuts is by approaching from above and harvesting in a downhill direction. Stokes and Lanford (1985) reported that harvesting productivity was reduced when traveling in the downslope or across-slope directions, compared with operation in the upslope direction; indeed, the operators in our study would not harvest in the downslope direction or across slope on other than flat to moderately sloping terrain.

Extending mechanized harvesting to steep terrain below or downslope from roads presents additional obstacles. Although machines such as the FMC can skid in an upslope direction, their productivity is certainly reduced when doing so; and above certain slopes it becomes necessary to use skyline or aerial systems. We made no attempt to operate in such circumstances.

Even if mechanized feller-bunchers and grapple skidders can be used, mechanized processing may not be practicable in the confinement of narrow roads in steep terrain. We intended to experiment with self-loading log trucks to determine if whole-tree forwarding by such means to favorable landings in the valley bottoms might be practicable, but we were unable to make necessary arrangements for such trials. Otherwise, while our brief experiment with the Harricana slide-boom delimber indicated reasonably good prospects for mechanized delimbing, bucking, and decking on narrow mountain roads, we did not conduct a fully operational trial.

In conclusion, technologies like the Timbco extend the advantages of mechanization to terrain that was formerly operable only with methods that are less efficient and more hazardous to workers. Extension of mechanized, multiproduct recovery systems into relatively steep terrain can readily occur if such terrain immediately adjoins and rises above gentle terrain on which opportunities for large landings are abundant. However, much mountainous terrain, with characteristically narrow, tortuous roads incised in steep slopes, presents obstacles to mechanized timber harvesting that remain to be overcome.

ACKNOWLEDGEMENTS

The foregoing was derived from a cooperative investigation by the Intermountain Research Station, Forest Service, U.S. Department of Agriculture, and Champion International's Timberlands Division. John Mandzak, silviculturist with Champion, instigated and managed the study. The patient cooperation of the employees and management of the Ed Cheff Logging and Hall Wood Products Companies--two of Champion's contractors--is gratefully acknowledged. Also appreciated is the dedication and careful work of Al Chase and his employees of Chase Forestry Services, who conducted stand inventories and collected time and motion data. Finally, Ron Babbitt and Kathy McDonald of the Intermountain Research Station are commended for their assistance in preparing this and supporting documentation.

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Machine Application of Herbicides for Hardwood Stump Sprout Control[1]

Clyde G. Vidrine[2]

Abstract: A method for selectively applying herbicides to the stump of undesirable hardwoods for stump sprout control combined with the operation of a feller-buncher tree harvester is presented. Potential advantages of the system result from early suppression of hardwood competition in pine reproduction, reduced regeneration costs, and reduced need for application of pine release herbicides in the future. The herbicide application system consists of a low cost sprayer attachment installed on a feller-buncher which has performed exceptionally well during installation of experimental plots.

Keywords: Cut Stump Treatment Herbicides, Feller-Buncher, Spraying Equipment

Introduction

The use of mobile whole-tree chippers to convert previously unmerchantable timber into pulp chips and fuel continues to be of importance to forestry managers and to the forest products industries. To the landowner, whole-tree harvesting reduces site preparation costs for reforestation by leaving the site clean and the soil relatively undisturbed. Although the landowner usually receives very little income from the sale of unmerchantable trees and logging residues, reforestation costs are reduced because there is usually no apparent need for intensive site preparation by mechanical methods. Also, from an aesthetic consideration, appearance of the whole-tree harvested site is more favorable than that of intensively prepared sites. These benefits may give added incentive to forest landowners to practice reforestation during times of marginal forestry profits.

Although whole-tree harvesting offers several advantages to forest managers and the forest products industry, a forest regeneration problem on those sites has been noted. Competition from stump sprouting on whole-tree harvested sites is more of a problem in forest regeneration than on intensively prepared sites. The nature of the whole-tree harvest operation contributes to a favorable environment for stump sprouting from two aspects--low stump height and harvest of immature trees (Smith, 1962). Smith also noted that sprouts of stump origin are more vigorous than sprouts originating otherwise. Furthermore, growth advantage of hardwoods of stump sprout origin is maintained on into later years. Smith (1979) reported that after 12 years, diameter and height growth of stems of stump origin was almost twice that of stems of seedling origin for some hardwoods. Ground coverage from hardwood stump stump sprouting two years following a whole-tree harvest was estimated by McMinn (1983) to be 6175 sq-ft per acre. Herbicides are available for cut stump treatment (CST) which control stump sprouting but their use for forestry purposes is limited. Some herbicides listed for CST are picloram + 2,4-D, 2,4-D ester + 2,4-DP ester, and dicamba (USDA, 1983). Application of herbicides to control stump sprouting has been principally by the electric power utilities in right-of-way maintenance. In those operations, the herbicide is usually applied by use of back-pack sprayers.

The efficacy of five herbicides in control of stump sprouting in Piedmont hardwoods was reported by Lewis et al. (1984). The herbicides used were picloram, glyphosate, triclopyr, dicamba, and hexazione. They were manually applied to the cambium area at a rate of 24 to 28 ml/sq-ft of basal area. The highest percent control (growth suppression) obtained was 96% and the highest percent kill was 69%--both of picloram.

The current regeneration practice in whole-tree harvested sites employed locally is to allow the site to lay idle one growing season for hardwood sprouts to develop. A foliar herbicide is then applied to "brown out" the growth followed by a control burn to get a complete kill of the pine competing vegetation. Pine seedlings are then outplanted the following winter. This "brown and burn" practice may delay planting one year under some conditions. The practice of applying CST herbicides during harvest may avoid this delay in planting.

Prevention of the establishment of competing hardwoods in pine stands would be of economic benefit to the southern forest industry. The selective application of CST herbicides in an ecologically sound manner combined with the operation of a feller-buncher tree harvester at the time of harvest should provide an opportunity to effectively and economically control sprouting of undesirable hardwoods in pine stands. Employment of this competing hardwoods control practice may eliminate the need for intensive site preparation for pine regeneration and also aerial application of herbicides for pine release--both expensive operations and both contributing to environmental problems.

Objectives

The objectives of this study were to:

(1) Design a sprayer system to be mounted on a feller-buncher for immediate herbicide application to the sheared stump.

(2) Evaluate system performance.

(3) Determine added time for spraying.

(4) Determine limitations of the system.

System Design

The design of the spray system included component selection, design and fabrication of protective shields and housings, and the selection of mounting locations for the components on the feller-buncher.

Major components selected for the spray system included a reservoir, a spray nozzle, hoses,

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[1]Presented at the 9th Annual Council of Forest Engineering Meeting, Mobile, AL, September 29-October 2, 1986.

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and a pump. The herbicide reservoir was fabricated from 5 inch by 0.125 wall square steel tubing and had a volume of 2 gallons. The spray nozzle selected produced a 50-degree full-cone spray pattern, had a rated flow rate of 0.38 gpm at 40 psig pressure, and was equipped with a drip-proof check valve built into its strainer. Hose used was 0.375-inch inside diameter, type EPDM, and was rated for operating pressures up to 200 psig. The sprayer pump was a diaphram type pump powered by a 12-volt dc self-contained motor. Its delivery was about 1.0-gpm at 40 psig and it was equipped with built-in pressure switches which kept pump operating pressure between 40 psig and 60 psig. A normally open push button switch was used to control pump operation. Wiring to power with the pump was 16-26 single conductor stranded (16-gauge) with TFFN insulation.

An enclosure to protect the pump was constructed out of 6 x 4 x 5/16-inch steel angle. The dimensions of the housing was 12 x 8-1/2 x 6 inches. The housing was also equipped with pipe fittings for installation of the sprayer nozzle and for strain relief hose connections. With the pump secured inside the housing and with provision for the spray nozzle and hose connections, the assembly provided a convenient package for easy mounting on the feller-buncher. A schematic diagram of the components is shown in Figure 1.

Proper placement of components on the feller-buncher was necessary to ensure protection from limbs and snags, avoid mechanical interference with the harvesting operation, effectively apply herbicide to the stump with minimum increased operation time, and allow adequate observation.

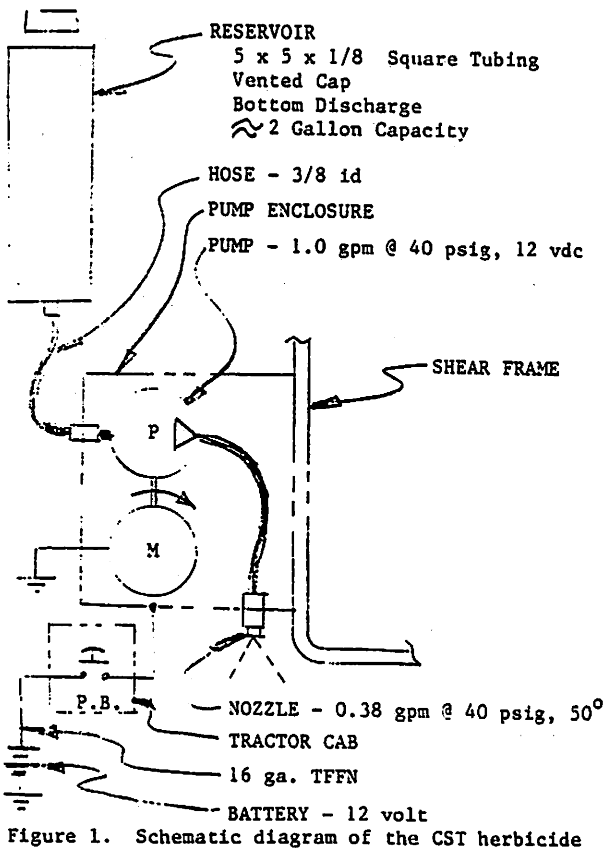

Figure 1. Schematic diagram of the CST herbicide sprayer system.

The housing containing the pump and nozzle was installed at the back of the shear head on the main structure. This placed the nozzle approximately one foot behind the tree being cut which required a slight forward movement of the machine to get in proper spraying position relative to the stump. The nozzle was further positioned above the bottom of the shear head to keep it free from soil and debris, since trees are often sheared at ground level. The positioning of the nozzle behind the shear also kept the nozzle away from the mechanical action of the shear. The nozzle was well protected from the working environment because of its location.

The 16-gauge electric wire powering the 12-volt dc powered pump was routed from the power source in the cab along with the feller-buncher hydraulic hoses to the pump enclosure. The wire was connected to the pump push-button control switch located in the cab.

The reservoir was mounted upright on the shear head frame at an elevation higher than the pump inlet which eliminated potential pump starvation problems.

Method

Fifteen 0.2 acre test plots located in north central Louisiana stocked predominately with mixed hardwoods were treated during July and August, 1985. Three replicates of 5 treatments made up the 15 plots for analysis as a randomized complete block experimental design. The five treatments consisted of a control (no herbicide applied), picloram, triclopyr (ester base), triclopyr (amine base), and dicamba--all labeled for cut stump treatment. The herbicides were applied undiluted to the freshly cut stump surface including a thorough wetting of the cambium layer which is in accordance with CST label instructions. The herbicides were applied by the feller-buncher sprayer system while performing a whole-tree clearcut harvest for chipped fuelwood. Immediately after shearing the tree, the feller-buncher operator positioned the shear head containing the full cone spray nozzle to spray the freshly cut stump by operating the pump control switch in the cab.

Discussion of Results

Evaluation of the results 10 months after installation of the plots show that sprouting on the control plots was significantly greater than that of the CST herbicide treated plots and that there was no significant difference at the .05 level in percent sprouting among the herbicide treated plots. Percent sprouting was as high as 79.8% for the non-treated (control) plots and as low as 12.0% for the ester based triclopyr treated plots. Stump sprout control was also evaluated for number of clusters per sprouted stump and sprout height. Although number of clusters and sprout height values in the control plots were greater than the CST herbicide treated plots, the differences were not significant at the .05 level. Performance results of the CST herbicides applied by use of a tree-to-tree type feller-buncher equipped with the sprayer attachment performing a clearcut harvest are given in Table 1. Analysis of outplanted 1-0 loblolly pine seedlings planted February, 1986, for survival and growth will be made at the end of the following growing season.

Table 1. Performance of the feller-buncher-sprayer applied CST herbicides on mixed hardwoods.

	Plot Means[1]		
Treatment	Percent Sprouting	# Sprt. Cl. per Stump	Sprout Height,in
Control	79.8[a]	3.31[a]	24.25[a]
Dicamba	23.5[b]	2.55[a]	18.16[a]
Picloram	21.2[b]	2.08[a]	14.87[a]
Triclopyr(amine)	15.5[b]	2.15[a]	15.43[a]
Triclopyr(ester)	12.0[b]	2.40[a]	12.65[a]

[1]Column values not followed by the same letter differ significantly at the .05 level.

Use of the sprayer system delayed feller-buncher productivity an average of 6.1 seconds per cutting cycle. Without interruption for the spraying operation, productivity was one tree per 22.8 seconds compared to 28.9 seconds per tree when stump spraying was performed. Time study measurements were obtained on a highly skilled feller-buncher operator but who was not familiar with use of the sprayer attachment.

Three problems associated with use of the sprayer system were identified. Excessive herbicide usage was the principal problem. Herbicide requirement to satisfy application according to label instructions was about 6 gallons per acre which was for a stand density of about 1000 trees per acre (1 gal/167 stems). In order to achieve cut surface wetting by the full cone spray tip, a considerable amount of overspray was required. This resulted in the 1 gal/167 stem application rate which is considered excessive. Cut stump treatment herbicide application rate for utility right-of-way maintenance is about 1 gal/450 trees for application by back-pack sprayer, according to industry representatives.

In addition to excessive herbicide usage, two other operational problems were identified during installation of the 15 test plots. Litter occasionally was thrown over the stump as the feller-buncher raised the cut tree and advanced to assume a spraying position. The litter intercepted the spray pattern and prevented complete cut surface wetting. It is not known to what extent this may reduce effectiveness of the treatment. Another problem occurred when the feller-buncher operator attempted to cut a tree larger in diameter than the machine could shear completely through. This required a second attempt at a location higher on the tree. The interrupted downward conducting cambium tissue may adversely affect performance of the herbicide. The severity of those two problems will be evaluated in this continued research effort.

Conclusion

A method for selectively applying cut stump treatment herbicides to the stump of undesirable hardwoods for stump sprout control by use of a low cost sprayer attachment mounted to a tree-to-tree type feller-buncher was developed. Results from fifteen 0.2 acre test plots using four labeled CST herbicides applied by the feller-buncher sprayer system performing a clearcut harvest operation show highly significant reductions in sprouting and indications of reduced sprout vigor. The sprayer system was shown to be mechanically reliable in 30 hours of operating time in that no appreciable downtime occured due to sprayer operation. Delay time affecting productivity was 6.1 seconds per tree cut. Principal problems associated with use of the system were excessive herbicide usage and litter intercepting the herbicide spray preventing complete spray coverage of the stump.

Acknowledgements

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Morbark Louisiana located at Shreveport, Louisiana, furnished a Morbark model Mark IV feller-buncher for installation of the fifteen test plots.

The herbicides triclopyr and picloram were furnished by Dow Chemical USA and dicamba was furnished by Velsicol Chemical Corp.

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Production Study of the Swedish Rottne Snoken 810 Harvester/Processor in Pennsylvania Softwood Plantations[1]

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Abstract: Production study results are presented for the Rottne Snoken 810 harvester/processor, recently imported to North American from Sweden. Capable of harvesting softwoods on adverse terrain, this machine can function as a harvester, felling and processing trees; or as a processor, limbing and bucking manually felled trees. Results presented for the machine operating in both modes include cycle-time statistics, production rates, and cost estimates. Tests were conducted in southwestern Pennsylvania, where unthinned plantations of Norway spruce and Scotch pine on slopes up to 40 percent were clearcut. When felling and processing in stands with tree volumes averaging 5 to 25 ft^3 volume per productive hour ranged from 280 to 630 ft^3. When processing manually felled trees in stands with tree volumes averaging 3 to 5 cubic feet, volume per productive hour ranged from 240 to 360 cubic feet. Regression equations are presented for estimating harvesting cycle time in minutes per tree as a function of tree and cycle characteristics for use in evaluating potential applications for this machine.

Keywords: Tree harvester, mechanized harvesting cost, production

The increased mechanization of timber harvesting has been motivated by the need for more efficient harvesting systems, and because of increasing labor costs, a scarcity of woods workers, and a growing concern for worker safety. The mechanization trend led to the evolution of tree harvesters--machines that fell, delimb, buck, and pile roundwood products. This technology is applied most often in the softwood stands of North America and Scandinavia. Efforts to increase forest productivity have required the harvesting of small diameter and frequently limby trees that are costly to fell and limb manually. Mechanized felling, limbing, bucking, and bunching has resulted in significant increases in production per manday, a safer work environment, and increased skidding or forwarding production.

The Rottne Snoken 810[3] harvester/processor recently was introduced to North America from Sweden, (fig. 1). This machine can function as a harvester to fell, delimb, buck products to length, and pile roundwood for forwarding. Replacing the felling tool with a grapple, the machine can process timber felled manually. This articulated six-wheel drive machine also can operate on the moderately steep slopes of the Northeastern United States. To determine the effect of harvest site variables upon productivity and cost, the Rottne Snoken 810 was studied on a commercial logging operation in southwestern Pennsylvania.

Figure 1--Rottne Snoken 810 harvester/processor.

The Rottne Snoken 810 Harvester/Processor

The following are technical specifications for the machine studied:

- Weight: 32,000 pounds
- Overall length: 41 feet with crane boom folded
- Width: 8.3 feet
- Engine: 98-hp Ford 7610 turbocharged diesel
- Transmission: Brockhouse 11F torque converter with 6 speeds forward and reverse
- Front Axle: Ford type A62
- Rear Bogie: cog-wheel driven with hub reductions, steel track over rubber tires.
- Hydraulic System: maximum working pressure: 4,400 psi; pump capacity at 2,000 rpm, 40 gpm

The crane carrying either the felling tool or grapple has a reach of 32.8 feet from the center of the machine. The 24-inch-capacity felling tool swings freely from a rotator at the end of the crane boom to provide directional felling. A clamping arm attaches the felling tool to the tree and a hydraulically driven chain saw cuts the tree. The grid of the clamping arm is maintained as the crane swings the tree to the processor. In the processing

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[1]Presented at Council on Forest Engineering 9th Annual Meeting, Sept 29-Oct. 2, 1986, Mobile, AL.

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

mode, manually felled trees are loaded into the processor with a small log grapple attached to the crane boom.

The processor unit mounted at the rear of the chassis has two rubber feed wheels that clamp the stem and pull it through moveable delimbing knives. A second hydraulically driven chainsaw bucks the delimbed stem at one of three preselected lengths or at a point selected by the operator. A hydraulic knife tops the stem. The entire processor unit can be rotated to accept stems butt first from either side of the machine, or tilted to maintain proper stem alignment on steep slopes.

Method of Operation

On slopes greater than 10 percent the operator harvested or processed a swath perpendicular to the contour, working from the top to the bottom of the hill and often returning to the top to start the next swath. On level terrain, swaths were worked in both directions. On sites operated in the processing mode, trees were felled manually with chain saws. All trees were directionally felled perpendicular to the planned direction of machine travel. The operator would move the machine to a location where one or more trees were within the boom's reach, harvest or process those trees, then move to another location. All logs bucked at a given location could be dropped into a single pile. By rotating the processor the operator could drop pulpwood and sawlogs into separate piles to allow the forwarder to move products to the appropriate landing deck.

During harvesting, the felling tool was used frequently to cut unmerchantable trees to clear the move path or access merchantable trees. In both the harvesting and processing modes, the felling tool or log grapple was used to move accumulated slash from below the processor to the move path. As a result, the machine generally traveled on a mat of tops and limbs to reduce soil disturbance.

Both sawlogs and pulpwood were bucked from the larger spruce trees on the harvested sites. Only pulpwood was utilized from the pine and small spruce trees on the processed sites. Lengths of both products averaged 17.5 feet, ranging from 9 to 22 feet. Departures from the desired 17.5-foot length generally occurred in the top log when the operator attempted to maximize utilization by bucking a short log or extending the length of the last log.

The Study

The study was conducted on seven sites where Norway spruce (*Picea abies*) and Scotch pine (*Pinus sylvestris*) plantations were clearcut. All merchantable softwoods and unmerchantable hardwoods were felled. Sites were selected to sample a diversity of site conditions with respect to tree size, trees per acre, and topography; variables that affect machine productivity. On the four harvested sites, the number of merchantable trees (softwoods ≥ 5.0 inches d.b.h.) per acre ranged from 140 to 375, the average d.b.h. of merchantable trees ranged from 7.1 to 11.0 inches, and percent slope ranged from 0 to 41 percent (table 1). On the three sites operated only in the processing mode, trees as small as 5.0 inches diameter outside bark (d.o.b.) at stump height were processed for roundwood pulpwood. The number of merchantable trees per acre ranged from 490 to 920. Average estimated d.b.h. ranged from 5.7 to 6.2 inches. Slopes ranged from 0 to 27 percent. (table 2).

Table 1--Summary of site and tree characteristics for machine working in harvesting mode.

Item	Harvest site			
	1	2	3	4
Merchantable tree species	Norway spruce	Norway spruce	Scotch pine	Norway spruce
Total trees/ acre[a] (no.)	275	405	745	475
Merchantable trees/ acre[b] (no.)	140	220	375	230
D.b.h.				
Mean (inches)	11.0	9.3	7.1	8.8
Range (inches)	5-19	5-15	5-10	5-13
Volume[c]				
Mean (ft^3)	25.2	17.0	5.2	16.2
Range (ft^3)	3-75	3-47	3-12	3-38
Number of logs/tree[d]				
Mean	2.4	2.3	1.2	2.5
Range	1-4	1-4	1-2	1-4
Percent slope	0-34	0-41	0-15	0-25

[a] All hardwood and softwood trees ≥ 3.0 inches d.b.h.
[b] Softwood trees ≥ 5.0 inches d.b.h.
[c] Wood and bark
[d] Includes pulpwood and sawlogs

Sample plots were installed at each harvest site to determine the number of merchantable and unmerchantable trees per acre, measure and record merchantable tree attributes, and mark identification numbers on each tree so that time and motion study data could be correlated with tree attributes. Summary statistics of recorded tree attributes are:

	Mean	Range
D.b.h. (inches)	8.9	5-19
Stump d.o.b (inches)	11.6	6-22
Height to 4.0-inch top (feet)	37.8	13-64
Total height (feet)	58.0	29-90
Length of clear bole (feet)	4.5	1-22
Number of limbs > 2 inches	2.2	0-35

During the harvesting of each plot the following production variables were measured and recorded:

- Time to move between harvesting locations.
- Distance between locations.
- Percent slope in direction of move.
- Tree number.
- Number of logs processed per tree.
- Felling time: swing boom to tree, position felling tool, cut stem free of stump.
- Loading time - swing cut tree to processor.
- Processing time - delimb, buck, and top.
- Downtime duration and cause.

Table 2—Summary of site and tree characteristics for machine processing manually felled trees.

Item	Processing Site		
	5	6	7
Merchantable tree species	Norway spruce	Norway spruce	Scotch pine
Total trees/acre[a] (no.)	1440	1070	750
Merchantable trees/acre[b] (no.)	920	710	490
Mean d.b.h. (inches)	5.7	5.8	6.2
Mean volume[c] (ft^3)	3.1	3.3	4.8
Mean no. logs/tree	1.1	1.1	1.2
Percent slope	22-27	15-17	0-10

[a]All hardwood and softwoods ≥ 3.0 inches d.b.h.
[b]Softwood trees ≥ 5.0 inches stump d.o.b.
[c]Wood and bark.

Time to fell unmerchantable trees or to move accumulated slash was not recorded as separate time elements, but was included in the move or felling time record. Felling and move records were coded to show the occurrence of the two nonproductive elements.

Because trees on the processed sites were felled before to the study, the number of trees per acre and tree diameters were estimated from stump diameters on 0.01-acre plots located throughout each sample site. Diameter at breast height was estimated using conversion factors developed from cut trees at each site. Production variables measured and recorded during processing were the same as in harvesting except for tree number and felling time. In processing, the time to swing the boom to the tree and clamp the grapple was included in loading time.

Average tree volume was determined by scaling approximately 50 percent of the logs processed at each site. On the harvested plots, volume harvested per tree was estimated from regression equations developed from scaled tree volumes of each tree species. These equations estimate cubic volume of wood and bark as a function of d.b.h., merchantable height, and number of pieces processed.

On the basis of 1985 costs, the purchase price of the Rottne Snoken 810 was $215,700 with felling tool and $200,650 without the felling tool. The salvage value is calculated as 20 percent of the purchase price, and the estimated machine life is 5 years. Interest,insurance, and taxes are calculated as 20 percent of average annual investment. Scheduled operating hours are estimated at 2,000 per year.

Machine rates were calculated for the Rottne Snoken 810 to show the effect of production-rate variations on estimated harvesting and processing cost (table 3). Due to the limited duration of this study and the lack of performance data for this recent import, it was necessary to make assumptions concerning maintenance and repair costs and utilization rates. Two levels of utilization and two maintenance and repair rates were included in the analysis to show the sensitivity of costs to these critical variables. Higher utilization rates were used for processing to reflect an expected reduction in downtime due to use of the grapple versus the felling tool. A utilization rate of 86 percent was reported for the Rottne Snoken 810 processing softwoods in Canada (Pawlett 1985).

Table 3—Machine rates for Rottne Snoken 810 based on 1985 costs, in dollars per productive machine hour (p.m.h.).

Item	Harvesting		Processing	
	Low rate	High rate	Low rate	High rate
Utilization rate[a]	0.80	0.70	0.85	0.75
Depreciation[b]	21.57	24.66	18.88	21.40
Interest, insurance, taxes	18.34	20.95	16.05	18.19
Maintenance and repair[c]	16.18	24.66	14.16	21.40
Fuel, oil, and lube[d]	3.70	3.70	2.50	2.50
Labor[e]	12.50	14.28	11.76	13.33
Total	72.29	88.25	63.35	76.82

[a](Productive hours)/(scheduled hours).
[b]Straight line.
[c]Low rate = (0.75)(Depreciation); high rate = (1.0)(Depreciation).
[d]Information furnished by machine operator.
[e]($10/hr total cost)/(utilization rate).

Results from Harvesting Sites

The production and cost analysis results show distinct differences between sites with respect to cycle time, production rates, and unit cost estimates (table 4). Based on the high machine rate, harvesting costs per 100 ft^3 ranged from $14 to $31.50. The low machine rate reduced costs by approximately 18 percent. These results demonstrate the importance of site related variables that affect machine productivity as well as those variables that affect the machine rate.

The effect of tree attributes on cycle time are shown by the average fell/load/process times. These ranged from 0.88 min/tree on site 3 to 2.10 min/tree on site 1; increasing with average tree volume. The largest trees harvested were on site 1, where tree diameter frequently approached machine capacity. These open-grown Norway spruce trees had several hundred limbs growing in dense whorls along the entire merchantable bole. The large number of limbs on the lower bole of these trees made it difficult to grasp the bole with the felling tool grapple and slowed feeding of the bole into the processor unit. Several passes through the delimbing knives often were required to clean the lower bole section. As a result, total fell-load-process times as high as 6.4 min/tree were recorded on site 1 (table 4).

The following is the percent of felling times that include felling of unmerchantable trees or moving slash (figures for each site are not additive because many felling times included both activities):

Item	Harvest site				
	1	2	3	4	All
Fell unmerchantable trees	27	16	31	22	26
Move slash	18	16	11	8	13

Table 4--Production data, production rates, and cost estimates for harvesting.

Item	Harvest site			
	1	2	3	4
Moves sampled (no.)	25	23	35	22
Move distance				
Mean (ft)	24.9	10.0	12.8	9.7
Range (ft)	1-98	1-23	1-26	4-23
Move time				
Mean (min)	2.05	1.23	0.92	1.00
Range (min)	0.1-9.2	0.1-4.1	0.2-2.5	0.1-3.8
Trees/move				
Mean (no.)	1.96	3.0	3.80	2.68
Range (no.)	1-5	1-5	1-8	1-6
Move/tree				
Mean (min)	1.05	0.41	0.24	0.37
Range (min)	0.1-3.2	0.1-2.0	0.1-0.6	0.1-1.6
Trees sampled (no.)	49	69	133	59
Fell/load/process				
Mean (min/tree)	2.10	1.20	0.88	1.28
Range (min/tree)	0.6-6.4	0.4-4.1	0.4-2.5	0.4-3.5
Total cycle time				
Mean (min/tree)	3.15	1.61	1.12	1.65
Range (min/tree)	0.9-7.0	0.5-4.8	0.5-2.8	0.5-3.6
Trees/p.m.h. (no.)	19	37	54	36
Cubic feet/p.m.h.	480	630	280	580
Estimated cost ($/100 ft^3)				
Low rate ($72.30/p.m.h.)	15.10	11.50	25.80	12.50
High rate ($88.20/p.m.h.)	18.40	14.00	31.50	15.20

Move time per tree also was a significant component of total cycle time. This component was calculated by dividing the time to move between successive harvesting locations by the number of trees harvested at the new location. The relatively low number of merchantable trees per acre on site 1 resulted in longer move distances, longer move time, and fewer trees harvested per move. Move time averaged 1.05 min/tree on site 1 (table 4). This compares to 0.24 min/tree on site 3, which had the most merchantable trees per acre and the highest average number of trees harvested per move.

The following is the percent of moves during which unmerchantable trees were cut or slash was moved:

Item	Harvest sites				
	1	2	3	4	All
Fell unmerchantable trees	72	39	40	27	45
Move slash	80	70	43	68	63

Production rates were a function of both cycle time and tree volume. The highest production rate was attained on site 2, 630 ft^3 per productive machine hour (p.m.h.). Low tree volume limited production on site 3 to 280 ft^3/p.m.h., whereas high cycle times limited site 1 production to 480 ft^3/p.m.h. The sampled range of production rates is similar to the 5 to 8 cord/hour rates reported for the Rottne Snoken 810 by Meyer (1984).

Nonproductive or delay time recorded during the time and motion study of harvest sites accounted for 24 percent of the scheduled machine operating time. Most delays were mechanical downtime attributed to minor repairs of the felling tool. Only 5 percent of all cycles incurred delays. Time per delay averaged 7.8 minutes and ranged from 1 to 42 minutes.

Results from Processing Manually Felled Trees

Relatively low cycle times resulted in 72 to 88 trees processed per hour. However, production rates that ranged from 240 to 360 ft^3/p.m.h. were constrained by the low average volume of the trees processed. Estimated processing costs based on the high machine rate ranged from $21.30 TO $32 per hundred ft^3; the larger trees on site 7 were the least costly to process (table 5). The low machine rate reduced processing costs by 17 percent.

Processing manually felled trees required approximately half as much time per tree as harvesting standing trees. The reduction in total cycle time can be attributed to site characteristics as well as differences between the two modes of machine operation. The small trees processed usually had only one log to limb and buck. Grasping felled trees with the grapple required less time than positioning the felling tool on the limby boles of standing trees. Relatively low move time per tree resulted from the increased number of merchantable trees per acre on the processed sites and the corresponding increase in the average number of trees processed per move. Processing trees felled perpendicular to the direction of machine travel effectively extends the swath width. In the harvesting mode, the boom must reach the tree stump; in processing, any part of the bole can be grasped.

Development and Application of Prediction Equations

Equations for predicting move time and total felling/loading/processing time were developed from the harvesting data collected on sites 1 through 4. Using linear regression methods, dummy variables were used to indicate if unmerchantable trees had been felled or accumulated slash was scattered.

Independent variables tested in the move-time analysis include cycle codes, move distance, and percent slope in the direction of the move. Only cycle codes and move distance were significant at the 0.05 level. The move-time regression statistics and model are:

$R^2 = 0.58$ $\quad$ $Sy.x = 0.785$

$MT = -0.1831 + 0.5993X_1 + 0.8319X_2 + 0.0488X_3$

where MT = move time, in minutes per move

X_1 = 1 if slash scattered during move

X_1 = 0 if slash not scattered

X_2 = 1 if unmerchantable trees cut during move

X_2 = 0 if no unmerchantable trees cut

X_3 = move distance, in feet

Table 5--Production data, production rates, and cost estimates for processing manually felled trees.

Item	Processing Site 5	6	7
Moves sampled (no.	11	22	38
Move distance			
Mean (feet)	20.7	19.1	19.0
Range (feet)	15-26	12-28	6-34
Move time			
Mean (min/move)	0.85	0.99	0.85
Range (min/move)	0.27-2.22	0.51-1.74	0.21-2.20
Trees/move			
Mean (no.)	11.2	6.8	6.4
Range (no.)	6-17	1-11	1-14
Move/tree			
Mean (min)	0.08	0.14	0.13
Range (min)	0.03-0.32	0.05-0.29	0.02-1.06
Trees sampled (no.)	123	149	245
Load and process			
Mean (min/tree)	0.60	0.69	0.68
Range (min/tree)	0.28-2.00	0.16-2.65	0.15-2.45
Total cycle time			
Mean (min/tree)	0.68	0.83	0.81
Range (min/tree)	0.20-2.98	0.18-3.60	0.17-3.40
Trees/p.m.h. (no)	88	72	74
Cubic feet/p.m.h.	270	240	360
Estimated cost ($/100 ft^3)			
Low rate ($63.40/p.m.h.)	23.50	26.40	17.60
High rate ($76.80 p.m.h.)	28.40	32.00	21.30

The analysis of fell-load-process time tested all recorded tree attributes using stepwise regression. Cycle code dummy variables, tree volume, feet of clear bole, and number of limbs > 2 inches were all significant at the 0.05 level. The fell-load-process time regression statistics and model are:

$$R^2 = 0.62 \qquad Sy.x = 0.58$$

$$FLPT = 0.5546 + 0.4233X_1 + 0.5310X_2 + 0.0039X_3 + 0.0007X_4 + 0.2898X_5 + 0.0010X_6$$

where FLPT = fell-load-process time, in minutes per tree

X_1 = 1 if slash scattered during cycle
X_1 = 0 if no slash scattered
X_2 = 1 if unmerchantable trees cut during cycle
X_2 = 0 if no unmerchantable trees cut
X_3 = merchantable tree volume in ft^3
X_4 = $(X_3)^2$
X_5 = (feet of clear bole)$^{-1}$
X_6 = (number of limbs > 2 inches)^2

The cost curves shown in Figure 2 were developed using the regression equations to estimate total cycle time and production rates. Assumptions included in this analysis include frequencies of

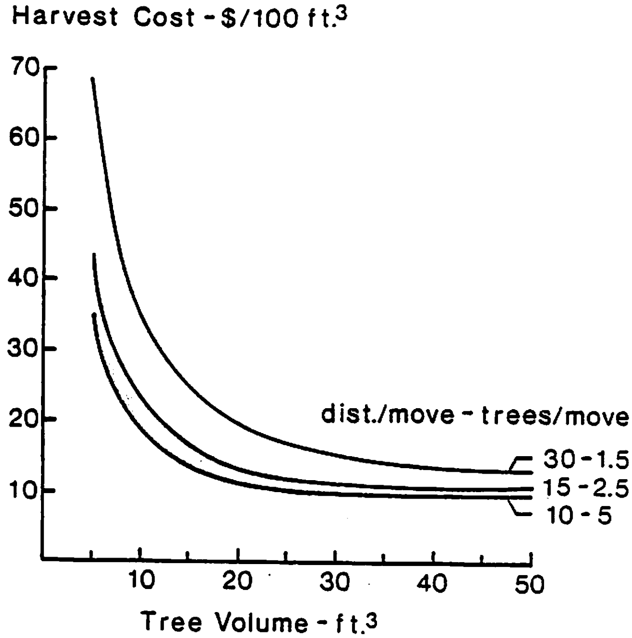

Figure 2--Plot of harvesting costs estimated from move and fell/load/process equations; assumes machine rate of $88/p.m.h. Curves indicate move distance and number of trees harvested per move.

slash moving and felling unmerchantable trees equal to those sampled for all harvest sites combined. Feet of clear bole equaled the overall sample mean of 4.5 feet, and number of limbs > 2 inches represented the average sampled for each tree volume class.

The relationships shown between harvesting cost and tree volume, move distance, and number of trees harvested per move are more important than the actual cost levels, which are dependent on machine rate assumptions. Most important, these results show that cost declines rapidly as tree volume increases from 5 to 20 ft^3. Cost remains relatively stable for tree volumes > 20 ft^3. The effects of move distance and number of trees harvested per move also are more pronounced for small trees.

Study results indicate that when clearcutting in fully stocked stands, average move distance would range from 10 to 15 feet and the average number of trees harvested per move would be at least 2.5. The effect on cycle time of the number of trees harvested per move diminishes as the number increases. Consequently, harvesting more than five 5 trees per move would result in a small reduction in harvesting cost. The area between the lower two curves in figure 2 would then represent the harvesting cost zone for this application. The upper curve that represents a 30-foot move harvesting only 1.5 trees would be inappropriate for clearcutting in fully stocked stands. However, this curve shows the effect of longer move distances and fewer trees per move, conditions that could occur in thinning fully stocked stands or clearcutting poorly stocked stands.

Clear bole length, number of limbs > 2 inches, the felling of unmerchantable trees, and the occurrence of slash moving all affect cycle time, production, and cost. The sensitivity of harvesting cost to these variables was estimated using the following assumptions: tree volume = 15 ft^3, move distance = 15 feet, three trees harvested per move. The sampled range of clear-bole lengths resulted in a 19 percent increase in harvesting cost. Estimated cost with the highest number of limbs > 2 inches was 17 percent higher than the cost for the lowest number sampled for 15-cubic-foot trees. Increasing the frequency of slash moving and felling unmerchantable trees from the lowest to the highest sample site values resulted in a 22-percent increase in harvesting cost.

The difference between the cost of harvesting and processing small trees can be approximated by comparing site 3 harvesting costs to site 7 processing costs. These two pine stands were very similar. The lower merchantability standards applied on site 7 explain most of the differences between stands with respect to the number of merchantable trees per acre and average tree diameter or volume. This comparison shows that processing manually felled trees costs $8 to $10 per hundred ft^3 less than for harvesting standing trees.

Regression equations used to estimate the cost of harvesting the 3-to-4-cubic-foot trees processed on site 5 and 6, showed that harvesting costs exceeded processing costs by more than $30 per hundred ft^3. This margin represents the allowable cost of manual felling. With 25 to 33 trees per hundred ft^3, the break-even cost of manual felling is approximately $1 per tree. For the site 3 to site 7 comparison, the break-even felling cost is $0.40 to $0.50 dollar/per tree. Sampling limitations preclude the extension of this comparison to larger trees. However, it appears that manual felling and processing would be less costly than harvesting when tree volumes average 5 ft^3 or less.

Summary

The Rottne Snoken 810 proved capable of harvesting 280 to 630 ft^3/p.m.h. in standing timber, and processing 240 to 360 ft^3/p.m.h. when small trees are felled manually. Working on slopes as steep as 40 percent, processed roundwood was sorted and piled for forwarding to roadside decks. Tops and limbs remained in the woods to protect the soil during harvesting and forwarding, thus avoiding accumulations of slash at the landing.

Study results show that production and cost in both the harvesting and processing modes are sensitive to changes in tree and site attributes. These results demonstrate the importance of considering machine-site relationships when applying highly mechanized harvesting equipment such as the Rottne Snoken 810. The effect of tree volume was very pronounced, with costs declining rapidly as tree volume increased. The exception to this was the large, open-grown spruce trees with very limby butt logs. For more heavily stocked stands or better pruning species, tree diameters approaching machine capacity may prove less costly to harvest than those sampled in this study.

The regression equations presented for move time and fell/load/process time can be applied to estimate harvesting production and cost for specific sites as a function of expected tree and cycle attributes. Because of the squared and inverse terms in the fell/load/process equation, best results will be obtained applying this equation to individual sample trees rather than to mean attributes for all trees on a given site. Refining production and cost estimates also will require the use of appropriate values for move distance, number of trees harvested per move, and the frequencies of slash moving or felling unmerchantable trees. Move distance and number of trees will be a function of stand density and mode of operation, while felling of unmerchantable tree will be influenced by the number of unmerchantable trees per acre and the silvicultural prescription. Slash moving, occasionally required to clear space around the processor, is largely an optional site-protection measure. Estimates of these parameters can be obtained by monitoring machine performance on a variety of sites. An alternative would be to apply computer simulation to model performance over a wide range of operating conditions (Goulet et al. 1979).

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Productivity of In-Woods Chippers Processing Understory Biomass[1]

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Abstract: Productivity and cost per ton are predicted for two in-woods chippers (Morbark 20 and 27) where DBH, species groups, and moisture content are varied.

Keyword: Transpirational drying

Typical logging operations in the South average removing less than 45% of the aboveground biomass (USFS 1983). The bulk of the biomass produced must be dealt with in site preparation and re-establishment of the stand. If a market for this residue biomass is available, a case can be made for harvesting this material that is normally left on the site. The cost of recovering this residue or potential residue, minus the value of the residue to a utilizing facility must be less than the cost of re-establishment when the material is left on the site.

Two types of residue are found on a site following clearcut logging. There are the tops of merchantable stems and the understory stems which do not meet the specifications for the material being harvested. We have observed natural pine stands with up to 60 tons of understory material per acre and pine plantations with as much as 40 tons of this material.

The key to the cost effectiveness of any intensive utilization operation is the economical handling of small stems. Our previous work has shown that skidding can be cost effective when utilizing small stems if there is a sufficient quantity of these stems available on the site to make a full load for each skidder turn (Stokes et al. 1984, Miller et al. 1985, Watson et al. 1986). This was true for a preharvest operation when only the understory stems were taken as well as for an operation in which the merchantable overstory and the understory stems were taken in a single pass.

Felling the small stems economically is possible with some of the currently available equipment and if large quantities of understory material are available on the site. Feller-bunchers with high speed heads, which are highly maneuverable, and have a fast travel speed, can perform very well when harvesting the understory. The cost of felling understory has been found to be reasonable provided there is ample quantity of material to be felled (Watson et al. 1986). However, the felling costs become prohibitive when there is less than 15 green tons of material to be cut per acre (Miller et al. 1985). The feller-buncher spends much more of its time in traveling cycle when there is low volume of this material on the site.

Chipping is the predominant method of handling the small stems once they have been moved to a loading area. Chipping allows for the reduction in airspace that is necessary for the economical transport of small stems. The sole current use of this understory material is for fuel, thus chipping or hogging the material would be necessary in preparing the stems for burning. The results of a study that was conducted to investigate the economies and productivity of chippers in processing small stems are reported in this paper.

The power required for converting small stems to chips should not be as great as for the conversion of large stems to chips. Most companies producing chips in the South are using chippers in the 650 horsepower class. We first set out to determine if these larger chippers were necessary if only small stems were being processed.

Some companies are using transpirational drying to reduce the moisture content of wood for fuel. By felling the trees and allowing the stems to dry for several weeks, one can gratly increase the net Btu yield from the wood. However, processing the dried material requires that the knives be changed more often and it was felt that the chippers were losing productivity on a productive hour basis when handling this drier material. Thus, the impact of moisture content of the stems processed on productivity was also examined.

PROCEDURES

The study site (near Range, Alabama) was chosen so that a wide variety of species were available for processing. Felling of stems began 6 weeks prior to the chipping tests. Stems were segregated into separate piles by DBH and species group as they were felled. Species groups were hard hardwoods, soft hardwoods, and pines. The hard hardwoods found on the site included oaks, hickories, ashes, and dogwood. The soft hardwoods species included sweetgum, blackgum, red maple, holly, sweetbay, magnolia, and yaupon. DBH classes were the odd numbered classes from the 1 inch class to the maximum sized stem on the site for the hard and soft hardwoods and were 1, 3, and 5 inches for the pine.

Preparing a bundle sufficiently large for a chipper test would require several days. Thus, the bundles were labeled according to the week in which the trees were felled. This information was used to determine the length of time the trees had dried before being chipped.

On the day of the chipper test, the bundles were weighed. A converted prehauler was used to lift the stems from the ground. A load cell attached to the boom on the prehauler was used to determine the weight. The digital readout on the load cell was mounted at eye level on the rear of the prehauler.

Two chippers were used in this study. Models 27 and 20 Morbark chippers were utilized. The model 27 had a 650 horsepower power supply and 27

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inch throat while the model 20 had a 350 horsepower power unit and 20 inch throat.

After a bundle of stems was weighed, the bundle was skidded up to the chipper. The chipper operator would take a grapple full of the stems and feed the stems into the throat of the chipper. Timing of an observation would begin at this point. Timing of an observation would continue as the remainder of the stems in the bundle were fed into the chipper. Timing of the observation ended when the last chips were blown from the chip spout for the bundle. Chipper knives were changed after loading each van so that knife sharpness would not influence productivity.

A sample of chips was taken for each bundle for moisture content determination. A joint of schedule 40, 4" PVC pipe with a 90° elbow glued to the end was used for catching the sample. The elbow end of the pipe was moved in front of the chip spout to catch a sample of the chips as the bundle was being processed. Several random samples were taken during the processing of a bundle so that an unbiased estimate of moisture content could be made. The sampled chips were placed in a plastic bag immediately and were returned to a lab for drying and weighing.

ANALYSIS

An observation for this study consisted of the following information for use as independent variables:

1. species group of the bundle,
2. moisture content of the stems,
3. DBH class for the bundle,
4. chipper model, and
5. chipper operator.

The dependent variable was productivity in tons per productive hour which was derived from the bundle weight and the time to process the bundle. Productivity was predicted for both green tons and bone dry tons.

First, productivity was determined to be significantly different for the two models of chippers; thus, separate predictors were developed for each model. Productivity was found to be significantly different among the species groups for the model 27 chipper but the differences among the species groups were not significantly different for the model 20 chipper.

Model 27

The best predictors for the productivity of the model 27 chipper are given below:

1. For pine:

   A. $GPROD = 35.5 + 0.430\ (DBH)^3$
   ($n = 16$, $R^2 = 66.6$ percent)

   B. $DPROD = 22.7 + 0.211\ (DBH)^3$
   ($n = 16$, $R^2 = 56.6$ percent)

2. For hard hardwood:

   A. $GPROD = 29.4 + 4.66\ DBH$
   ($n = 40$, $R^2 = 45.2$ percent)

   B. $DPROD = 20.7 + 2.68\ DBH$
   ($n = 40$, $R^2 = 38.4$ percent)

3. For soft hardwood:

   A. $GPROD = 9.48 + 10.1\ DBH - 0.530\ (DBH)^2$
   ($n = 37$, $R^2 = 55.5$ percent)

   B. $DPROD = 7.35 + 6.13\ DBH - 0.321\ (DBH)^2$
   ($n = 37$, $R^2 = 52.0$ percent)

where

GPROD = productivity in green tons per productive hour
DPROD = productivity in bone-dry tons per productive hour
DBH = diameter at breast height
n = number of observations
R^2 = coefficient of determination (from regression analysis).

Productivity estimates derived from these predictors are reported in Tables 1 and 2.

An interesting occurrence in this data is that moisture content had no impact on productivity. This is especially interesting in the green tons productivity since as much as 50 percent of the weight of wood chipped would be moisture.

The productivity of the chipper processing soft hardwoods exhibited traits that were expected. Productivity increased rapidly as DBH is increased from the 1 inch class and was at a maximum at the 9 inch class. The maximum productivity when processing hard hardwoods was the largest class observed which means that we did not test enough stems in the higher diameter classes to adequately predict an optimum stem size.

Model 20

Two operators were used on the model 20 chipper during this study. No significant differences were found in the productivity when

Table 1—Predicted green productivity and cost of the Morbark Model 27 chipper for each species group.

	Pine		Hard Hardwood		Soft Hardwood	
DBH	Tons/ Prod. Hour	Cost/ Ton	Tons/ Prod. Hour	Cost/ Ton	Tons/ Prod. Hour	Cost/ Ton
1	35.9	$2.64	34.1	$2.78	19.1	$4.96
3	47.1	2.01	43.4	2.18	35.0	2.71
5	89.3	1.06	52.7	1.80	46.7	2.03
7			62.0	1.53	54.2	1.75
9			71.3	1.33	57.5	1.65
11			80.7	1.17	56.5	1.68
13			90.0	1.05	51.2	1.85
15			99.3	0.95		

Table 2--Predicted bone-dry productivity and cost of the Morbark Model 27 chipper for each species group.

	Pine		Hard Hardwood		Soft Hardwood	
DBH	Tons/ Prod. Hour	Cost/ Ton	Tons/ Prod. Hour	Cost/ Ton	Tons/ Prod. Hour	Cost/ Ton
1	22.9	$4.14	23.4	$4.05	13.2	$7.18
3	28.4	3.34	28.7	3.30	22.9	4.14
5	49.1	1.93	34.1	2.78	30.0	3.16
7			39.5	2.40	34.5	2.75
9			44.8	2.12	36.5	2.60
11			50.2	1.89	35.9	2.64
13			55.5	1.71	32.8	2.89
15			60.9	1.56		

Table 3--Predicted green and bone-dry productivity[a] and cost of the Morbark Model 20 chipper.

	Green		Bone-dry	
DBH	Tons/ Prod. Hour	Cost/ Ton	Tons/ Prod. Hour	Cost/ Ton
1	16.9	$3.56	9.0	$6.68
3	20.7	2.91	14.1	4.27
5	27.7	2.17	19.3	3.12
7	37.0	1.63	24.4	2.46
9	46.7	1.29	29.5	2.04
11	55.0	1.09	34.7	1.73
13	58.9	1.02	39.8	1.51

[a]Productivity at mean percent moisture content of 52.9 percent.

each operated the machine; thus, the data gathered on both operators could be pooled.

The best predictors for productivity are given below:

1. $GPROD = 11.2 + 0.488\,(DBH)^2 - 0.00140\,(DBH)^4 + 0.00186\,(MC\ percent)^2$
   ($n = 97$, $R^2 = 62.6$ percent)

2. $DPROD = 6.41 + 2.57\,DBH$
   ($n = 97$, $R^2 = 59.4$ percent)

where

GPROD = productivity in green tons per productive hour
DPROD = productivity in bone-dry tons per productive hour
DBH = diameter at breast height
MC percent = percent moisture content
n = number of observations
R^2 = coefficient of determination (from regression analysis)

Productivity predictions derived from these equations are reported in Table 3.

Note that moisture content was significant in explaining the variation in green ton productivity for the model 20 chipper. As would be expected, productivity decreased as moisture content decreased.

Cost Analysis

Cost estimates were developed for the models 27 and 20 chippers (Sabo 1986). These costs are given below:

	Model 27	Model 20
Machine rate	$78.83	$44.13
Rental rate	94.83	60.13

The rental rate (operating per productive hour including labor) of each chipper was used to calculate the cost per ton of production in Tables 1, 2, and 3.

CONCLUSIONS

Note that the model 27 chipper was more productive and more cost effective in almost all diameter classes for the pines and hard hardwoods. Further, the model 27 chipper was more cost effective than the model 20 chipper in the smaller diameter classes. This means that in the smaller stems throat size is more important than power. However, these results are not definitive for the case of purchasing the larger chipper. Other considerations could sway the case for either size machine.

Reduced moisture content did not reduce the productivity per productive hour of the larger chipper. Sharp knives were always used in this study, thus the more powerful chipper was not overloaded with harder dry stems. One should realize that this study did not take into account the fact that drier stems will require more knife changes. (We have observed situations where a set of knives will last for only 3 van loads of chips in dry material but will last through 10 or more van loads when chipping green material.) More knife changes will reduce productive time and drive the cost per productive hour and cost per ton of chips up further.

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Firewood Production from Logging Residue: A Cost Assessment[1]

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Abstract: A hydraulic shear and grinder were used to process wood residue concurrent with delivery to the landing and after the material was cold decked. Cost and production were documented for both the delivery and processing of the residue. Cold decking operations were generally less costly than operations involving concurrent processing.

Keywords: wood residue, utilization, wood energy, firewood production

Additional utilization of forest residues has been constrained by the cost of recovery and by the lack of reliable markets for residue products. There are locations, however, where recovery and processing of certain residue products are close to being feasible. In these instances small changes in the efficiency of the recovery operation could make the difference between recovery and disposal of the residue. The field experiments reported here involve modifications and changes to previously tested methods of forest residue recovery. One system modification that appeared from calculations to be cost effective involves processing of residue as it is delivered to a landing. This procedure can increase processing costs because of underutilization of the processing equipment, but should save material handling steps in stockpiling the material and in subsequently removing it from the stockpile.

Field demonstrations and experiments involving both concurrent and subsequent processing of residue were tested during the summers of 1985 and 1986 using both a cable yarder and ground based skidders to move residue to a landing and a hydraulic shear and grinder to process the residue. Concurrent operations (also called hot processing) involved processing of residue pieces into firewood as it was delivered to the landing. Subsequent operations (also called cold decking) required stockpiling of the residue after skidding and subsequent removal and processing of the residue from the stockpiles. Logs and tree length pieces were converted into 18 inch firewood with a hydraulic shear. Non-usable firewood pieces were fed into a hydraulic grinder to produce hog fuel. Equipment operators and site variables were generally the same for all cases, but a case study was developed to allow comparison of production and cost for equal skid distances and with the same average piece size.

Equipment tested and demonstrated in moving residue to the landing included a two drum live skyline called the Clearwater Yarder, an International Model S8 wheeled skidder, a hydrostatic drive, tracked skidder called the Lucky Logger, and an older Caterpiller Model D6 crawler tractor. The crawler tractor pushed material to an access road with techniques similar to those used in conventional dozer piling operations. The other units dragged residue to a landing in a manner similar to conventional skidding and yarding. Residue processing utilized a hydraulic loader to feed variable length residue material to a hydraulic shear. The shear was designed specifically to produce firewood ranging in lengths from 18 to 48 inches. It was constructed by the Clearwater-Potlatch Timber Protective Association (CPTPA), a quasi-govermental agency charged with fire protection and fire hazard abatement on state and private lands in north-central Idaho. CPTPA built the shear with components obtained from a variety of surplus equipment sources and used it primarily to reduce the fire hazard created by piles of logging debris left at landings after logging. They subsequently constructed the grinder to process material that was unsuitable for use as firewood.

The shearing and grinding mechanisms of both machines rely heavily on hydraulic motors. The shear is driven by a 60 HP diesel engine and is mounted on a 6 x 6 military carrier originally designed as a floating bridge transport. The system can shear pieces up to 23 inches diameter. Its primary component is a shear blade 24 inches wide by 1 inch thick that is controlled by a 7 1/4 inch hydraulic cylinder. The system has the capability of cycling the shear blade every 7 seconds. Subsequent processing of material too small or nonuniform to make good firewood can be done with the hydraulic grinder. The hydraulic motor of the grinder drives a single horizontal rotor measuring 6 feet by 30 inches. Grinding is accomplished with 10 oversized teeth attached to the rotor. A 120 HP diesel engine powers the hydraulic system and turns the rotor at 330 R.P.M. The system is capable of developing 1850 foot-pounds of torque.

STUDY SITE AND CONDITIONS

The field demonstrations were conducted as a cooperative effort between the Forest Products Department of the Unviersity of Idaho and the Clearwater-Potlatch Timber Protective Association with funding provided by the Bonneville Power Administration. CPTPA supplied equipment, operators, and the site for the studies. The University of Idaho was responsible for data collection, processing, and analysis.

Work during the 1985 field season was located on industrial timber land that had been clearcut in 1984. Recovery operations were conducted on 8.53 acres of the large clearcut. This area breaks down with 3.26 acres recovered with cable systems, 2.86 acres with ground based skidders, and 2.41 acres with a modified dozer piling operation. One objective of the operations from the standpoint of CPTPA was to create firelines along the edges of the harvest unit. This effort would provide savings to CPTPA in the cost of preparing the site for disposal through broadcast burning.

Initial commercial harvest volume on the site was estimated at 25.9 MBF (thousand board feet) per acre. Down and dead inventories were conducted on the recovery portions of the site before and after residue recovery operations. Initial residue estimates ranged from 16.6 to 28.8 green tons per acre at an average moisture content of 30%. Residue inventory on the site after recovery ranged from .8 to 5.6 green tons per acre. The line intersect method of down and dead inventory used to obtain

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these estimates produced low estimates of the net volume recovered. The small unit sizes limited the number and uniformity of the line transect samples that could be taken and probably affected the reliability of the down and dead inventory. CPTPA considered the fireline preparation more than adequate from the standpoint of fire hazard abatement and did not see a need for additional preparation of the recovery portion of the site before general burning.

Tests of grinding operations were conducted during June 1986 in an area that had been used to stockpile 18 inch firewood material. Moisture content of the feedstock, distribution of species, and the average diameter and length of pieces were similar to these respective conditions at the 1985 recovery site. The 1986 site provided better all weather access and allowed operations to be completed earlier in the field season.

PRODUCTION AND TIME STUDY RESULTS

Production statistics from the field tests are summarized in Table 1. The amount of time spent in hot operations was limited by landing conditions at the site and by mechanical breakdowns of critical equipment. Concurrent operations of the shear, loader, and skidding vehicle required a landing that would allow the proper orientation of the equipment and room for a temporary log deck. The loader had to be situated at a 90 degree angle to the shear. Additional room was required parallel to the loader for the log deck. These factors limited areas where the hot processing system could work, especially when yarding with the Clearwater yarder. Mechanical availability of equipment in a hot operation is also a critical concern. Seasonal startup problems with the loader shut down both the loader and shear several times and resulted in more cold decking operations than had been originally planned. Considerations of the reliability of equipment should be a major factor when considering the benefits and disadvantages of hot processing.

Volumes were calculated from the piece size estimates obtained during the skidding cycle. Production was measured both in pieces and cubic feet per hour. Skidding and yarding volumes are higher than the loader volumes and the loader volumes are higher than those respective values for the shear. These differences reflect pieces that were skidded or handled by the loader but were not sheared. The loader and shear also processed some material from a landing slash pile that was left after the commercial harvest of the area. Volumes of recovered residue calculated from piece size estimates are higher than the estimates provided by the down and dead inventory by about 24 percent.

Total productive times and percent productivity for each study and equipment module are summarized in Table 2. Mechanical breakdowns made up a

TABLE 1: Production in pieces and cubic feet for equipment and options tested for forest residue recovery.

MACHINE / SETTING	TURNS	PIECES	CUBIC FEET	AVG CU FT PER PIECE
S8 / HOT	35	199	727.29	3.65
S8 / COLD	122	728	2589.68	3.56
S8 / WORK TOGETHER	17	86	185.95	2.16
S8 / TOTAL-AVG	174	1013	3502.92	3.46
LUCKY / HOT	26	126	196.96	1.56
LUCKY / COLD	3	11	20.74	1.89
LUCKY / WORK TGTHER	17	111	243.75	2.20
LUCKY / TOTAL-AVG	46	248	461.45	1.86
GROUND HOT SUBTOTAL	61	325	924.25	2.84
CABLE / HOT	88	242	658.79	2.72
CABLE / COLD	659	1820	6677.99	3.67
CABLE / TOTAL-AVG	747	2062	7336.78	3.56
SKID/YARD SUBTOTAL	967	3323	11301.15	3.40
DOZER / PILE TO RD	75	405	1342.08	3.31
SKID/YARD ------ TOTALS/AVERAGES	1042	3728	12643.23	3.39
LOADER / GRD HOT	314	645	1834.28	
GRD HOT FROM SKID	120	261	742.24	
GRD HOT FROM DECK	148	267	759.31	
LOADER / GRD COLD	233	584	1896.83	
LOADER / CABLE HOT	92	222	604.34	
LOADER / CABLE COLD	758	1762	6465.17	
LOADER / SUBTOTAL	1397	3213	10800.62	
LOADER / DOZER PILE	460	757	2508.53	
LOADER / SLASH PILE	53	78	118.58	
LOADER / TOTAL W/SHR	1910	4048	13427.73	
LOADER / GRINDER	772		3545.87	
	STEMS IN	PCS (18") OUT		
SHEAR / GRD HOT	601	8118	1709.15	
GRD HOT FROM SKID	243	3285	805.25	
GRD HOT FROM DECK	249	3360	825.13	
SHEAR / GRD COLD	559	6416	1815.63	
SHEAR / CABLE HOT	202	2631	549.90	
SHEAR / CABLE COLD	1599	17159	5867.09	
SHEAR / SUBTOTAL	2961	34324	9941.77	
SHEAR / DOZER PILE	708	7344	2346.15	
SHEAR / SLASH PILE	81	500	118.58	
SHEAR / TOTAL	3750	42168	12406.50	
GRINDER/SHRED WOOD	110		3545.87	

TABLE 2: Percent productivity of system components under observed conditions and after modifications for the case study. Productive hours are the delay free hours required to accomplish work in each study module.

MACHINE / SETTING	PRODUCTIVE TIME IN HOURS	OBSERVED PERCENT PRODUCTIVE	CASE STUDY PERCENT PRODUCTIVE
S8 / HOT	5.686	55.102	68.800
S8 / COLD	26.886	79.111	80.058
S8 / WORK TOGETHER	3.050	47.768	73.370
S8 / TOTAL	35.622	70.276	77.017
LUCKY / HOT	3.568	71.921	68.801
LUCKY / COLD	.676	40.166	46.429
LUCKY / WORK TGTHER	3.728	80.955	83.513
LUCKY / TOTAL	7.972	70.869	71.781
CABLE / HOT	3.475	56.781	65.344
CABLE / COLD	28.564	66.488	65.294
CABLE / TOTAL	32.039	65.278	65.299
DOZER / PILE TO RD	5.954	54.619	65.508
LOADER / GRD HOT	4.936	23.976	43.774
LOADER / GRD COLD	3.571	31.762	47.856
LOADER / CABLE HOT	1.914	38.488	48.358
LOADER / CABLE COLD	11.090	33.856	48.203
LOADER / SUBTOTAL	21.511	30.925	47.067
LOADER / DOZER PILE	6.285	38.667	48.443
LOADER / SLASH PILE	.864	45.836	87.185
LOADER / TOTAL W/SHR	28.660	32.680	48.332
LOADER / GRINDER	6.367	31.374	40.331
SHEAR / GRD HOT	8.352	49.961	67.317
SHEAR / GRD COLD	6.079	73.021	80.549
SHEAR / CABLE HOT	2.733	56.316	55.887
SHEAR / CABLE COLD	18.379	61.813	78.248
SHEAR / SUBTOTAL	35.543	59.608	74.686
SHEAR / DOZER PILE	8.899	65.782	66.168
SHEAR / SLASH PILE	.581	37.030	71.552
SHEAR / TOTAL	45.023	60.252	72.793
GRINDER/SHRED WOOD	13.069	65.905	79.096

disproportionately high percentage of some operational segments and were unrealistically small in others. Several other delays appeared to be correctable with some logical, realistic equipment modifications. An earlier version of the hydraulic shear, for example, utilized an outfeed conveyor that carried sheared wood away from shear operations. Changes to the shear to allow experiments with the concurrent production of both 18 and 48 inch firewood included a new outfeed system. The new layout caused many delays related to cleaning of material from the outlet chute and conveyor and for the loader to move processed firewood away from the shear. Given these correctable and non-uniform delays, case study conditions were developed to allow a fairer comparison between study options. Case study assumptions included a 10 percent mechanical delay time for all equipment and elimination of delays related to correctable equipment problems. Percent productivities under case study conditions are also shown in Table 2. Note that in cases where observed mechanical delay times were low, the percent productivity decreased for case study conditions.

INFLUENCE OF OPERATING MODE ON SYSTEM DELAYS

Hot operations of the ground based machines resulted in interference between the skidders and the loader. The S8 skidder encountered a delay of 9 percent of its total time for this interference; the Lucky Logger had a 4 percent delay. The Lucky Logger proved to be less maneuverable than the skidder and crawler and required additional time to build good decks. This additional decking time totaled 13 percent of total Lucky Logger time in cold decking operations. Operations of the skidder and Lucky Logger together caused interference between the two machines and resulted in additional decking delays for both machines. Additional decking duties under these conditions accounted for 9 percent of the skidder's time; an interference delay of 4 percent was recorded for the Lucky Logger. Time spent changing cable yarder setups increased in cold operations. The additional set changes were needed to create more decking area for the unprocessed residue material. Percent of time spent changing tailholds and settings of the cable yarder increased from 13.8 percent in hot processing to 15.8 percent in cold decking operations.

Average minutes per turn unhooking and decking material at the landing were larger in cold decking operations for all options. Average time for the skidder increased from 1.10 minutes per turn to 2.11 minutes. Time for the Lucky Logger increased from 1.48 minutes to 2.24 minutes. Time for the cable yarder increased from .302 minutes to .636 minutes. These results are consistent with one of the original assumptions of the study that hot operations should make the skidding or yarding operation more efficient.

Loader delays ranged from 9 to 20 percent of its total time for the removal of sheared firewood from around the shear. This delay would not have been encountered with the earlier design of the shear and was eliminated in the assumptions made for case study conditions. The largest single delay category after removal of sheared firewood involved repositioning and moving of the loader and shear. This accounted for 17 percent of loader time in hot processing with the ground system, 16 percent of the time during processing from skidder and cable cold decks, and 18 percent of the time when working in decks created by the modified dozer piling operation. It is a function of working from many, scattered cold decks.

Waiting for wood represented the largest delay category for the shear. It averaged 9 percent of the time when operating under a hot processing system with ground skidding machines. In these cases, however, the loader was also retrieving material from adjacent cold decks when there was no wood available from the skidder. Without the adjacent cold decks, delays waiting for wood would have totaled an additional 24 percent of the total time of the loader and shear. When operating in a hot processing mode with the cable yarder, the shear was waiting for wood 16 percent of the time. Delays waiting for wood were reduced to 4 percent when operations shifted totally to cold decked material. The percentage differences in these cases verify the initial assumption that the processing equipment would not be fully utilized in hot processing operations.

REGRESSION ANALYSIS OF TURN TIMES

Regression equations were developed to predict the productive turn times of each of the skidding machines used in the study. Predictive equations for the cycle time of the loader and for the cubic foot/minute production rate of the shear were also developed. These are shown in Table 3.

TABLE 3: Regression equations developed for the skidder, yarder, loader, and shear. Distances are in feet, diameters and areas are in inches, and volume is in cubic feet.

```
CLEARWATER YARDER:             R-SQUARE = .426

TURN TIME =     1.5055 + 0.0120 (VOLUME PER TURN)
              + 0.0111 (DECK HEIGHT) (PIECES/TURN)
              + 0.0214 (DECK HEIGHT) (TOTAL END AREA OF PIECES
                                      IN TURN)
              + 0.0037 (YARDING DISTANCE + LATERAL DISTANCE)
              + 0.0002 ( LATERAL DISTANCE ** 2)

LUCKY LOGGER:                  R-SQUARE = .755

TURN TIME =     5.0830 + 0.0088 (SKIDDING DISTANCE)
              - 1.0800 (CREW: 0, 1 PERSON: 1, 2 PERSON:
                        2, 3 PERSON)
              + 1.5687 (MODE: 0, HOT: 1, COLD)
              + 3.8445 (END AREA OF TURN/ PIECES IN TURN)

WHEELED SKIDDER MODEL S8:      R-SQUARE = .427

TURN TIME =   - 15.5772 + 0.3448 (PIECES IN TURN)
              +  0.0367 (VOLUME IN TURN)
              +  4.0525 (ln (SKIDDING DISTANCE + WINCH DISTANCE))

HYDRAULIC LOG LOADER:          R-SQUARE = .254

CYCLE TIME =    0.8425 + 0.0611 (RELATIVE LENGTH OF LOAD ** 2:
                                 0, 0 -  4 feet: 1,  4 -  8 feet:
                                 2, 8 - 16 feet: 3, 16 - 32 feet:
                                 4, 32 feet and longer)
              - 0.0338 (TYPE OF DECK: 1, COLD DECK: 0, NO DECK)
              - 0.1363 (RELATIVE LOAD LENGTH / NUMBER OF PIECES)

SHEAR / FIREWOOD PROCESSOR:    R-SQUARE = .416

PRODUCTION RATE (CU.FT. / MIN)  = - 4.0282 +
                                + 1.3375 (AVERAGE DIAMETER)
```

Volume of the load and pieces and distances skidded or yarded had expected effects on the turn times for the skidders and the yarder. Deck height, only a factor in cold decking operations, also affected yarding time. An increase in deck height caused a significant increase in the time spent decking and unhooking the load. The mode of operation (hot or cold) proved to be a significant variable for the Lucky Logger, but did not significantly affect production of the S8 wheeled skidder. Loader turn times were shorter when working from a deck built in a cold decking operation than when working in a hot processing mode, but length of the pieces loaded had the greatest effect on the cycle time. Turns or cycles were not a reliable measure of shear production so the predictive equation was designed to estimate cubic foot/minute production. The diameter of the log fed to the machine was the only variable shown to significantly affect this measure of shear production.

COMPARISON OF SYSTEM COSTS

The regression equations and general statistics were used to develop production and cost estimates under equal conditions of skidding distance and piece size for each of the options considered in the study. Data collected on dozer piling did not allow development of any equations relating production to distance or other site factors so the base comparison between options was made at the average dozing distance of 69 feet. Machine rates used in the study are those incurred by CPTPA in regular operations. These are listed in Table 4. The relatively low fixed costs of the shear and grinder reflect the used equipment components that were used to construct the machines. Fixed costs would be higher for comparable machines commercially manufactured and sold.

TABLE 4: Hourly machine and labor rates used to determine the cost of residue recovery.

MACHINE	FIXED COST $ / HOUR	VARIABLE COST $ / HOUR	LABOR COST $ / HOUR
CLEARWATER YARDER	17.00	18.00	35.70
S8 WHEELED SKIDDER	17.00	11.00	11.90
LUCKY LOGGER	15.00	11.00	11.90
HYDRAULIC LOADER	17.00	10.00	14.70
HYDRAULIC SHEAR	8.00	10.00	11.90
GRINDER	8.00	10.00	11.90

Total costs per piece, cubic foot, green ton, and cord are shown in Table 5. A productive hour is defined as delay free time so costs per productive hour represent the maximum potential and lowest cost of a system. These costs will be realized only if all delays are eliminated. Scheduled hours include the delays incurred by the systems after the assumptions and modifications for case study conditions. Total costs for hot operations were higher than costs associated with cold decking within each skidding option. Costs of hot operations for the S8 wheeled skidder exceed cold decking costs by 39 percent, hot operations for the Lucky Logger are 33 percent higher than those for cold decking, and cable system costs for hot operations are 8 percent higher. Cold decking operations with the S8 wheeled skidder and with the modified dozer piling concept produced

TABLE 5 : Summary of total system costs developed under equal conditions for all recovery options from regression equations of turn times and with delays adjusted for correctable problems.

AVERAGE SKID DISTANCE 69 FEET

---- COST TO SKID, LOAD, AND SHEAR ----

MACHINE / SETTING	BY PRODUCTIVE HOUR		BY SCHEDULED HOUR	
	$/PIECE	$/CUFT	$/PIECE	$/CUFT
TOTAL GRD HOT W/DECK	$1.362	$.401	$1.808	$.595
TOTAL GROUND HOT S8	$1.314	$.386	$2.124	$.625
TOTAL GRD HOT LUCKY	$1.428	$.420	$2.504	$.737
TOTAL GROUND COLD S8	$1.160	$.341	$1.533	$.451
TOTAL GRD COLD LUCKY	$1.451	$.427	$1.890	$.556
TOTAL CABLE HOT	$1.644	$.483	$2.431	$.715
TOTAL CABLE COLD	$1.588	$.467	$2.255	$.663
TOTAL DOZER PILED	$1.028	$.302	$1.556	$.458

--- COST TO LOAD AND SHEAR OR GRIND ---

TOTAL IN SKID PILE	$.600	$.177	$.874	$.257
TOTAL IN SLASH PILE	$.676	$.199	$.785	$.231
TOTAL LOAD AND GRIND		$.185		$.289

---- COST TO SKID, LOAD, AND SHEAR ----

	$/GRN TON	$/CORD	$/GRN TON	$/CORD
TOTAL GRD HOT W/DECK	$26.22	$34.06	$38.93	$50.58
TOTAL GROUND HOT S8	$25.28	$32.84	$40.87	$53.11
TOTAL GRD HOT LUCKY	$27.48	$35.70	$48.18	$62.61
TOTAL GROUND COLD S8	$22.31	$28.99	$29.50	$38.33
TOTAL GRD COLD LUCKY	$27.92	$36.28	$36.36	$47.24
TOTAL CABLE HOT	$31.62	$41.09	$46.78	$60.77
TOTAL CABLE COLD	$30.56	$39.70	$43.39	$56.38
TOTAL DOZER PILED	$19.78	$25.70	$29.93	$38.89

--- COST TO LOAD AND SHEAR OR GRIND ---

TOTAL IN SKID PILE	$11.58	$15.04	$16.81	$21.84
TOTAL IN SLASH PILE	$13.01	$16.91	$15.10	$19.62
TOTAL LOAD AND GRIND	$12.11	$15.73	$18.89	$24.54

the lowest total system costs. As expected, operations with the cable yarder are higher than any of the ground skidding alternatives. The option titled "ground-hot with deck" represents hot processing with the ground skidders where the loader can also remove material from adjacent cold decks. Cost for this option is lower than for hot processing alone but is still higher than costs of cold decking because of interference between the loader and skidder.

The cost of loading and shearing or loading and grinding represents a cost to process material already delivered to a landing. Costs of processing material from skid decks and from the less uniform slash piles were about equal. The calculated costs of $20-$22 per cord make sale and recovery of residue from landing decks a feasible alternative to disposal. Using estimated investment costs for a new loader, shear, and grinder of $190,000, $75,000 and $50,000 respectively, the costs to load and shear or grind would increase to $23-$25 per cord to shear the wood and to $28 per cord to grind the material.

These costs can be compared to the cost of producing firewood manually. Gross production times to cut and load firewood were obtained from several independent firewood producers. Times ranges from 75 to 90 minutes per cord. Using an average of 1.3 hours per cord, a cost for the chainsaw of $3.50 per hour, and a labor cost of $11.90 per hour, manual firewood costs to cut and load were calculated at $20.08 per cord. The labor rate appears high, but is set at the same rate as used for general labor with the shear and loader. It includes a 40 percent overhead rate for benefits. Manual costs under these assumptions are close to those of mechanically produced firewood, but the mechanical system provides another distinct advantage. The loader has the ability to break material out of previously constructed slash decks, but manual operations are usually limited to material that is readily accessible. Firewood producers generally have no way of retrieving large material buried very deeply in slash decks. Any equipment maintained by a manual producer to do this would add to the cost of the manual system.

COST AND PRACTICABILITY OF IN-WOODS GRINDING

The cost of loading and grinding the residue was slightly higher than the cost of producing firewood. In most settings this would be an additional processing step since the grinder could not effectively process any piece longer than 3 feet. The cost of the hog fuel produced under these constraints is quite expensive and at current hog fuel prices, is not economically feasible. If the hog fuel user had equipment capable of hogging moderately sized material, output of the shear that was not suitable for firewood could be loaded directly into trucks and hauled to the hogging site. This method of recovery could reduce the value of the material at its destination, but would also significantly reduce the delivered cost of the material. Transportation of unprocessed firewood would also allow more efficiency and lower costs in the hauling operation. In one of the final field tests thirty cubic yard haul trucks were alternately loaded with the product of the grinding operation and with the unprocessed feedstock, the low quality firewood pieces. Net loads of the ground fuel averaged 10,915 green pounds; the firewood averaged 17,428 green pounds. This 60 percent increase in net weight of the load with firewood is a function of the higher density of the material when left in a larger form. Delivery of the larger pieces to the final destination also gives the user more options for use and treatment of the material.

COST OF SKIDDING AND YARDING

Costs per unit of output to skid and yard the material are shown in Table 6. Costs of hot operations for the Lucky Logger and yarder are lower than their respective costs in cold decking operations. This difference does not show in the costs of the S8 wheeled skidder because the regression analysis for that module did not produce any significant factors related to the mode of operation. The original data did show a lower skidding cost for the S8 skidder in hot operations. Cost per productive hour was 25 percent lower; cost per scheduled hour was 13 percent lower. Dozer piling costs are much lower than the skidding costs of any of the other options. Total costs when using the dozer piling concept were slightly higher than those of the S8 skidder, however, because of increased processing costs in the dozer piled areas. The dozer produced many small decks along the access road and this resulted in more frequent moves and lower production for the loader and shear.

Costs per acre are a function of the unit size of the respective study areas and of the volume recovered from those units. Dozer piling also resulted in a much lower cost per acre. If the skidding or dozer piling operation is viewed as an alternate method of residue disposal, the costs per acre can be compared to costs incurred in the most

TABLE 6 : Summary of skidding and yarding costs developed under equal conditions for all recovery options from regression equations of turn times and delays adjusted for correctable problems.

SKIDDING AND YARDING COSTS

AVERAGE SKID DISTANCE 69 FEET

	COST PER UNIT OF OUTPUT			
MACHINE / SETTING	BY PRODUCTIVE	HOURS	BY SCHEDULED	HOURS
	$/PIECE	$/CUFT	$/PIECE	$/CUFT
S8 / HOT	$.579	$.170	$.788	$.232
S8 / COLD	$.579	$.170	$.689	$.203
S8 / AVERAGE	$.579	$.170	$.709	$.208
LUCKY / HOT	$.693	$.204	$.917	$.270
LUCKY / COLD	$.871	$.256	$1.046	$.308
LUCKY / AVERAGE	$.769	$.226	$.970	$.285
CABLE / HOT	$.879	$.259	$1.227	$.361
CABLE / COLD	$.982	$.289	$1.371	$.403
CABLE / AVERAGE	$.970	$.285	$1.354	$.398
DOZER / PILE TO RD	$.306	$.090	$.426	$.125
	$/GREEN TON	$/ACRE	$/GREEN TON	$/ACRE
S8 / HOT	$11.23		$15.27	
S8 / COLD	$11.24		$13.37	
S8 / AVERAGE	$11.23		$13.74	
LUCKY / HOT	$13.45		$17.77	
LUCKY / COLD	$16.89		$20.28	
LUCKY / AVERAGE	$14.91		$18.82	
S8 / LUCKY AVERAGE		$272.73		$336.54
CABLE / HOT	$16.82		$23.47	
CABLE / COLD	$18.78		$26.22	
CABLE / AVERAGE	$18.55	$613.38	$25.89	$856.34
DOZER / PILE TO RD	$6.00	$96.10	$8.34	$133.70

common residue disposal method, broadcast burning. Records of recent CPTPA burning costs were analyzed and correlated to the size of the burn unit. Analysis of their data produced the following equation:

COST/ACRE = 43.094 + (314,589.6 / (UNIT SIZE ** 3))

R square = .831.

The results indicate that per acre costs to burn small units will be quite high. Using this equation, a 10 acre unit would cost $358/acre, a 20 acre unit would cost $82/acre, and a 40 acre unit, $48/acre. The equation relates specifically to equipment and management costs of CPTPA, but the general relationship will be true for other residue disposal organizations. Recovery of residue with a wheeled skidder over an average skid distance of 69 feet would cost slightly less than disposal of a 10 acre tract by broadcast burning. A 10 acre unit would have to be laid out as a long, narrow strip along an access road, however, to allow an average skid distance of 69 feet. The unit would need general dimensions of 140 feet of depth by 3111 feet of width. Size and layout of harvest units will both affect decisions on the method of residue treatment.

FEASIBILITY OF RESIDUE RECOVERY FOR FIREWOOD

Current prices for firewood in north-central Idaho vary widely with the quality and location of the firewood. Delivered prices for cut and split wood range from $70 to $85 per cord. Costs at easily accessible log decks, but with the requirement that you cut the wood average $50 per cord. Comparable prices closer to population centers would likely be much higher. The total costs per cord in Table 5 show some potential for recovery at costs that would be close to breakeven with a realistic selling price for the firewood. These recovery costs are very sensitive to the skidding distance, however. Figure 1 shows total recovery costs as a function of skidding distance for the S8 wheeled skidder and the cable yarder for both the concurrent (hot processing) and subsequent (cold decking) recovery modes. At an average skidding distance of 414 feet, the overall average skid distance observed for the skidders and cable yarder, total costs increase to $61 per cord for the S8 skidder working into cold decks and to $75 per cord for the cable yarder. Costs for hot processing operations are much higher. Hot processing becomes progressively less attractive with increasing skidding and yarding distances because of decreasing utilization of the potential of the processing equipment.

Decisions on disposal or recovery of residue will likely be determined on the basis of size and layout of the recovery unit. Large units will usually require longer skidding distances and recovery costs will be on the high end of the curve. Disposal costs through burning, however, will be at their lowest cost per acre. In small units the situation is reversed. Disposal costs are relatively high; recovery costs are at their lowest. These trends are illustrated in Figure 2 for data collected on the study sites and for the costs incurred by CPTPA in burning. Additional incentive for recovery of residue could be provided if credit were given for the cost that would be incurred in burning operations. This would decrease the revenue that would be needed from the residue product to allow the recovery operation to pay for itself. The middle curve in Figure 2 reflects the net cost of recovery after credit for residue disposal. This credit can have a significant effect in small units, but will have little effect on the breakeven price that needs to be received for the firewood in large units.

SUMMARY AND RECOMMENDATIONS

Hot processing operations resulted in higher costs than their cold decking counterparts, but there may be instances when hot processing is needed. Landing areas may be too small to allow cold decking of significant volumes of material. In these instances some combination of hot processing with limited cold decking would be cost effective. The field studies revealed real inadequacies in a pure hot processing operation. Alternatives must be built into the planning and scheduling to allow part of the system to function when one component goes down with mechanical breakdowns or other problems. This becomes even more important when using older equipment that may not have high mechanical availability.

Grinding on site was more costly than shearing and the material appeared to have no advantages in subsequent handling and transportation operations. The grinder was very limited in the size piece it could handle and in the effectiveness of the single rotor in providing continuous feed for the raw material. The design flaws could be corrected, but a more relevant question is whether it is necessary to produce this sized material in the woods. Pieces reduced to 18 inch firewood size and smaller by the shear may provide the uniformity necessary to allow economic transportation away from the recovery site.

Cost results indicate that in areas where there is a high demand for firewood, recovery and processing with this type of system may be economically feasible. The recovery operation becomes more attractive as the size of the original harvest unit decreases.

Figure: 1

Total Recovery Costs as a Function of Skidding Distance

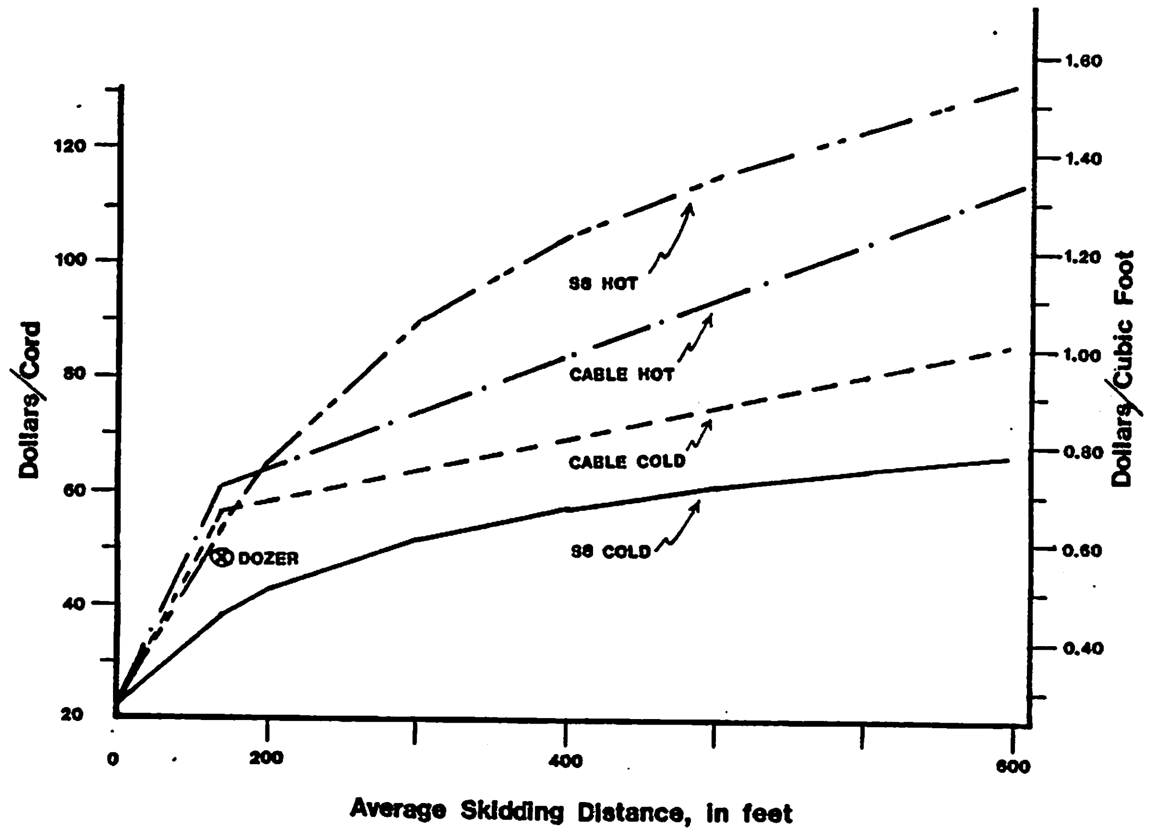
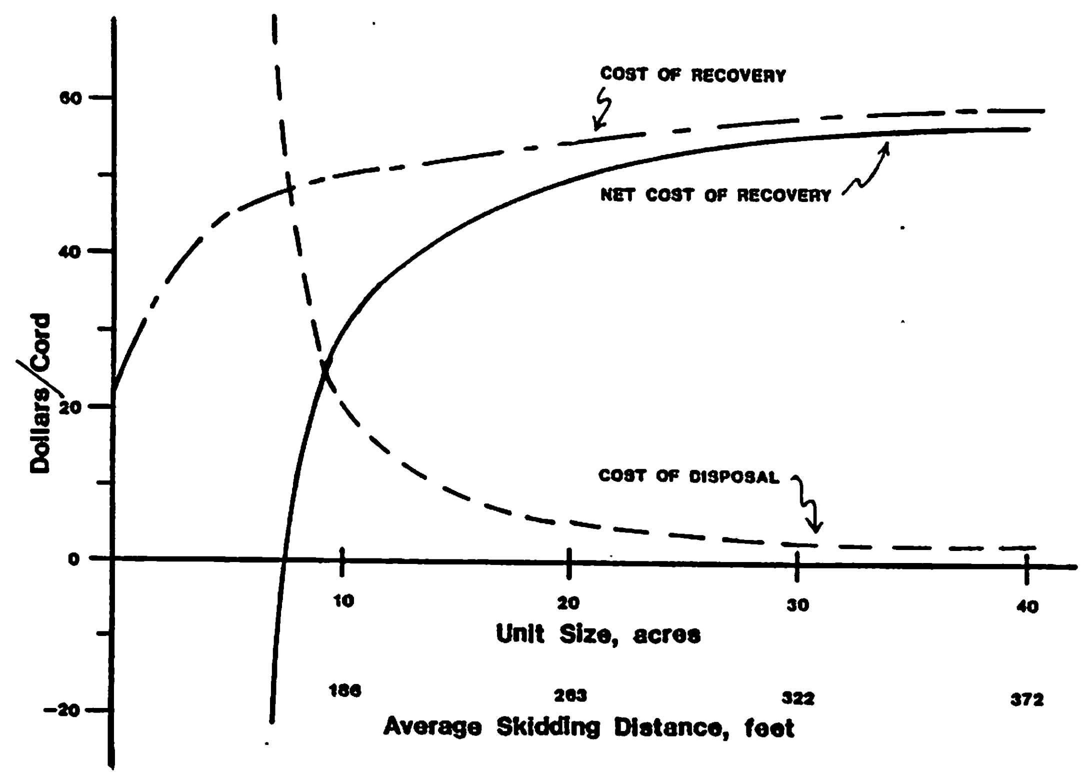


Figure 2: Net cost of recovery of residue after adjustment for the savings in disposal cost.



COMPARISON OF MICROCOMPUTER PROGRAMS FOR ANALYSIS OF TIMBER HARVESTING OPERATIONS[1]

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Abstract: Several microcomputer-based programs have recently been developed for analyzing harvesting system cost and production problems. This paper evaluates and provides comparative information on five such programs: Logging Cost Analysis Package; PROLOG: Program for Logging Cost Estimation; Auburn Harvesting Analyzer; Harvesting System Analyzer; and Harvesting System Simulator. A description of each program is presented and the program results from an analysis of a mechanized tree-length system are compared.

Keywords: harvesting systems, cost and production analysis, microcomputer

Rapid advancements and applications of microcomputer technology have provided forest engineers, industrial managers, and logging contractors with better methods for analyzing timber harvesting operations. Currently, there are several microcomputer based programs for analyzing harvesting cost and production problems. These programs have been developed by extension specialists and researchers with universities, the U.S. Forest Service and other government agencies, and forestry consultants. Each program takes a slightly different approach to evaluating the same problem -- how to properly analyze individual machine and system productivity and/or fixed and operating cost information for harvesting equipment.

Ultimately, the goal is to reduce harvesting costs and improve operating efficiency of logging operations by using computers and/or more quantitative methods for making better business decisions. Early efforts to introduce quantitative techniques were often unsuccessful because the methods for analyzing harvesting operations were often too complicated and input requirements too detailed to be useful to most procurement foresters and loggers. Today, however, inexpensive and user-friendly microcomputer-based harvesting software can be used to simplify tedious and repetitive cost and production calculations and to quickly answer "what-if" questions about system performance. Sensitivity analyses can be easily performed to evaluate the effects of changing tract size, stand characteristics, number or type of machines used, haul distance or a number of other controlling factors.

This paper provides comparative information on five microcomputer-based programs for analyzing harvesting operations: Logging Cost Analysis Package, PROLOG: Program for Logging Cost Estimation, Auburn Harvesting Analyzer, Harvesting System Analyzer, and Harvesting System Simulator. Although there are other computer programs in the harvesting/forest engineering area (FORS 1986, Farrar 1984), these programs represent some of the most recent and comprehensive programs available. These programs also utilize different approaches for evaluating the complete system rather than just individual functions of the harvesting process. After each program was used extensively, the following criteria were selected to compare the five programs: initial cost, hardware/software requirements, problem-solving approach, input requirements, results/output generated, and existing documentation. Each program is described followed by a comparison of program results from an analysis of a mechanized tree-length system.

LOGGING COST ANALYSIS PACKAGE

The Logging Cost Analysis Package (LCAP), developed by Earl Deal and William Swint (1984) at North Carolina State University, is an easy to use menu-driven program for calculating logging costs based on the machine rate approach. The program is written in BASIC for the IBM-PC (or compatibles) and requires a single disk drive and 64K memory. A printer is optional. LCAP is divided into four main sections: Machinery Costs, Labor Costs, Miscellaneous Costs, and Summary Table.

The 'Machinery Cost' section is designed to accept a variety of fixed and operating cost data for individual machines in a logging system. The fixed cost information is standard for a machine rate calculation (e.g. purchase price, machine life, salvage value, interest, insurance and taxes), and operating costs include fuel, oil/lube, maintenance and repair, hydraulic oil, and tire costs. Since data input is rather lengthy and time-consuming for systems with several different machines, this section (as well as other sections of LCAP) has the option for editing and storing data for each machine. Output from this section consists of individual machine cost reports in terms of a scheduled hour, day, week, month or year.

The 'Labor Cost' section accepts information for both hourly and salaried employees. Current rates for Social Security, worker compensation, unemployment and life insurance, and other employee expenses can also be included along with wage rates and salaries. Output from this section consists of a summary of annual labor costs by employee.

The 'Miscellaneous Cost' section enables the user to input overhead expenses such as bookkeeping, office supplies, crew travel, and other miscellaneous costs. Output consists of a summary table of these costs.

The 'Summary Table' section summarizes total system costs for the previous three cost calculations on a hourly, daily, monthly and yearly basis.

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Documentation in the form of a user's manual is not available, but ample on-screen instructions are provided throughout the program and in the form of 'Help' displays. The program can be obtained at no cost by sending a diskette to Earl Deal, Extension Forest Resources, North Carolina State University, Raleigh, NC 27695.

PROLOG: PROGRAM FOR LOGGING COST ESTIMATION

PROLOG is a menu-driven harvesting cost analysis program developed by Peter Dyson, Lois Shackelford, and Mark Johnson at the University of Georgia (1982). Originally developed for use on a mainframe computer, PROLOG was adapted for microcomputer use and runs as a compiled FORTRAN program on the IBM-PC and most PC compatibles. The program requires 128K memory, two disk drives, and a printer.

The program guides the user through a series of five sections or subroutines where data is provided about the system: General Assumptions, Equipment Description, Labor Wage Information, reporting options, and file management.

The General Assumptions section requests information about the hours worked per day, days worked per year, pieces of equipment in the operation, the cost of money, tax costs, fuel costs, and harvesting production averages.

The Equipment Description section accepts information about individual machines. Data includes purchase price, salvage value, life, depreciation period, insurance costs, fuel costs, tire costs, and any special costs particular to the machine. The program then computes fixed and operating costs associated with each machine using the machine rate approach.

Labor wage information is entered in the third section, and includes wage levels with percentage estimates for workers compensation costs, unemployment insurance, and overhead.

The user can choose from seven different reporting options in the fourth section, although two of these are tax-related reports using outdated tax rules in the computations. Output includes the system description, equipment cost summary, labor cost summary, and the summary of system costs per crew hour and per unit of production.

The last section allows the user to save the information on disk and direct output to either the monitor or the printer. Monitor output is poorly formatted, however, and wraps around the screen, making the output difficult to read. The printer should be set for compressed print before requesting printed output from PROLOG.

PROLOG was originally developed as a teaching tool for forestry students and has not been updated since the original program was written. The program shows this in the poor screen output and outdated tax computations. Overall, the program performs adequately, although enhancements could increase its utility in harvesting cost analysis. The program can be obtained from Peter Dyson, University of Georgia, Athens, GA 30602 by sending a $100 donation to the School of Forest Resources. No written documentation is currently available.

AUBURN HARVESTING ANALYZER

The Auburn Harvesting Analyzer (AHA) is a spreadsheet-based program designed to analyze the performance of logging systems on different tracts of timber (Tufts and others 1985). The program is structured to analyze a harvesting system consisting of several basic functions (i.e., felling, skidding, loading, and hauling). The program or template is designed as a single-page table separated into four sections that deal with per acre stocking, general tract information, machine productivity, and machine cost.

In the 'Stand & Stock Table' section, the user provides a per acre stand and stock table for the tract being harvested. This data is later used with regression equations to estimate function productivity. The 'General Information' section requests information about support equipment costs and work schedules. In addition, the user is asked to describe tract characteristics, quota restrictions, and road building requirements. This information can be changed in the template to determine how quotas, tract size, and road construction costs affect system productivity and costs.

The 'Machine Productivity' section combines the user-supplied stand data with regression equations to estimate the productivity in cords per productive machine hour of each function. These productivity figures provide an estimate of the flow of harvested wood from one function to another and a measure of system balance. The 'Machine Cost' section contains information about the machine and labor costs associated with a system. A simplified cash flow analysis is used to estimate machine costs, although only slight changes are required to the spreadsheet if machine rates are desired. (Machine rates are used in the AHA template reviewed here.) Fixed costs (either depreciation or monthly payments), insurance and taxes, fuel and lubricants, maintenance and repair, maximum utilization rates, and labor costs are supplied by the user for each harvesting function. Costs, based on this information, are then summarized on a scheduled machine hour basis. The number of machines per function can be modified to balance system productivity. A summary at the end of the table provides estimates of weekly production and of total system cost on a scheduled hour and cord basis.

The original AHA template was available for a highly mechanized tree-length system, but other templates are now available for systems using forwarders, chainsaw felling, and cable skidders. System requirements include an IBM-PC or compatible with 256K RAM and a printer. The template, originally developed on Lotus 1-2-3, is now also available for Framework users. Users of other spreadsheet software can manually type the template into their package. Templates may be obtained by sending a blank diskette to either Bob Lanford or Robert Tufts, School of Forestry, Auburn University, AL 36849-4201. Documentation is available on request.

HARVESTING SYSTEM ANALYZER

The Harvesting System Analyzer (HSA) developed by Greg Hendricks and Dennis Curtin (1985) of the Tennessee Valley Authority is a two part harvesting analysis program written in PASCAL and designed for use on the IBM-PC and PC-compatibles. A compiled version of the program is available and requires two disk drives, a MS-DOS operating system, 256K memory, and a printer.

HSA is separated into two menu-driven component programs, the FILEM and SYSBUILD modules. These actually come on separate disks, but are linked by data files used in both modules.

In FILEM, a file management program, 'machine' files are created that describe the individual machines used in a logging operation. Data for each machine is entered into the 'machine' file and used to compute fixed and operating costs. The program will also assist the user in developing cost estimates on interest, hourly fuel and lubricant costs, tire costs, and maintenance and repair. Each machine is defined as a particular 'machine type', selected from one of sixteen pre-defined categories. Selection of a particular machine type produces default productivity variables that are used later in the SYSBUILD program.

FILEM uses the machine rate method of computing fixed and operating costs as described by Miyata (1980). While FILEM is used primarily to provide data to the SYSBUILD program, it can also be used to answer 'what if' questions concerning variable costs, depreciation methods, and equipment purchase decisions. Output from FILEM consists of a summary of the input data plus the computed fixed and operating costs for each piece of equipment entered. Fixed cost estimates are provided on a scheduled hour basis, while operating costs are estimated on a productive hour basis.

The second component of HSA is SYSBUILD which is designed to estimate time and cost requirements for a particular harvesting system to log a selected tract of timber. SYSBUILD uses three separate data files that describe the harvesting system, the machines in that system, and the tract being harvested. The machine file constructed in FILEM is used to describe individual machines, while the tract and system files are constructed using the SYSBUILD program.

The tract file contains information about the species, mean DBH, mean height, per acre volume, terrain and brush characteristics, average skid distance, and average haul cycle times. More detailed stand information can be provided using the stand table input screen.

The harvesting system file is created using a flow diagram which specifies the different harvesting functions of the system. The user may select from one of three different diagrams, depending on the system being analyzed. Options include conventional shortwood, conventional longwood, or mechanized shortwood systems.

Production equations provided through the FILEM program are used to develop productivity for each machine in the system file. Production rates can be manually entered if desired. Other costs, such as labor and road building costs, can be added to the system in the harvesting system file. These costs are specified as either fixed hourly or one-time costs incurred in a specified function.

The REVIEW option in the system file allows the user to rapidly analyze the system on the screen. Output for the system, each function, and each machine is provided, allowing the user to ensure that the tract and harvesting system files have been correctly developed.

Printed output consists of a tract and system level report. The tract report summarizes the tract characteristics, and the system level report details the system performance by machine, function and total system for the tract being analyzed. All output specifies productivity in CCF and costs in dollars per CCF.

The program can be obtained by sending two blank diskettes to Greg Hendricks, Tennessee Valley Authority, Norris, TN 37828. A well-documented user's guide can also be obtained free of charge (Hendricks 1986).

HARVESTING SYSTEM SIMULATOR

The Harvesting System Simulator (HSS) is the system simulation component of the Harvesting Analysis Technique, HAT (Stuart 1981) -- a flexible, mainframe-based harvesting simulation program with stand, machine, and system simulation capabilities. The PC-version of HSS reviewed here is the mainframe (FORTRAN) version downloaded and compiled for use on an IBM-PC with 312K of RAM and a math coprocessor. Revision of the program to more fully utilize the capabilities of a personal computer and integration with HAT are under consideration (Farrar 1986).

HSS can model systems consisting of up to 14 different machine types operating on tracts composed of up to 14 different harvesting areas. Harvesting areas can possess different stand conditions and are not limited in size or wood volume. A major strength of HSS is it's ability to account for productive and non-productive times, including up to 20 different delay or down times and a variety of productive activities. Major output reports include: (1) income and expense reports by machine, phase, and system on a weekly basis, (2) operating cost analysis reports for each machine and the entire system, and (3) time allocation reports for each machine.

Data inputs for HSS are extensive and first-time users will likely require the assistance of an experienced user to successfully use the program. Documentation for HSS consists of the author's doctoral dissertation (Stuart 1980) and a detailed 62-page set of input forms describing the type and format of required input data. However, a dedicated user's manual would be most helpful, particularly if it included a better explanation of inputs forms, the calculations and assumptions used in the program, and examples to indicate the proper modeling approach to typical problems.

The mainframe version of HSS has been widely used in the past by government, industry, and university researchers and continues to be used to model harvesting systems. Current users of the mainframe version can receive the PC version at no additional cost. Linking of GENMAC and PTAEDA (Stuart 1981) to the microcomputer version would retain the major advantage of using HSS on the mainframe. HSS is available to new users for $600 from the Industrial Forestry Operations Section, Department of Forestry, VPI&SU, Blacksburg, VA 24061.

COMPARISON/DISCUSSION

Several characteristics of LCAP, PROLOG, AHA, HSA, and HSS have been stated in the preceeding program descriptions. Table 1 summarizes selected differences among these programs and also evaluates them in terms of additional features that Cooney (1986) considers characteristic of a "good" program. As Table 1 indicates, obvious differences and similarities exist in the ease of use, written documentation, on-screen instruction/help, and controlled reporting categories. The remainder of this paper is devoted to comparing the five programs in terms of: Model Assumptions and Applications; Input Requirements; Output Generated; and Comparison of Test Results.

Model Assumptions and Applications

All five programs evaluated can use the machine rate approach (Miyata 1980) to estimate fixed and operating costs for individual machines. Although the original AHA template utilizes a simplified cash flow approach, the template used in this analysis has been modified to compute a machine rate. Both HSA and HSS include options for calculating monthly equipment payments as well as machine rates. LCAP and PROLOG rely entirely on the machine rate approach, but utilize a slightly different formula for computing the "average value of yearly investment" (AVI). Instead of using years of economic life (N) as reported by Miyata (1980), AVI is computed using N in months. This results in a lower value for AVI which in turn reduces the annual estimates for interest, insurance and taxes.

All but one of the programs assume that fixed costs and operating costs are best estimated using straight-line depreciation or AVI (i.e. machine rates) rather than actual costs. Therefore, all equipment must be depreciable in order to be used by most of these programs. The original AHA template comes the closest to being a cash flow analysis. From a logging contractor's perspective, the inability to input actual equipment costs (when known) is a major disadvantage of using a program to analyze existing systems.

All five programs calculate system costs, but only AHA, HSA, and HSS can be used to evaluate system productivity based on information about the timber stand to be harvested. AHA and HSA are designed to accommodate information on stand characteristics (e.g. DBH, volume) and operating conditions (e.g. slope, brush, skid distance). AHA, HSA, and HSS use harvesting production equations for individual machine functions. HSS, however, is the most comprehensive program for research applications if detailed production information in terms of average productivity or distributions of production per worked hour is available. AHA, HSA, and HSS are essentially limited to deterministic, fixed event simulation of productivity, but HSS does have some stochastic elements.

Input Requirements

Data input for all five programs is a tedious and time-consuming requirement, particularly for analyzing large systems with many machines. Even though similarities exist, input requirements for the programs evaluated vary widely in the way in which data is accepted. In several cases, individual programs were not flexible enough to accept input data in different forms. A few examples include: PROLOG will only accept one interest rate which must be used for all machines; LCAP can not handle different work hours per day for different employees; AHA assumes all equipment operators within a function are paid at the same hourly rate. This does not imply that each program should accept data in all possible forms. However, programs which are more flexible in data input are much easier to use.

As indicated in Table 1, LCAP, PROLOG, AHA, and HSA have the ability to review and edit input data before program execution. These programs also have the capability of storing and retrieving data files on the program diskette. HSS only accepts a complete data file somewhat like batch processing, and any modification of the data file must use external editing software.

Table 1--Comparison of LCAP, PROLOG, AHA, HSA and HSS programs for harvesting system analysis.

Characteristics	LCAP	PROLOG	AHA	HSA	HSS
Ease of Use	Easy	Easy	Easy[a]	Moderately Easy	Difficult
Menu-Driven	Yes	Yes	Yes	Yes	No
Written Documentation	No	No	Yes[b]	Yes	Yes[b]
On-Screen Instructions/Help	Yes	No	No	Yes	No
Input Error Checking/Corrections	Yes	No	No	Yes	No
Input Verification/Editing	Yes	Yes	Yes	Yes	No[c]
Default Input Values	No	No	No	Yes	No
Controlled Program Termination	Yes	Yes	Yes	Yes	No
Controlled Reporting	Yes	Yes	Yes	Yes	No
Initial Cost	Free[d]	$100	Free[d]	Free[d]	$600

[a]Assumes user is familiar with spreadsheet software.
[b]Not in the form of a user's manual.
[c]Batch processing and external editing of data file.
[d]By sending blank diskette(s) to author(s).

Output Generated

All five programs evaluated have well organized and neatly formatted hardcopy output. As mentioned earlier, screen output for PROLOG contains some wrap-around problems, and user control of reporting for HSS, which is available in the mainframe version, is not currently available in the PC version. As a result, a lengthy set of reports (e.g. 120-140 pages) is generated for each simulation run. Given the slow speed of even the fastest reasonably priced dot matrix printer, this can be a severe handicap.

Productivity and cost output from HSA is in terms of 100 cubic feet (CCF) rather than other more commonly used units such as cords or MBF (1000 board feet). LCAP is designed to output cost information, and no provision is made for reporting productivity or costs on a per unit volume basis.

Comparison of Test Results

A set of cost and production data for a mechanized tree-length system was developed and used to compare each of the five harvesting programs. The general cost information (Table 2), labor wages and salaries (Table 3), and equipment costs (Table 4) are representative of a "typical" mechanized tree-length harvesting system operating in Southeastern U.S. The test data was used to compare the results of program calculations with realistic cost estimates for a "typical" mechanized tree-length system obtained from industry sources.

Harvest productivity for AHA, HSA, and HSS was generated using the same production data/equations. This data came from Lanford and Sirois (1983), Tufts (1986), and industry sources. Stand data for an "average" plantation of loblolly pine (Plummer 1977) was used to generate tract information.

Table 2--General assumptions and miscellaneous costs for the test data set.

Scheduled Hours per Day:	In-woods	9
	Truckers	12
Scheduled Days per Week:		5
Operating Weeks per Year:		45
Average Production (Cords per Week):		385

Support Equipment:	No.	Annual Cost ($/unit)
Pickup Truck	2	8550
Service Truck	1	6150
Chainsaw	4	1715
Gate Delimber	1	1000

Table 3--Labor cost assumptions for the test data set.

	No.	Wage/Salary	Fringes (%)[a]
Productive:			
Feller Buncher Operator	1	$7.50/hr.	36
Skidder Operator	2	7.00/hr.	36
Sawyer	1	5.50/hr.	36
Truckers	3	5.00/hr.	36
Support:			
Foreman/Loader Operator	1	$22,500/yr.	50

[a]Includes Social Security, federal/state unemployment insurance, Worker's Compensation and miscellaneous benefits.

Table 4--Equipment cost assumptions for the test data set.

		Owning						Operating[a]		
Equipment	No.	Delivered Price	Salvage[b] Value (%)	Life (yrs.)	Interest[c] (%)	Insur. &[c] Taxes (%)	Utiliz. (%)	Fuel & Lube	Maint. & Repair	Tires
Productive:										
Feller-Buncher	1	$ 98,500	30	3	12	5.3	65[d]	$1.83	$10.48	$0.51
Grapple Skidder	2	103,250	25	3	11	5.3	67[d]	3.81	12.37	1.11
KB Loader	1	74,400	30	5	11	5.3	65[d]	2.55	3.96	--
Haul Truck	3	63,000	30	4	12	19.6	90[e]	5.14	2.04	0.56
Trailer	3	10,400	30	8	10	5.3	90[e]	--	0.15	0.40

[a]Per productive machine hour (PMH).
[b]Percent (%) of delivered price.
[c]Percent (%) of average value of yearly investment (AVI).
[d]Based on 2025 scheduled machine hours (SMH) per year.
[e]Based on 2700 scheduled machine hours (SMH) per year.

The results obtained from running LCAP, PROLOG, AHA, HSA, and HSS using the test data set are shown in Table 5. Since each program required the data to be entered in a particular format, numerous conversions or recalculations of the base assumptions were made before execution. Even though the same data was used, the system analysis results on a scheduled machine hour basis varied widely (Table 5). The system cost per cord generated using LCAP and PROLOG are comparable, but somewhat lower than results from AHA, HSS, and HSA. Some of the variation can be attributed to different methods of calculating the machine rate AVI and assumptions used for handling productive vs. scheduled time and number of weeks per year. Since AHA, HSA, and HSS used similar production equations to determine productivity, some agreement in final results was expected. Weekly production for HSS was slightly lower than that computed by AHA and HSA because down and delay time was included in the simulation. No attempt was made to verify the accuracy or consistency of results for any other data set or conditions.

Table 5--Comparison of total system costs and weekly production for the test data set.

Program	Costs ($) per SMHr.[a]	Production Cords per Week	Costs ($) per Cord
LCAP	$272.14	--[b]	31.79
PROLOG	259.29	--[b]	30.79
AHA	237.80	383	32.21
HSA	341.61	385	39.95
HSS	250.49	350[c]	32.19

[a]Scheduled Machine Hour.
[b]Assumed weekly production average of 385 cords.
[c]HSS models down and delay times which results in lower weekly production.

Total system cost generated by each program was slightly higher, but very close to an industry average of $29.67 per cord. This average was obtained by contacting six different forest industries operating throughout the South. Their "estimate" of actual costs for the "typical" mechanized tree length system ranged from $26 to $33 per cord. As shown in Table 5, system cost per schedule machine hour and per cord was higher for HSA than for the other programs. A reason for this difference was not determined.

CONCLUSIONS

Since objectives and constraints of individual user's will vary, it is difficult and perhaps inappropriate to select a specific program as the "best." A program that produces an acceptable system analysis of harvesting costs and productivity for one user may not be appropriate for another user or system. The authors do not recommend specific programs, because the choice ultimately rests with the user and depends on his/her specific needs. The comparative information presented in this paper should help interested users evaluate and select an appropriate program based on program cost, flexibility, ease of use, and written documentation.

The five microcomputer-based programs described and evaluated here, LCAP, PROLOG, AHA, HSA, and HSS, represent currently available programs for analysis of harvesting operations. The evaluation did point out that these programs produced comparable results using realistic system data even though there seems to be some inconsistency in the way harvesting costs and productivity are computed. Any of the programs evaluated should help forest engineers, industrial managers, and logging contractors make better business decisions, reduce costs, and improve operating efficiency through more detailed analysis of harvesting operations.

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TREESIM: A new Analysis Tool for Harvest System Evaluation[1]

A. P. Dremann[2]

Abstract: Loggers today are being squeezed between a rock and a hard place...quotas and price sensitive markets on one side and expensive equipment operating in a non-controllable environment on the other side. To survive and prosper in today's situation loggers must become better managers of their systems. TREESIM analysis is a computer-based tool developed by Caterpillar Inc. that the logger can use to sharpen his system management decisions. The program was "field tested" by several forest products industry users. Minor changes were made based on this testing resulting in the final version of the TREESIM analysis. This paper describes the capabilities of the program, the types of systems that can be analyzed, and presents two examples of its use.

Keywords: simulation, bottleneck, spreadsheet, sensitivity, cost, productivity, forest

Caterpillar's Research Department has been active in many ways in the forest products area. For example, we've developed concepts and tested new vehicles and attachments, studied forest floor compaction, surveyed equipment users to determine their needs and problems and conducted long range industry studies. One current program is to concept and evaluate future harvesting systems. As a part of that program we wanted to be able to evaluate system changes and do sensitivity studies of system characteristics. This led to developing methods of simulating harvest systems on the computer. One of these was a spreadsheet program based on Lotus 1-2-3[3].

We soon realized that this program could be very useful to logging contractors to help them analyze their systems and make intelligent business decisions. The program was reworked to make it more user-friendly and to add financial analysis of equipment purchase; owning and operating costs, including tax implications. The results were "field tested" by several forest products industry users and the feedback was very positive. Minor changes were made based on this testing and the final version of the TREESIM program was ready.

The goal of the program is to help harvesting managers and contractors understand their systems and make informed business decisions. Harvest equipment data and financial data are coupled with stand data to predict system output and costs. Equipment can include combinations of feller-bunchers, skidders, forwarders, chippers, loaders, trucks and support machines such as pickup trucks and chain saws. Financial data includes price, down payment, trade in, interest rates, depreciation schedules, taxes and operating costs such as fuel, tires, repairs and labor. Stand data includes tract size, trees sizes, trees per acre or cruise data.

Output data covers many aspects of the system. These include system productivity, balance and bottlenecks, individual machine and total system hourly operating costs and costs per cord and financial information such as monthly payments, tax credits and savings and after tax owning costs.

The program allows very quick "what if" analysis of system changes and sensitivity studies to see how any one or two system variables affect other system performance or cost. The user will have a better basis for making good management decisions.

TREESIM: SYSTEM ANALYSIS TOOL

The TREESIM (short for TREE harvesting SIMulator) program is a tool for estimating costs of an entire forest harvesting system. This program, along with experience, common sense, and basic information on his logging system, is an addition to the logger's toolbox which he can use to improve the performance of his spread. Just as a wrench helps to tighten bolts, the TREESIM program helps the logging contractor understand his system and make informed business decisions. There are two areas of interest: the first is performance-related and the second is cost-related. Both are equally important.

CAPABILITIES

What can the TREESIM analysis do? It figures out (on a "steady-state" basis) things that a logger needs to know to pare his costs and improve the output of his spread. Performance-related results include estimates of weekly production, number of days to cut the tract, and hourly productivity. Cost-related results consist of before- or after-tax owning and operating costs for each machine and the entire spread on both an hourly and per cord basis. By looking at the results, a logger can quickly determine how well balanced his spread is. The bottlenecks show up as hourly productivities which are much lower than the rest of the system. The TREESIM program does not do stockpile calculations, or attempt to schedule downtimes, lunch breaks, or startups.

Knowing the problems is one thing. Knowing what to do to fix the problems is another. That's where the real power of the TREESIM program comes in. In a matter of a few minutes, a logger can determine the how sensitive the system balance or cost is to the various system characteristics. He can quickly answer questions like, "What is the critical skid distance where two skidders are cheaper than one?", or "What happens if I add that new machine that the XYZ Equipment Co. is trying to sell me?", or "What happens to my costs if my quota is reduced?", or "What will happen to my bottom line costs if fuel prices jump by 25 cents?". The results of a sensitivity analysis quickly tells a logger how sensitive the bottom line is to any input. This helps him

[1]Presented at the 9th Annual Council on Forest Engineering Meeting, Mobile, AL, September 29-October 2, 1986.

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[3]Lotus and 1-2-3 are registered trademarks of Lotus Development Corporation.

determine where his cost reduction efforts would do the most good, and where they won't have much impact.

FEATURES OF THE TREESIM PROGRAM

Easy to Use

One beauty of the TREESIM program is its ease of use. The typical logger may not have an extensive background in computers, and probably doesn't have the time to develop one. By taking advantage of the Lotus 1-2-3 software package, and designing the spreadsheet with the unfamiliar user in mind, we've developed a package can be used by almost anyone -- "computer smart" or not.

Menu-driven

Since the TREESIM program is menu-driven, the user never has to guess at commands or which keys to press next. The computer is always either asking for information or reporting back. Another feature of the program is that it is interactive. The guy at the keyboard is in control -- calculating what he wants to calculate or looking at just those results that are of interest.

Flexible

Each logger's spread differs from the next one: every one is unique. To handle a wide range of timber harvesting situations, the TREESIM program was designed to be flexible. Feller-bunchers, skidders, forwarders, chippers, loaders and trucks may be specified in a variety of combinations. One spread may have a feller-buncher, two skidders, a chipper and four vans. Another may have two different models of feller-bunchers, three models of skidders, a loader and five trucks for hauling tree-length roundwood. The smallest system the program considers legitimate would consist of one truck and one loader (or chipper). Although the TREESIM program may not handle every possible situation, almost all can be analyzed.

Inexpensive

Finally, a huge investment in computer power is not a requirement. Any personal computer which is IBM-compatible and has at least 300 kilo-bytes of memory will do the job.

REQUIRED INPUT DATA

The TREESIM program requires information from four different areas to perform its calculations. Armed with this information, the TREESIM analysis determines the performance and cost of the combination of men and machines required to move wood from the forest to the mill.

Productivity Data

Several machines may be used to transport the wood: feller-bunchers, skidders, forwarders, loaders, chippers and trucks. Productivity data is in terms of time to process (or haul) a tree, or speeds and distances. The TREESIM program automatically selects processing time or calculates the time if speeds and distances are input.

Cost Data

Cost data include all owning and operating costs -- everything from down payments and interest rates to tire life and lubrication costs.

Stand Data

A typical stand and stock table derived from a cruise of the woods makes up the stand data. No pre-calculations are required. If a logger doesn't have cruise data, he can use an estimate of average tree size and trees per acre instead.

Overhead Data

Finally, no business is run without overhead, so overhead and support costs and equipment are also included. Some of the items which fall under this category include: pickups, foreman's salary, road building, and miscellaneous equipment like saws, slashers, etc. A quota may even be specified.

OUTPUTS AND EXAMPLES

Tables and Graphs

Most TREESIM results are displayed in tables and appear on the screen by selecting the appropriate menu item. For most comparisons, tables of numbers work well. But, there are times when "a picture is worth a thousand words". So, the TREESIM program reports results of sensitivity analyses in both graphical and tabular form. After telling the computer the variables of interest, it automatically does all the calculations and displays the results in a table, complete with a title. Three more key strokes display a graph of the results on the screen.

Financial Results

The bottom line for any system is the cost per cord of wood produced. Two sets of results go into calculating cost per cord: hourly costs and hourly production. According to the TREESIM analysis, the hourly production for the system is limited by the least productive set of machines. If skidders can't keep up with the feller-bunchers or loaders, they are limiting the system's hourly production.

The other side of the equation -- hourly costs -- include all owning and operating costs. This gives a logger a true picture of his costs. For example, even though he doesn't have to replace tires on the skidders every month, they are still costing him money every month. Similarly, owning costs include all costs: the obvious ones like monthly payments for principal and interest, and the hidden ones like insurance, taxes and depreciation. In addition, the financial calculations include the effects of tax savings, such as interest deductions and investment credits. One of the results screens contains results of the owning and operating cost calculations. For each machine, monthly payments, System Balance and After-tax Cost Summary

Function:	Fell	Forward	Skid	Load	Chip	Haul	System
Productivity:							
Cords/PMH	16.3	0.0	11.7	15.8	0.0	14.2	
Max Availabil.	84%	0%	83%	87%	0%	120%	
Cords/SMH	13.7	0.0	9.7	13.8	0.0	17.0	9.7
Net Utilizaton	60%	0%	83%	61%	0%	69%	
Costs/SMH:							
Owning	$7.14	$0.00	$6.95	$8.60	$0.00	$8.43	
Operating	$9.05	$0.00	$10.77	$6.81	$0.00	$50.15	
Labor	$12.50	$0.00	$12.50	$15.00	$0.00	$38.07	
Total	$28.69	$0.00	$30.21	$30.41	$0.00	$96.65	$185.96
Cost/Cord:	$2.95	$0.00	$3.11	$3.13	$0.00	$9.95	$19.14

Support:
Pickups, Foreman, Overhead, Laborer, Miscellaneous $4.83
Road Work $0.29
Moving 18 hours spent moving men & equipment to tract . . $0.71
Total: System Cost/Cord $24.97
Weekly production 437 cords.
Time to cut tract 32 days.

Figure 1--The System Balance and Cost Summary screen contains all the information necessary to evaluate the performance of the system. This photograph displays the data which appears on the screen.

true monthly owning costs (both before- and after-tax), and hourly operating costs are reported.

Other screens detail the supporting financial calculations, and allow a closer look at the items which contribute to the total hourly costs.

System Results Screen

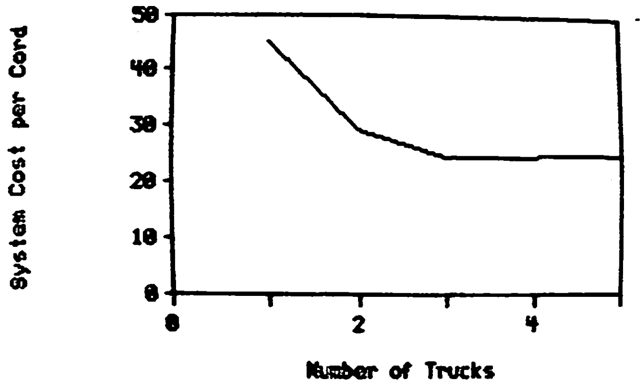
Although several screens contain results, the system results screen (fig. 1) is the most interesting one. It contains all the items listed in the CAPABILITIES paragraph, above. In the example in figure 1, the spread consists of a feller-buncher, a skidder, a loader, and 5 trucks. Since no other machines were specified, results for them are zeroes. Notice the system balance. Productivity (Cords/SMH) for the trucks is much higher than other functions. A sensitivity analysis to determine an appropriate number of trucks for this system would be worthwhile. (Note also that the skidder is the current bottleneck, limiting system production. We need to look at that, too. Another skidder could increase our system output from 9.7 to 13.7 cords/hour. Is it worth it?)

Number of Trucks

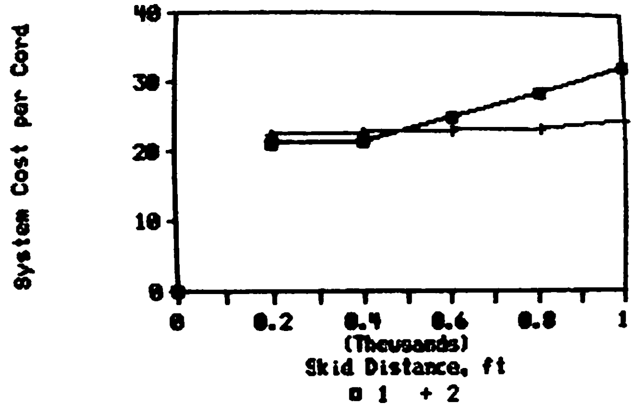
A sensitivity analysis for the spread in figure 1 resulted in the graph shown in figure 2A. The effects of number of trucks on the system cost per cord can easily be seen. Note that the System Cost decreases until three trucks are part of the system. For more than three trucks, System Cost increases with each additional truck (since trucks are no longer the bottleneck). But, it does not rise very fast, so we wouldn't mind being over-trucked in this situation, especially if we know we'll need the extra trucks next month on that job with the long haul distance to the mill. Better keep them.

Number of Skidders vs Skid Distance

In the next example, the number of trucks is more in line with the rest of the system. But what would happen if a creek crossing washed out and the skidder had to detour via a longer skid trail? Should we stick with one skidder, or would two be better? (Another alternative we could easily



A



B

Figure 2--Graphs of data calculated in sensitivity studies make it easy to evaluate of changes in the system. These graphs (photographs of the computer screen) are examples of the results of sensitivity analyses in one and two independent variables. In figure 2A we see, for one specific system and stand, the effect of the number of trucks on the system's cost per cord. In figure 2B we see, for the same system and stand, the relationship between skid distance, number of skidders and system cost. At skid distances greater than 500 feet, two skidders are more economical. Below 500 feet, one skidder gives the lowest system cost per cord.

examine is rebuilding the crossing.) The graph in figure 2B shows that if the skid distance is less than about 500 feet, one skidder would be better -- greater than 500 feet, two skidders are more economical.

These are only two examples of the kinds of things the TREESIM program can do. Other comparisons are limited only by the imagination.

SUMMARY

Mechanics have tools to take machines apart and re-assemble them. Loggers and harvest system managers also need tools to take their systems apart, examine them and then change them as needed to get the lowest production cost. We have taken a brief look at one tool: the TREESIM program, which helps harvesting managers and contractors understand their harvesting systems and make informed business decisions. We have also discussed the kinds of things the TREESIM program can do, its flexibility and ease of use. Finally, we have seen how the TREESIM program can put the logger in control, not only of the program, but also of his harvesting system.

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PRELIMINARY EVALUATION OF THE EFFECT OF VERTICAL ANGLE OF PULL ON STUMP UPROOTING FAILURE [1]

Penn A. Peters and Cleveland J. Biller [2]

Abstract: Stumps are commonly used as guyline anchors for construction, oil drilling, and cable yarding equipment. In these applications, stumps are often loaded at a steep angle relative to the ground. Stump failure loads as reported in the literature are restricted to stumps loaded parallel to the ground. To investigate the effect of vertical angle on stump failure loads, 10 pairs of matched stumps on level terrain were loaded until failure occurred by uprooting; one stump of the pair was subjected to a parallel pull and the other stump was subjected to a 45-degree pull. The mean value of the 45-degree-pull failure loads was 7 percent less than the mean value of the parallel-pull failure loads. However, a paired t-test of the hypothesis that 45-degree-pull failure loads are greater than or equal to parallel-pull failure loads could not be rejected at the $\alpha = 0.05$ level. Maximum stump d.b.h. pulled was 7.7 inches.

Keywords: Forest Engineering, timber harvesting, anchors, cable yarding

Stumps are commonly used as guyline anchors for construction, oil drilling, and cable yarding equipment. Failure of the stump anchor in these applications can result in property damage and disabling injuries or fatalities. Occasionally, stumps fail by splitting or by shearing, but uprooting is the most common reason for failure. Several investigators have measured the loads required to uproot stumps (Liley, 1985; Stoupa, 1984; Golob et al., 1976). They found that failure loads were approximately proportional to the square of the diameter at breast height or stump height. A desired application of the information obtained thus far is to predict the adequacy of a stump as a guyline anchor. Unfortunately, in practical application, stump anchors are often loaded at a large angle relative to the ground, and all testing so far has been on stumps loaded parallel to the ground. If large-angle-pull failure loads are greater than or equal to parallel-pull failure loads, parallel-pull data can be used as conservative estimates of the holding strength of stump anchors. The purpose of this paper was to test this hypothesis.

The Experimental Method

A 2-acre site on the Fernow Experimental Forest near Parsons, WV, was selected for a test site because: (1) it was scheduled to be clearcut in the near future; (2) the ground was approximately level; (3) equipment required to conduct the test was nearby; and (4) sufficient pairs of healthy trees (same species and d.b.h.) were available to conduct the desired tests. The approximate number of pairs of trees required was determined from data presented by Stoupa (1984). Tree species selected for test included sugar maple (*Acer saccharum*), red maple (*A. rubrum*), and yellow-poplar (*Liriodendron tulipfera*). Other tree species in the stand included northern red oak (*Quercus rubra*), and black cherry (*Prunus serotina*).

Pairs of trees were selected that were the same species and had the same d.b.h. One tree was labeled A and the other B. Each tree was mapped to show ground slope, aspect, shape of the crown, and its spatial relationship to surrounding trees. The position of the tree in the canopy was classified as dominant, codominant, or suppressed. Most of the trees tested were suppressed; several were codominant; none was dominant. Other characteristics recorded were: total height, height to a 4-inch top, d.b.h., stump diameter (measured at 1 foot above ground). After the tree was felled, a 3/4-inch wire-rope strap was attached to the notched stump, which was attached to a 50,000-pound Dillon Dynamometer.[3] The other end of the dynamometer was attached to a D4 Caterpillar tractor cable winch, which applied the load (Figs. 1-2).

For a parallel pull, the cable pull was applied directly from the winch. Approximately 5,000 pounds of pull was applied to take the slack out of the system. The vertical angle of pull was measured by laying a clinometer on the wire rope (reading measurement error of 1 degree); the azimuth of pull and the ground slope in the direction of pull also were measured. Pull was applied continuously until the stump failed by uprooting. The pull, as indicated by the Dillon gauge, was monitored visually and the maximum pull associated with stump failure was indicated on the Dillon by a maximum-force pointer. Force measurement uncertainty was ± 250 pounds. The experimental procedure was similar when 45-degree pulls (relative to horizontal) were applied except that the cable pull was applied from the winch through the tractor sulky arch. The slack was taken out of the system and the vertical angle of pull was measured as before. If the vertical angle was not 45 degrees, the tractor arch was moved fore or aft until a 45-degree pull was obtained (tolerance of ±1 degree).

Loads were applied to the stump until the stump was uprooted or the pull capacity of the test equipment was exceeded. After the stump was uprooted, the stump and root wad were pulled out of the hole. Profiles of the stump hole geometry in the direction of pull and perpendicular to the direction of pull were measured and a soil sample was taken. Testing was conducted on September 9-11, 1985.

Discussion

Fifteen pairs of stumps were tested (Table 1); of these, five pairs were excluded from a paired-t-test analysis. Broken roots from adjacent trees occasionally were observed in the stump hole.

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[1] Presented at the 9th Annual Council on Forest Engineering Meeting, Mobile, AL, September 29-October 2, 1985.

[2] Project Leader, Engineering Research, Northeastern Forest Experiment Station, Morgantown, WV; Mechanical Engineer, Engineering Research, Northeastern Fore Experiment Station, Morgantown, WV.

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

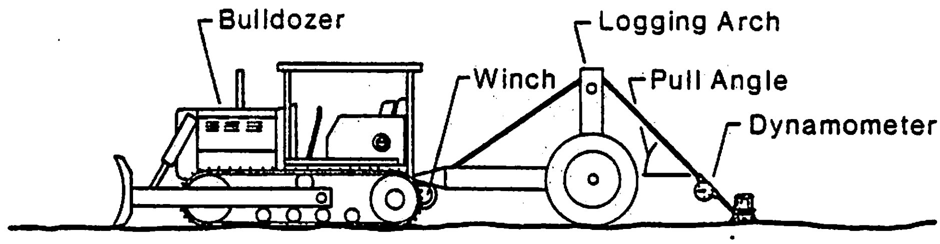

FIGURE 1. EQUIPMENT SET-UP FOR STUMP PULLING TESTS USING LOGGING ARCH.

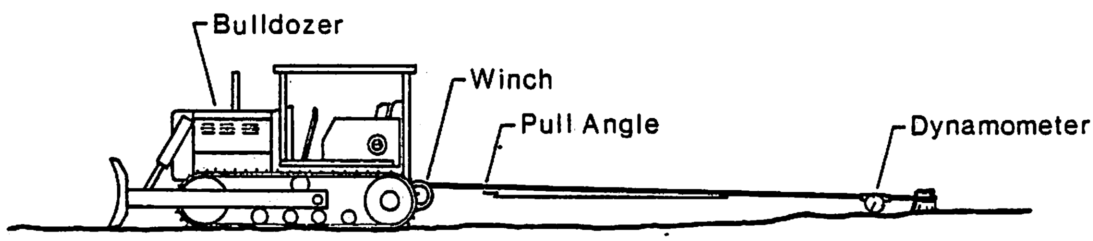

FIGURE 2. EQUIPMENT SET-UP FOR STUMP PULLING TESTS NOT USING LOGGING ARCH.

Table 1.--Failure pulls of stump anachors by uprooting as a function of species, d.b.h., and angle of pull.

Tree	Failure pull	Species	D.b.h.	Angle of pull
	pounds		inches	
1A	19,000	SM	5.9	Parallel
1B	13,900	SM	5.8	45°
2A	13,700	SM	4.1	Parallel
2B	13,600	SM	4.4	45°
3A	11,000	SM	4.6	45°
3B	9,600	SM	4.5	Parallel
4A	8,700	SM	4.6	Parallel
4B	11,000	SM	4.5	45°
5A	14,600	SM	5.1	45°
5B	20,000	SM	5.0	Parallel
6A	13,000	RM	6.1	Parallel
6B	17,000	SM	6.1	45°
7A	12,000	SM	4.8	Parallel
7B	7,800	SM	4.9	45°
8A	11,700	RM	7.7	45°
8B	26,000	RM	7.6	Parallel
9A	13,000	SM	6.4	45°
9B	1/	SM	6.6	Parallel
10A	22,000	SM	7.7	45°
10B	1/	SM	7.5	Parallel
11A	12,300	YP	6.2	45°
11B	10,700	YP	6.2	Parallel
12A	20,000	SM	5.6	Parallel
12B	16,000	SM	5.6	45°
13A	19,200	SM	5.5	45°
13B	16,200	SM	5.1	Parallel
14A	14,500	RM	6.6	Parallel
14B	22,000	SM	6.7	45°
15A	15,000	YP	6.4	45°
15B	15,000	YP	6.5	Parallel

1/ Could not pull with available equipment
SM = sugar maple: RM = red maple: YP = yellow-poplar.

Table 2.--Failure pulls of selected pairs of stump anchors by uprooting.

Pair	45-degree pull	Parallel pull	Difference
	pounds		
1	13,900	19,000	-5,100
2	13,600	13,700	- 100
3	11,000	9,600	1,400
4	11,000	8,700	2,300
5	14,600	20,000	-5,400
7	7,800	12,000	-4,200
11	12,300	10,700	1,600
12	16,000	20,000	-4,000
13	19,200	16,200	3,000
15	15,000	15,000	0
Total	134,400	144,900	-10,500
Average	13,440	14,490	-1,050

$\Sigma d_i = -10,500$; $\Sigma d_i^2 = 107,630,000$; $\bar{d} = -1,050$; $s_d^2 = 10,733,889$

This seemed to occur when the ratio of adjacent tree d.b.h. to distance from the adjacent tree to the test stump was greater than 0.1. Pairs 9 and 10 were excluded because Stumps 9B and 10B could not be pulled with the equipment available. Root interference from an adjacent tree increased the resistance of Stump 10B so that it could not be pulled, adjacent tree d.b.h. divided by the distance from the adjacent tree to stump 10B equaled 0.3. Pair 8 was excluded because 8B was an obvious outlier; 8B also was the only tree located extremely close to a graveled logging road, and had had the top knocked out of it by a felled tree during logging a few days prior to testing. Pairs 6 and 14 also were excluded because the trees in the pair were not the same species (human error).

A paired t-test of the 10 remaining pairs (Table 2) was used to test the hypothesis that failure pulls applied at 45 degrees were greater than or equal to failure pulls applied parallel to the ground. This hypothesis was tested:

$$H_o: \ F_{45°} \geq F_p$$
$$H_A: \ F_{45°} < F_p$$

where $F_{45°}$ = failure load of 45° pull, pounds
F_p = failure load of parallel pull, pounds

The probability of rejecting the null hypothesis was selected as 5%; $\alpha = 0.05$. The t statistic is given by $t = \bar{d}/s/\sqrt{N} = -1050 / \sqrt{10,733,889}/\sqrt{10} = -1.013$. The t statistic has 9 degrees of freedom. Therefore, reject the null hypothesis if $t < -1.833$. Since $t = -1.013$, the null hypothesis was accepted. It is more appropriate to state that the null hypothesis cannot be rejected because of the variability obtained. The mean value of the failure loads of 45-degree pulls was 1,050 pounds, or 7 percent less than the failure loads of parallel pulls.

Conclusions

Stump failure loads caused by a large vertical angle pull have not been reported even though this is a common configuration in practical applications. Large vertical angles (45°) were conveniently applied in this study using a tractor sulky arch. However, maximum applied load was approximately 26,000 pounds, which resulted in a maximum stump that could be pulled of 7.7 inches d.b.h.

The hypothesis that failure loads of 45-degree-angle pulls were greater than or equal to failure loads of parallel pulls could not be rejected using a paired t-test. If the relationship between vertical-angle-pull and parallel-pull failure loads can be determined, it would allow the large existing parallel-pull data base to be used to develop criteria for selecting stump anchors. Additional tests are recommended because of limitations in the present study imposed by the limited power of the statistical test and the maximum applied load.

These improvements in study design should be considered in future tests:

(1) maximum applied loads greater than 26,000 pounds, the higher the better,

(2) test stumps should be selected from dominant and codominant trees, and

(3) test stumps should be selected so that for every adjacent tree, the ratio of adjacent tree d.b.h. to distance from adjacent tree to test stump is less than 0.1. This would minimize confounding effects of root interference.

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A Monocable System for Handling Small Trees on Steep, Difficult Sites[1]

Edwin S. Miyata, D. Edward Aulerich, Gary C. Bergstrom[2]

Abstract: We field tested the endless-loop, monocable zig-zag logging system used to harvest small, low-value trees and logging residue from adverse sites. The initial cost was less than $10,000. Length of the monocable was 3,000 feet. It transported logs over a small creek and a rolling area of blind lead. The results of field experiments, the capabilities, and the possible applications for forestry management are discussed.

Keywords: zig-zag, endless cable, residue, logging, yarding

Of the 40 million acres of commercial forest land in the Pacific Northwest, about 70 percent in western Oregon and western Washington contains second-growth timber stands. Thinning is currently required on 25 percent of these lands (MacLean 1980), and acreage to be thinned in the future is projected to equal the acreage cut in old-growth timber (Binkley 1980).

Besides the small, low-value trees to be thinned, some 14 million tons of forest residues, such as dead or dying trees, tops, and limbs, accumulate each year (Grantham 1974). If these vast quantities of small, low value trees can be recovered and used through thinning and residue-recovery operations, the following benefits could be expected (Erickson 1976, Oliver 1986):

- Additional fiber supplies to meet the anticipated increasing demand.
- Reduction of fire, insect, and other environmental problems.
- Improvement of timber-stand quality through thinning operations.
- Reduction in dependence on petroleum imports. Smith and Tillman (1986) reported that the residential wood-fuel market is valued at about $4 billion per year, nearly equal to the value of all plywood produced in the United States. Grantham and Howard (1980) reported that the energy potential of logging residues produced annually in the United States is roughly equivalent to 100 million barrels of oil.
- Improvement of aesthetics and future management capability for regeneration, soil and water quality, fish and wildlife, and air quality.

One of the factors limiting the harvest of small, low-value trees and forest residues is the lack of economically efficient and environmentally acceptable equipment and systems to transport the material to landings in adverse sites. Steep slopes, fragile soils, limited road systems, and low-value scattered stands are characteristics often present on adverse sites.

Recently, various yarders for transporting small trees on steep slopes have been studied and the results reported by researchers in the United States (LeDoux 1985, Cubbage and others 1984, Fisher and others 1980).

With an 18 horsepower engine and 1/4-inch cable, the Bitterroot is the smallest among various yarders. The productivity of the Bitterroot was about 130 cubic feet per hour (Cubbage and others 1984). When cable yarding hardwoods with average slope yarding distance of 400 feet or shorter, it would be the best selection for stands with trees having an average diameter (DBH) of 7 to 9 inches in terms of productivity and production cost (LeDoux 1985).

Use of the Bitterroot yarder is limited, however, to uphill yarding and a maximum yarding span of 800 feet. This yarding system also needs a minimum degree of slope (>20 percent) for the carriage to return to the clamping location by gravity. It is highly sensitive to deflection because of its small lines and low horsepower. In the Pacific Northwest, typical yarding distances range from 500 to 2,500 feet. The ideal yarding system for this area should have the following characteristics:

- Low initial cost.
- Low hourly machine rate.
- Productivity equal to or better than the small yarders already available in the United States.
- Up to 2,000-2,500 feet of yarding capacity.
- Not limited by deflection.
- Capable of uphill and downhill yarding.
- Capacity to transport small trees (up to 12 inches DBH) from precommercial and commercial thinning operations and logging residues.

Do any yarding systems have the characteristics of the ideal yarding system? A small cable system widely used in Japan, called the monocable, zig-zag system, appears to fill the needs in the Pacific Northwest. The monocable, zig-zag system has an endless cable (1/4- to 9/16-inch diameter) that runs through a series of open-sided blocks. These blocks hang from support trees by tree-protecting straps. The trees are selected to support both the cable and logs over critical areas such as slope breaks, fragile soil, and streams. The endless cable is driven by a capstan winch, and the loads or logs are attached to the moving monocable by tying or hooking chokers; consequently, the logs 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 choker is cut with a knife or an automatic cutter,

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if nylon rope or baling twine is used, or is unhooked, if a cable or wire is used. The logs are dropped to the ground to be piled by hand or are dropped directly into the truck-bed. This system is similar to an endless conveyer belt. The length of the endless cable sometimes reaches over 5,000 feet. Before 1985 no one had experience with this system in the United States.

Because of a common interest in this cable system, the Pacific Northwest Research Station, Forest Engineering Systems, and the Pacific Northwest Region of the USDA Forest Service, Forest Engineering Incorporated (Corvallis, OR), and the University of Washington are cooperating on the monocable system for possible applications in the Pacific Northwest and other parts of the United States. This paper discusses the results of field experiments with the monocable, zig-zag system, its capabilities, and applications for forest-management problems.

FIELD TEST

In the summer of 1985, a monocable, zig-zag system was field tested to establish its capabilities and to identify possible applications for the system, in particular for yarding small, low-value trees and forest residues in the Pacific Northwest. The main purpose of this limited trial was to learn how to set up and operate the zig-zag system. A small, single drum winch was converted to a monocable system by fabricating a capstan collar and attaching it to the winch. Test runs were performed and the results were reported by Aulerich (1985). Because of its capability, the modified winch has been used continuously in subsequent studies.

Site Description

The study site was about 50 miles northeast of Medford, OR in the Bessy Creek area, Prospect Ranger District, Rogue River National Forest.

Thirty years ago the site was clearcut and replanted with ponderosa pine (Pinus ponderosa Dougl. ex Laws.), which was not indigenous to the area. A conversion cut was made to establish a fir stand in 1982, and the trees were machine piled. Fifty trees per acre of the original 350 trees per acre were left standing. Tree size was 6-12 inches DBH and up to 50 feet tall. An understory stand of naturally regenerated Douglas-fir (Pseudotsuga menziesiu (Mirb.) Franco) seedlings, 2-14 inches tall, was also present. The slope ranged from 0-20 percent, averaging 15 percent. The soil was a light to medium clay.

The piled trees were limbed, bucked, and pulled free before the logs could be transported to the landing. The average diameter, length, and weight of a log piece were 6 inches, 9 feet, and 56 pounds, respectively.

Layout Procedure and System Operation

Following the information and procedures put forth in publications (Kanazawa 1980, Moroto and Fujiwara 1979, Nakamura 1973), the monocable, zig-zag system was rigged up on 1.4 acres in the study site. The procedure was: (1) select support trees, (2) wrap the straps around the trees and hang the zig-zag blocks, (3) route the cable through all the blocks in the layout, (4) wrap the monocable around the capstan drive, (5) connect the two ends together to form an endless loop, (6) tension the line, (7) clear away any material in the pathway of the monocable, and (8) start the winch and go.

Figure 1 shows the layout of the system. The endless cable was 3,000 feet long. The maximum external yarding distance in a straight line was 1,100 feet. Starting from the winch, the cable passed 650 feet through a nearly flat, old-growth area with a stream crossing. No material was removed from this area. The cable then traversed downhill into the treated area. We experienced no problems in transporting logs to the landing past this blind-lead or over the stream. The layout demonstrated several capabilities: long reach, no deflection problems, uphill and downhill yarding, and logging through sensitive areas and over streams. The tensioning system was near the winch. Regular snatch blocks were used to make an extra loop for tensioning the monocable.

The average span between support trees was 69 feet. The average height above the ground of each block was 6 feet. The average tree strap length between the support tree and the zig-zag block was 3.7 feet. The typical inside angle of the monocable at each block was 125 degrees; we attempted to stay within a range of 90-140 degrees.

The speed of the monocable was 100 feet per minute (about a walking pace). The monocable was tensioned and held with a come-a-long. Initially, the cable was tensioned to about 700 pounds, or about 10 times the expected log weight. Later, tension was increased to 1,000 pounds to accommodate a wider range of log weights. A Dillon tensiometer[3] was used to monitor the cable tension.

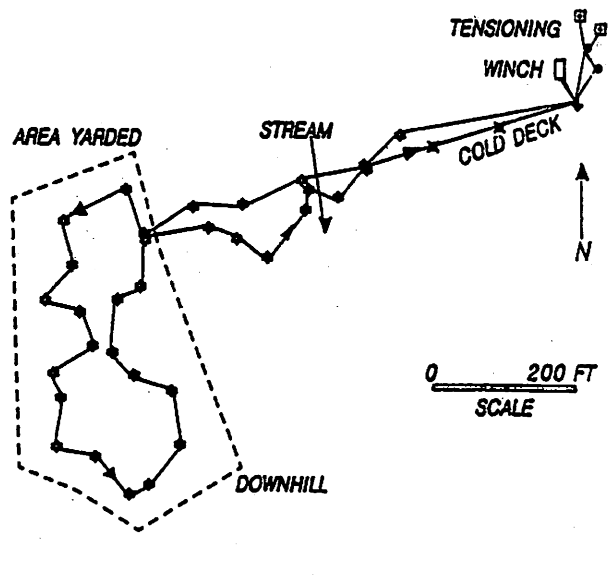

Figure 1--Zig-zag layout.

[3]Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.

Figure 2 shows the two loading methods we used: one-end suspension and two-end suspension. It also shows the snatch block that we call a "sucker-down block," which was used to draw the monocable down to a convenient loading height. The sucker-down block also provides a greater margin of safety for the hookers.

For removing the logs from the monocable at the landing, a Sandvik brush cutter blade was welded to a snatch block. For logs with both ends suspended, the rear choker was first cut by hand with a knife, then the front choker was cut by the cutter block.

The equipment used and initial costs were:

Item	Cost
3,000 ft of 3/8-inch cable	$1,200
600 ft of 3/8-inch guyline	240
Louis Zurfluh winch	5,000
33 Iwafuji zig-zag blocks, ZB-9	1,733
1 Iwafuji gear block, ZB-A-12	150
6 snatch blocks	390
20 polyester tree straps	1,000
7,200 ft of baling twine	20
Total	$9,733

RESULTS AND DISCUSSION

Two limited-time studies yielded some baseline productivity information:

1. Two inexperienced persons processed 48 pieces or 77 cubic feet per hour without delays: one person limbed, freed the logs from the nested machine piles, and moved the logs an average of 15 feet toward the monocable, and another person moved the logs an average of 10 feet and attached the logs directly to the monocable.

2. Two persons processed 120 pieces or 192 cubic feet per hour without delays; both persons attached the logs. Little handling was needed because the logs had been piled near the monocable.

A one-end suspension method and an automatic cutting block were used in both studies. One person stacked incoming logs at the landing so that the area under the cutting block remained clear for the next logs. Productivity was reasonable compared with that reported by Nakamura (1973). The daily productivity he reported was 350-530 cubic feet with two inexperienced workers and 990-1,130 cubic feet with two experienced workers. No information is available on whether delays were included or not. If delays were included to calculate productivity in his report, then productivity without delays should be higher than the given figures.

The productivity of the monocable, zig-zag system is affected by the speed of the monocable, the time needed to attach logs, size of logs, and the experience of the crew. Because there is no outhaul phase as with conventional yarders, high-cable speed does not correspond to high production. If the cable speed is too fast, then the log hooker takes more time to attach the logs. If the cable speed is too slow, then the log hooker is delayed in attaching the next log. We believe the speed of 100 feet per minute was too fast because it caused a slight delay in the hooking or attaching operations. A speed of 50-75 feet per minute appears to be more appropriate for attaching the logs.

The size or weight of logs did not cause any problems because the baling twine was doubled or tripled for heavier logs. Excessively large logs were bucked into logs of manageable size and weight. Various techniques and mechanical devices have been developed to shorten the attaching or deattaching time of larger and heavier logs (Etsuchu 1980, Kanazawa 1980, Nakamura 1973, Yamasaki and Tanaka 1978). If these are applied, larger and heavier logs can be transported in a shorter time than those reported in this paper.

Although the time was not measured, we believe one 8-hour day with three workers should be enough for rigging the monocable system. Although one day seems a long time for rigging (many small yarders typically available in the United States take 1 to 2 hours), advantages of the monocable system compensate for this shortcoming:

1. The longer yarding distance of the monocable system reduces the high cost of roadbuilding ($20,000 to $100,000 per mile) and the number of moves and the moving time of the yarder system (fig. 3).

2. The productivity is not affected by the yarding distance because of the endless-cable system, whereas the productivity of the conventional yarder is reduced with longer yarding distance.

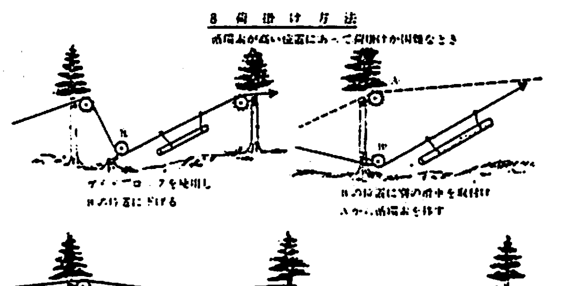

Figure 2--Loading configurations. Source: Illustrated Cable Logging Systems, by the Forestry Mechanization Society. No. 65. Page 33.

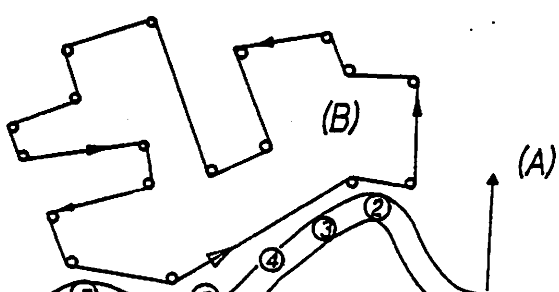

Figure 3--Comparison of endless-loop and conventional yarding systems.

Figure 3 illustrates conventional and endless-loop yarding systems. Part A shows the conventional small yarder with yarding distances ranging from 400 to 800 feet (uphill). This system has a single landing (1) and needs to move to the next location after the landing becomes full of logs. Part B shows the monocable. It is 3,000 feet or more long, with 2, 3, 4, 5, 6, or 7 landings. After landing (2) is full of logs, landing (3) is used without changing or moving the monocable system, and so on. The landings are undeveloped piling zones of small size requiring almost no construction. This system has more flexibility for various terrains and stand conditions, and it is easy to learn and operate.

Production cost is not presented in this paper; however, hourly machine rate and the attachment cost (dollar per cubic foot) are calculated in the appendix for interested readers. As a result of this study, a new study to determine production costs and develop efficient rigging methods began in the summer of 1986. It is on a thinning site with slopes up to 65 percent that is owned by Weyerhaeuser Company, Tacoma, WA. About 20 cords of wood have already been yarded with the monocable system. Results will be analyzed and published soon.

CONCLUSIONS

This study demonstrated the potential of the monocable, zig-zag system to transport small, low-value materials. The test was, however, of limited scope and duration. Much more experience with the system is needed to determine basic engineering information on allowable tensions in cables, block, loadings, and winch; requirements; operational characteristics; and safety considerations under U.S. conditions before we can fully use the system. Our information establishes a baseline, though, that can be used for comparing future studies and testing new concepts.

The monocable, zig-zag system appears to have the potential to perform well in forest operations in the United States. We have included a partial list of other possible forestry applications:

1. Individual tree selection (selective logging) for specialty products such as shake bolts, Christmas trees, boughs, firewood, high grade-clearbolts, burls, yew wood, nursery stock, and cones.

2. Building trails and servicing fires or helispots away from access roads or on closed roads.

3. Tree planting, seeding, and fertilizing along closed roads or at remote slides and sites.

4. Fish habitat improvement (moving logs and equipment).

5. Swing yarding.

6. Roadbuilding and moving culverts.

7. Use with other systems such as conventional small yarders, feller-bunchers, skidders, small sled winches, and helicopters.

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APPENDIX

1. Machine Rate - A Winch (6-10 hp)

A.	Initial investment (P)	$5,000
B.	Salvage value (S) (20% of P)	$1,000
C.	Estimated life (N) 5 years	
D.	Operating hours per year (H) 900 hours/year	
E.	Average value of yearly investment (AVI)	$3,400
	AVI = [(P-S)(N-1)]/2N + S	
F.	Depreciation (P-S)/N	$ 800
G.	Interest(12%) + insurance(3%) + taxes(3%) = 18% of AVI	$ 612
	FIXED COST PER YEAR	$1,412/yr
	FIXED COST PER HOUR	$ 1.57/H
H.	Maintenance and repair 90% x (P-S)/(NxH)	$ 0.90/H
I.	Fuel (0.5 gallon per hour x $0.80/gallon)	$ 0.40/H
J.	Oil and lubricants (15% of fuel cost)	$ 0.06/H
	OPERATING COST PER HOUR	$ 1.36/H
	HOURLY MACHINE RATE = FIXED COST + OPERATING COST =	$ 2.93/H

2. Attachment Cost

A.	Cable	3,000 ft x $ 0.40/ft x (0.0111)/100[4]	$ 0.13
B.	Guyline	600 ft x $ 0.40/ft x (0.0111)/100[4]	$ 0.03
C.	Blocks	$2,273 x (0.0083)/100[4]	$ 0.19
D.	Rope	$1,000 x (0.0083)/100[4]	$ 0.08
		TOTAL ATTACHMENT COST PER CUBIC METER =	$ 0.43
		TOTAL ATTACHMENT COST PER CUBIC FOOT =	$ 0.012

[4] Coefficient of operating loss per cubic meter (Umeda and others 1982).

A New Computer Model For Running Skyline Analysis 1/

James E. Crane and Frank W. Ferguson 2/

Abstract: For the past 20 years, the basic method used to compute skyline analysis for running skyline systems involved the solution of point load potential at each terrain point based on tower height, profile geometry, cable sizes, cable weight and an assumed maximum tension (i.e. SWL). Inherently, the method assumes that all yarders are capable of achieving the assumed tensions at all points along the profile. A new computer model incorporating Torque-Tension-Wrap concepts and the mechanical capabilities of running skyline yarders has been developed and used on the Plumas National Forest, Region 5, Forest Service. In comparative analysis, the new computer model has shown that the previous analysis routines significantly over estimate payloads by large margins in some, but not all, situations.

Keywords: Torque-Tension-Wrap, point load potential, skyline analysis, safe working load

Since the introduction of the chain and board model (Lyson and Mann, 1967) for predicting skyline payloads, little has changed regarding the basic assumption that safe working tensions are obtainable in all of the working lines. Some early computer models (eg, Carson and Studier, 1973) provided higher precision and the consideration of log drag (eg, Carson, 1975) increased the predicted loads. With all these changes, the "safe working load" assumption remained as the basis for predicting payloads. (Darling and Ferguson, 1985), showed that, for one running skyline yarder, the SWL assumption was not always true. They considered the torque limits at the maindrum clutch and haulback brake during inhaul, and the change in the effective radii of drums as lines were spooled on or off. This work lead to a more detailed study which modeled the tensioning capacities of fifteen running skyline yarders (Hartsough and others, 1985). The study concluded that, in many situations, the mechanical limitations of running skyline yarders is often the limiting factor in the determination of the potential point load and not the assumed safe working tensions. This paper describes a new computer model written incorporating these new findings.

Computer Model

Current computer models available for analysis of running skyline yarders consider only profile geometry, tower height, carriage weight, line sizes and weight in predicting payloads. The new model incorporates these same physical dimensions but includes Torque-Tension-Wrap (TTW) relationships and specific yarder characteristics. The specific yarder characteristics included in the program are shown in Table 1.

Table 1--Yarder Input Data File

R$ - Yarder Configuration
L1 - Haulback Weight, lb/ft
L3 - Mainline + Slackpuller Weight, lb/ft
C - Carriage Weight, lb
Z1 - Tower Height
Y$ - Yarder Name
C$ - Carriage Name
L$ - Haulback Diameter, in
M$ - Mainline Diameter, in
P1$ - Slackpuller Diameter, in
D1 - Main Drum Width, in
D2 - Main Drum Barrel Radius, in
D3 - Haulback Drum Width, in
D4 - Haulback Barrel Radius, in
F1 - Main Drum Flange Radius, in
F2 - Haulback Drum Flange Radius, in
P3 - Main Clutch Standard Pressure, PSI
T7 - Main Drum Standard Torque, in-lb (Converted to lb-ft)
P4 - Main Clutch Set Pressure
P5 - Haulback Standard Pressure, PSI
T8 - Haulback Standard Torque, in-lb (Converted to lb-ft)
P6 - Haulback Maximum Pressure, PSI
D5 - Mainline Diameter, in
D6 - Haulback Line Diameter, in
C4 - Safe Working Load of Haulback, lb
C5 - Safe Working Load of Mainline, lb
E(1)...E(5) - Drive Train Efficiency
G(I,J) - Main Drum Speed at Which Shift Into the Jth Gear
RPM (I: 1=Full Throttle, 2=Closed Throttle)
N1 - Number of Gears
N2 - Number of points in torque table
I2 - Yarder Type Code:
1=Non-Interlocked
2=Slipping Clutch Interlock
3=Variable Ratio Interlock

1/ Presented at the 9th Annual Council on Forest Engineering Conference, Mobile, Alabama, September 29 - October 2, 1986.

2/ Logging Systems/Transportaton planner and Forest Logging Engineer, respectively, Plumas National Forest, Forest Service, U.S. Department of Agriculture, Quincy, Calfiornia.

The program, currently in use on the Plumas National Forest, is a modified version based on Falk's analysis (1981), and modifications by John Henshaw. This program was further adapted to include algorithms developed by Hartsough (1985) and Darling and Ferguson (1985). The approach taken in the program is to enter a production load. Given this load, profile and clearance requirements, the model calculates the required line tensions using the same basic algorithms as found in the original program.

The effective drum radii is then used to calculate the required mainline and haulback torques. These are then compared to the calculated mainline clutch limit and the maximum possible haulback torque, respectively. If either required torques exceed the maximum torques, an asterisk (*) or the letter "C" appear in the "Machine Limited" column on the analysis printout.

The program then calculates the torque required from the converter/transmission and enters a speed-torque table. From this table, a corresponding line speed is determined.

The fifteen yarders selected for the study were a representative sample of each class of running skyline yarders (non-interlocked, slipping clutch interlock and variable ratio interlock) and a variety of tower heights and drum capabilities.

Operating System

The new Skyline Analysis Program (SAP) is written in BASIC (Beginner's All-Purpose Symbolic Instruction Code) computer language for the Digital WT-78 computer. This particular computer was chosen due to it's accessibility in Region 5, California where the program was developed. Since BASIC is a standard programming language included with most computer systems, the new program could be adapted to a wide range of computers.

Program Operation

The inputs for the new computer model are considerably different in comparison to existing programs. Once the program is loaded, the user is prompted to input a yarder data input file. The yarders available for analysis and their corresponding input file names are listed in Table 2. Once the input file name is entered, a sale name and profile number are input.

The profile being analyzed appears on the screen and layout specifications are entered. These specifications include headspar location, tailspar location, tailspar height, unit boundary, and are entered by terrain point location.

Table 2--Yarders and Corresponding Input File Names

Berger C-19	BERC19	TMY 50	TMY50
Berger C-23	BERC23	TSY 50	TSY50
Madill 044	MAD044	TSY 200	TSY200
Madill 071	MAD071	WASH 78-A	WA78A
Madill 144	MAD144	WASH 78-40	WA7840
Mustang II	MUSII	WASH 88	WA88
Mustang III	MUSIII	WASH 108	WA108
		WASH 118	WA118

Once the layout specifications are entered, the user is asked to enter the terrain points of the Streamside Management Zone (SMZ). This is designed to allow the planner the option to choose a portion of the profile where the payload will be analyzed with full suspension. All other terrain points will be analyzed assuming single end suspension.

The program then prompts the user to input the amount of line on the haulback and the mainline drums. The line lengths entered should be rigging lengths and not chord slope length.

After line lengths are entered, the user is prompted to enter a production load. This is the load that will be used in the profile analysis.

Once the production load is input, the program will take one of three directions. If the user entered line lengths that were too short to rig the profile, an error message will appear on the terminal and program execution will terminate. If the line lengths entered were greater than full drum capacity, the terminal will display a warning statement for the haulback and/or the mainline:

```
** WARNING **  THE HB DRUM IS FULL.  LINE
               LENGTH ENTERED EXCEEDS DRUM
               CAPACITY BY 231 FEET OR 1.2
               WRAPS.  PROGRAM WILL ANALYZE
               WITH THIS AMOUNT OF LINE.
```

If these warnings appear on the screen, program exection will halt until the user presses the <RETURN> key.

Once the <RETURN> key is pressed, program execution will continue and the profile analysis will appear on the terminal screen. As shown in the line length warning statement, the program will execute the profile analysis regardless of the amount of line on the haulback and mainline drums. Therefore, it is the operator's judgement in determining how to interpret the line length warning(s) in relation to sale feasibility.

The profile analysis printout generated by the new computer program (Figure 1.) lists the sale name, profile I.D. and system. The operating line lengths correspond to the line lengths entered into the program by the user. For each terrain point, the mainline and haulback tensions, line speed, haulback interlock PSI and gear are calculated. The "LIMITS EXCEEDED" portion of the printout includes machine and line limits. All lines in all yarder data files are improved plow steel (IPS).

```
SALE: WILCOX    PROFILE.: 1
SYSTEM: RUNNING SKYLINE
YARDER: MUSTANG III  CARRIAGE: DANEBO
                     MSP  600 LBS

OPERATING LINE LENGTHS:
     3460 FT. OF 7/8 IN. HB - IPS
     1730 FT. OF 7/8 IN. ML - IPS
                 3/4 IN. SP

PRODUCTION LOAD EQUALS: 12 (KIPS)

LINE SPEEDS ARE AT FULL THROTTLE (AT
CLOSED THROTTLE IF ENGINE BRAKING
REQUIRED)

HB MAXIMUM PSI = 120

LOAD CLEARANCE (FT): FLYING   = 50
                     DRAGGING = 20
                     L(C) = 15
TAIL SPAR = 50 FT
                                LIMITS
  TENSIONS                     EXCEEDED
   (KIPS)  SPEED   HB     MACH.  SWL
TP ML  HB (FT/MIN) PSI    ML/HB  ML/HB GEAR

3 15.4 8.7  665.0  35.3  C      *  *   1
4 23.2 9.4  679.8  65.3         *      1
5 20.7 9.9  704.3  92.1     *          1
6 21.7 9.8  600.2  85.6 F              1
7 22.5 9.4  680.8  80.5 F              1

RIGGING LENGTH REQUIRED = 3458

**WARNING** DESIGN LOAD INFEASIBLE IF
MACHINE LIMIT IS EXCEEDED.DESIGN
LOAD MAY BE UNSAFE IF LINE LIMIT IS
EXCEEDED. ENGINE IS BRAKING IF
MACHINE FLAG EQUALS 'B'.

CAUTION: THE INDICATED PERFORMANCE OF
THIS YARDER HAS BEEN EMPIRICALLY
DERIVED AND MAY BE USED AS A GUIDE
FOR PLANNING AND ADMINISTRATION. THE
ACTUAL PERFORMANCE MAY VARY FROM THAT
INDICATED.
```

Figure 1--Analysis Printout

The "HAULBACK INTERLOCK PSI" column represents the control pressures for the three yarder types. They are:

1. Non Interlock Yarders: Brake Control Pressure
2. Slipping Clutch Yarders: Clutch Control Pressure
3. Variable Ratio Interlock Yarders: Hydraulic Pump Pressure

The letter "F" will appear to the right of the HB INTERLOCK PSI column. These terrain points correspond with the ones you input as the SMZ terrain points.

Once the analysis is completed, the user has the option of receiving a hard copy of the analysis. Then, the user is asked to choose an option code. The options available are listed in Table 3.

Table 3--Program Options

0) Rerun As Is
1) New Sale and Profile
2) New Profile
3) New Layout Spec.
4) New Yarder Selection
5) New Clearances
6) New Headspar, Tailspar Changes
7) New Running Skyline
8) New Mainline
9) New Carriage
10) New Unit Boundary
11) New Log Drag Information
12) New Production Load

Analysis Demonstration

While there is very little difference in the actual user operation of this program in comparison to programs which do not utilize machine power train information, the following will demonstrate the differences in; (1) output format, (2) information, (3) error messages and (4) interaction of variables on the program output.

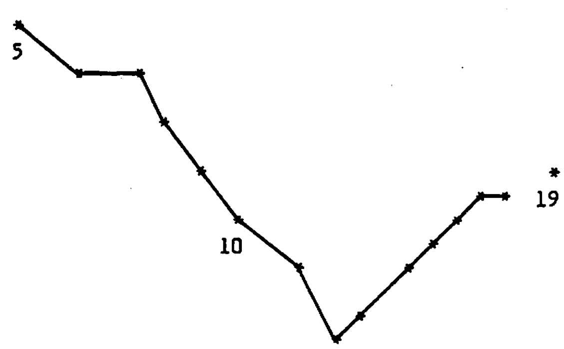

Figure 2--Analysis Profile

Since there is no recognizable difference between yarders using the same line sizes, profile analysis without power train variables typically yield a "yarder generic" solution. Yarder characteristics such as interlock type and power train factors specific to individual yarders are not considered in the analysis of a given profile.

Hartsough and others (1985) and Darling and Ferguson (1985) have shown that these factors are frequently limiting. This computer model considers these factors and shows that for identical profile geometry, each yarder performs differently in relation to it's specific power train (Figure 4.).

	PAYLOAD (LBS)	
TP	FLYING	DRAGGING
6	8966	18405
7	10180	16901
8	13023	18097
9	15921	20047
10	21469	23688
11	25040	25814
12	29576	28498
13	44110	47152
14	41731	44523
15	14353	30220
16	11575	31425
17	3686	21247
18	0	12405

Figure 3--Payload analysis using SWL Based Program for a Non Interlocked and Variable Ratio Interlocked Yarder.

In figure 3., the dragging payload at terrain point 13 equals 47,152 pounds. This equates to one truck load. This would lead the planner to believe that the yarder could bring one truckload of logs to the landing on a single turn. This is not a logical assumption. In some cases, payloads have exceeded 100,000 lbs at a single terrain point. These types of payloads are difficult to relate to profile feasibility.

The new model allows the user to input an acceptable load. This may be a minimally acceptable, maximum, or any load determined to be necessary for the analysis. By inputing a load (lbs), and having the program output speed (ft/min), the user is provided with lb ft/ min. This is the primary variable in any production equation. This is the first step in building an economic link into the process of a sale design load and production estimation directly related to yarder performance.

	NON INTERLOCKED		VAR RATIO INTERLOCK		SLIP CLUTCH INTERLOCK	
TP	SPEED	PSI	SPEED	PSI	SPEED	PSI
6	595	51	1393	1129	961	68
7	336	94	1367	2069	716	124
8	540	57	1359	1263	913	77
9	582	55	1382	1198	997	65
10	655	46	1360	1196	1229	56
11	695	45	1379	1108	1298	52
12	730	54	1522	1318	1380	62
13	761	44	1599	1166	1375	50
14	757	48	1555	1166	1384	55
15	784	34	13	818	1341'	38
16	760	42	11	959	1339	44
17	759	45	30	1073	69	49
18	689	52	36	1172	71	54

Figure 4--Analysis Run

Most logging systems designers have little difficulty in relating the computer analysis to field conditions but few loggers appreciate the relevence of maximum potential loads expressed in KIPS. The output, by providing transmission gear and necessary brake or interlock pressure settings, provide a clear communication media understandable by the yarder operator. These are directly related to what he is doing in the yarder cab.

Figure 1. illustrates several error messages that may appear on the program printout. Under the "LIMITS EXCEEDED MACHINE" column, the asterisks indicated the haulback torque limits have been exceeded and the letter "C" indicates the mainline clutch torque limit has been exceeded. Maximum limits are printed in the header and the user can qucikly refer to and ascertain the significance of the error flag. Under the "LIMITS EXCEEDED SWL" column, the asterisks indicate that the safe working load has been exceeded for both the mainline and haulback.

Once the production load is entered, the program provides a solution to moving that load to the yarder. If any machine or safe working load errors appear, the user has to decide what options will produce a feasible solution. Reducing the production load and or changing the line lengths are two options not offered before in skyline analysis programs.

By reducing the production load, the required tensions will decrease. Adjusting the line lengths will cause a change in the effective drum radii thereby changing the torque required to suspend the load.

Future Work

Since this program version is currently available only on the Digital WT-78 computer, the next logical step is to adapt it to a more accessable computer system.

Funding for field testing and evaluation needs to be provided. We do feel this program provides reasonable solutions to profile analysis problems but, the algorithms developed have been empirically derived.

Conclusion

The new computer model is a superior improvement over existing running skyline analysis programs. With the inclusion of algorithms describing power train outputs and limitations, the logging systems planner has the ability to more accurately predict sale feasibility.

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EARLY ACHIEVEMENTS IN DEVELOPMENT OF A SUBSTITUTE EARTH ANCHOR SYSTEM [1]

Briar Cook and Bob Simonson [2]

Abstract: An immediate need for development of a Substitute Earth Anchor System exists in the logging industry where timber harvesting is progressing into cutover second-growth plantations. The development of such a system was contracted for by the Forest Service, U.S. Department of Agriculture. Equipment is still in the development phase.

Development of a Substitute Earth Anchor System (SEAS) is called for by a rapidly growing demand for earth anchors, which are capable of resisting large static and dynamic pullout loads in soils of widely varying properties and in rough, steep terrain. These anchors are needed for short-term tie-down applications: e.g., for use on many logging operations, and a large number of other guyline applications.

The most immediate need for the SEAS exists in the logging industry, where anchors are needed for guylines to secure yarding towers, and as tailholds for skylines which may span distances of 5,000 ft or more. Requirements for anchors which can resist static pullout loads in excess of 130,000 lb are not uncommon in this industry. Until recently, this demand was readily satisfied by large tree stumps that were available in sufficient number in the areas where timber harvesting took place. Now, however, harvesting is progressing into areas, such as cutover second growth plantations and nontimbered ridges, where large, undecayed stumps are not available. It is primarily for this reason that the Forest Service has a vital interest in the development of the system.

The Forest Service decided to expedite the effort by awarding a contract in 1982 to Foster Miller, Inc. of Waltham, Mass. The San Dimas Equipment Development Center (SDEDC) was assigned the task of administering the contract.

The scope of the contract was to provide the necessary engineering materials to design, develop, fabricate, and test a safe, reliable, and economical SEAS for cable logging systems. The system is to consist of anchors, anchor installation equipment, anchor field test equipment, soil testing equipment, transportation equipment, drawings of all equipment, applicable documents, and training manuals. Furthermore, an analytical and experimental investigation of the dynamic characteristics of commonly used logging systems was carried out to determine the performance requirements for the SEAS. Anchor testing equipment which can be used to test holding capacity of anchors under static and dynamic loading conditions during development was also developed. The project deals with all but the weakest (SPT blow count < 10) inorganic soils.

The contract was divided into four phases: (1) Dynamic Analysis and Test (DAT); (2) Soil Test Equipment and Methods (STEM); (3) Anchor Test Equipment (ATE); and (4) Substitute Earth Anchor System (SEAS).

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[1] Presented at the 9th Annual Council on Forest Engineering Meeting—Mobile, Alabama—September 30 thru October 2, 1986.

[2] Assistant Manager and Civil Engineer, respectively, USDA—Forest Service, Equipment Development Center, 444 E. Bonita Avenue, San Dimas, CA 91773.

DESCRIPTION OF PHASES

Dynamic Analysis and Test (DAT)

The objective of this phase was to develop the information needed for an improved understanding of the dynamic behavior of skyline logging systems, so that the load requirements on man-made anchors could be specified for the SEAS.

Preliminary to actual field testing, an analytical model of a typical skyline logging system was developed. The model consists of a geometrical and mathematical formulation of the structural aspects of a system. This includes the material characteristics and properties of the components of the system such as the length, area, moment of inertia, mass, modulus of eleasticity, Poisson's ratio, friction angle, etc. of the guylines, operating lines, towers, anchors, and soil, as applicable. This model is to be used to preduct the dynamic response of similar logging systems to a variety of loading and initial cable tension conditions, as well as to make changes in geometry of the system layout. The model can predict worst-case loading conditions for geometric configurations of skyline logging systems and thus is an aid to field test planning. The model verified that, no matter how the system was loaded, forces above 1 Hz were at very low dynamic amplitude.

The model has been tested at the Forest Service's Pacific Northwest Forest and Range Experiment Station, Seattle, Wash.

The anchors of the SEAS will be subjected to very high static and dynamic loads. The static loads in the cables and, consequently, the static loads on the anchors can be predicted readily by the principles of engineering mechanics and geometry. Dynamic loads, however, are usually more difficult and sometimes impossible to predict without experimentally determined dynamic load data.

To evaluate the dynamic behavior of a skyline logging system and to gather the necessary data to develop the analytical model, field tests, static and dynamic, using a working logging system was conducted in July 1983 (fig. 1). The test site was at the Simpson Timber Company Dry Creek Site near Camp Govey, Wash.

The objective of the static tests was to determine the nominal tensions in guylines with various loads on the carriage, with the carriage at various positions on the skyline.

The objective of the dynamic tests was to determine system response to time varying loads; specifically, the frequency content of anchor loads and amplification of input loads.

The yarder was a Skagit model BU-739 with 110-ft telescoping tower, three drums, and eight duylines. The skyline was 1-3/8-in; the mainline was 1 in, and the haulback was 7/8-in diameter. The carriage was custom-made by Simpson with two sheaves riding on the skyline. A swivel block with a choker was attached to the mainline, and two chokers were attached to the body of the carriage. The carriage weighed 2,100 lb not including the chokers.

The seven guylines were all 1-3/8-in diameter wire rope made up of various lengths connected by line shackles through hand-spliced eyes. They were anchored to the notched stumps by one wrap with a flat shackle around the guyline. Three of the load sensors were placed "in-line," which means they were midway between the tower and stump anchor. In these cases the guyline ran over the ground, so that loads measured at the stump would be somewhat less than the load in the guyline. The skyline was approximately 1,500-ft long. Two tailhold changes were made during the test series, so three skyline configurations were monitored. The terrain under the skyline allowed full suspension at virtually any point along the skyline for two of the corridors.

Three types of sensors were used: Cable load, anchor and tower acceleration, and displacement of the cable at the stump anchors. Anchors directly opposite the skyline were the most heavily loaded. For this reason, accelerometers and displacement transducers were placed on these stumps rather than the others. The tailhold was instrumented with a load sensor, accelerometer, and displacement transducer—but because of a failure in the multiplexer system, only the load sensor was used during testing.

The load sensors were straingauged pins which fit into rigging designed to match the guyline stump anchors. The straingauge bridges were temperature compensated and were not sensitive to torque loads developed in the cables.

Accelerometers were used on two stump anchors and at the top of the tower. The "X" direction was parallel to the guyline (or skyline in the case of the tower), and in the horizontal plane. The "Y" direction was perpendicular to the guyline, and "Z" was vertical. The accelerometers were in the ± 10 g range, and were internally damped to avoid ringing. They were attached to the stumps by means of screws. The tower accelerometers were attached to a board which was strapped around the top of the steel tower, above the guyline sheaves.

Displacements were measured by means of "string pots" which are potentiometric transducers (variable resistance devices). The string pots had a range of ± 1 in and were attached to posts 25 to 30 ft from the stump. Steel wire was used to connect the string pots to the stump. The wire was attached to the flat shackle so that the motion of the cable was measured. This included any motion due to the cable cutting through the stump.

Soil-Test Equipment and Methods (STEM)

The objective of this task was to (a) identify or develop field soil testing equipment and methods which are most appropriate for the purposes of the SEAS and (b) compile and/or develop the necessary data to correlate field test results with actual soil properties. The following information about soil conditions at the proposed anchor site is needed:

- Depth
- Type (cohesive, noncohesive)
- Condition (degree of saturation)
- Variation of type and condition with depth
- Strength (shear strength, angle of internal friction, unconfined compressive strength).

Ideally, all of this information could be obtained by performing one single test. Some of these tests may consist of visual and manipulatory examination of soil samples to aid in the determination of the type and condition of the soil. The objective was that the test could be used by nontechnical personnel with nominal training to determine the depth, type, condition, and category of the soil.

After a very long and involved analysis of the problems associated with gathering soil samples, Foster Miller, Inc. designed and built what is known as the "STAIR" (Soil Test and Anchor Installation Rig) for use with the deeper, tipping plate anchors This piece of equipment can break down into components of 70 lb or less, perform soil testing, augering, rock drilling, and anchor emplacement.

The STAIR concept was modeled after proven commercial units, but modified to fit the exacting needs of the field conditions. The STAIR can resist 4,000 ft-lb of torque, apply a pulldown load of 2,000 lb, has a retract load of 4,000 lb at a stroke of 70 in, and support a slide hammer weighing 140 lb with a stroke of up to 9 ft. The entire unit is assembled with pins, maximizing flexibility and ease of field assembly without special tools. Set up time is about 15 min once transported to the site.

The STAIR will perform the standard penetration test (SPT). This was one of the requirements in order to keep soil tests similar within the engineering community.

Anchor Test Equipment (ATE)

The objective of this phase was to develop anchor testing equipment which was used to test the holding capacity of anchors under static and dynamic loading conditions as required for the development of anchors for the SEAS.

ATE provides the capability of accurate and expeditious testing of SEAS anchors during their development. This anchor testing equipment is not necessarily the same as the anchor field testing equipment which will be a component of the SEAS. The equipment developed under this phase conforms to less restrictive requirements with respect to the type and condition of the terrain in which it must be operable. In considering the performance requirements, however, this equipment had more stringent requirements than the SEAS anchor field testing equipment.

The static load requirements of the ATE was set at 200,000 lb to simulate the breaking strength of a 1-3/8-in cable. The dynamic load requirements were determined by analyzing the actual results of the field test on a logging operation. The ATE loading will vary with the frequency from 100 ± 100 kips at 0.1 Hz to 195 ± 5 kips at 5.0 Hz.

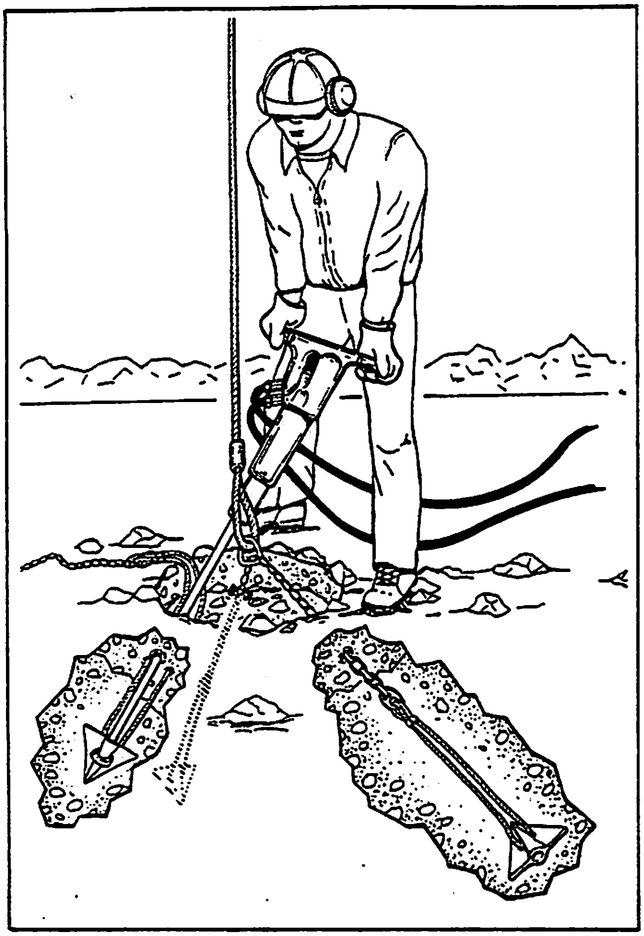
An instrumentation system capable of monitoring cylinder pressure, anchor load, and anchor displacement was also constructed as part of the ATE. The ATE was used to pull bridled anchor systems at various angles.

Substitute Earth Anchor Systems (SEAS)

The objective of this phase is to produce a complete system consisting of anchors, soil testing equipment, anchor installation equipment, anchor field testing equipment, transportation equipment, documents, and training manuals.

During the preliminary stages following the literature search, Foster Miller, Inc. presented 14 types of potential anchors. A technical review committee reviewed the anchors and after considering all the parameters surrounding the SEAS program authorized Foster Miller, Inc. to proceed with five types—hinge, net, grout, leaf, and buried stake auger. Numerous design variations of the five types were considered. To test the resistance of these individual anchors, a piece of equipment was required to pull the individual anchors to failure. The ATE previously mentioned is obviously too big and economically impossible to move from site to site. Consequently, the MATE (Mini Anchor Test Equipment) was born. The MATE has a pull-out capacity of 100,000 lb. A year of testing in various soil types, depths, and bridle geometries, has lead to the adaptation of two anchor types—the tipping plate and the tree root. Foster Miller, Inc. installed anchors and field tested the equipment that they designed.

The tree root (fig. 1) has evolved from the original idea of a series of grouted tendons to a series of 6-in arrow-shaped tipping plates connected by tendons of chain and cable. The tipping plates are driven into the ground (using a jackhammer) in a radial pattern at a 45-degree angle from the surface. Static capacities have reached 70 kips installed at a depth of 5 ft. Current work is concentrating on developing a lightweight tool for prediction of tree root capacity at the specific site of installation.



The tipping plates installed at depths greater than 10 ft have exceeded a capacity of 100 kips. The STAIR unit. described under Soil Test Equipment Methods, is currently being used to install plates.

Transporting all of the equipment may require different techniques. The most economical concept for ease of transport through the woods appears to be a torpedo system. The torpedos are constructed of an abrasion-resistant PVC material and are pulled through the woods utilizing the capstan from the STAIR unit. All SEAS hardware breaks down into sizes which fit within the 1-ft diameter torpedos. Larger operations will justify the use of helicopters for transport.

Due to the size and complexity of this project, an evaluation team was established at the onset of the project. Through many meetings and decisions, the project is now in its final year. The evaluation team's objective is to analyze all facets of the work and make decisions to guide the project to the best possible conclusion.

With the experience of the field tests and the pulling of anchors. the Forest Service soon hopes to proceed down the final path of design and construction of the final components necessary to supply the logging industry with a total Substitute Earth Anchor System.

CAT'S New Custom Skidders[1]

Thomas C. Meisel[2]

ABSTRACT:

The new Custom Skidders from Caterpillar combine traditional crawler tractor durability with skidder oriented design features. Much of the design criteria was based on information from "in the field" experience interpreted with traditional engineering analysis. Reducing the ground pressure of the machine while it was skidding logs (the dynamic ground pressure) was an important design goal.

These tractors are balanced for woods drawbar work by using the flexibility of the elevated sprocket to move the roller frames rearward. This same flexibility also lets the roller frames be mounted lower on the main frame to raise the tractor and increase ground clearance. Other key features include a wider track gauge for increased sidehill stability and an integral grapple arch and winch design for the grapple version.

Available as an option is the new "Quad-Link" track arrangement that greatly increases track chain life with wide shoes or severe underfoot conditions.

This paper will discuss the design logic behind these features and their value to the user.

Keywords: crawler, tracks, harvest, skidder, bulldozer

INTRODUCTION:

The new Custom Skidders from CAT Inc. are versions of the new D4H and D5H crawler tractors that were specifically designed for skidder use. They are much more than just a crawler tractor with a grapple or a winch used for skidding. Lets look at the features that make them different and see why they are important.

ELEVATED SPROCKET:

The first thing which strikes the eye (fig.1) is the elevated sprocket arrangement. This is not unique to the skidder but is an integral feature of the new D4H and D5H standard crawler designs. The elevated sprocket has many advantages of its own, including improved reliability, durability and seviceability. Getting the final drives off the ground isolates them from impact, dirt, moisture and roller frame alignment loads. Sprocket and track bushing wear is reduced. Power train component life is increased since they now only carry torque loads. A big advantage for the Custom Skidders was the new freedom given the designer to move the roller frames to the best location for the application. Oval track tractors have the rear of the track (the rear balance point) dictated by sprocket location. The elevated sprocket does away with this restriction. The roller frames on the skidders are moved both rearward to give the optimum balance for skidding and winching and downward to improve ground clearance. (Fig. 2) Proper balance and ground clearance are very important attributes of any skidding vehicle.

Figure 1--D4H Custom Skidder, grapple version.

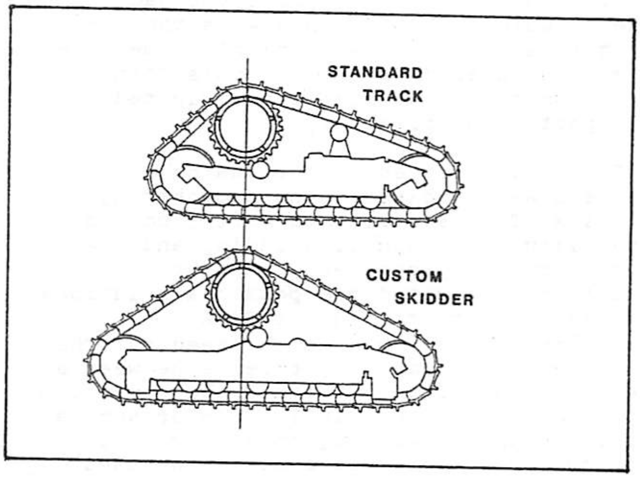


Figure 2--Relative roller frame positioning on standard and Custom Skidder versions of D4H/D5H tractors.

1 Presented at the 9th Annual Council on Forest Engineering Meeting, Mobile, Al, September 29-October 2, 1986.

2 Senior Project Engineer, Caterpillar Inc, Peoria, Il.

BALANCE AND GROUND CLEARANCE:

<u>Balance:</u>

We can't discuss skidder balance without bringing up ground pressure. The two go together. For uphill skidding the importance of a more forward center of gravity is easily understandable. Less well known, however, is how strongly the balance influences flotation on soft terrain, ground compaction and disturbance. Usually we try to relate the standard spec sheet ground pressure to flotation and compaction capability. This approach might be easy but it ignores reality. The forest floor can't see or read the spec sheet. It only knows what the machine does to it. We need to know the ground pressure under the machine while it is working before we can predict its performance. We call this "dynamic ground pressure". (Meisel,1983)

Figure 3 shows how two machines with the same spec sheet ground pressures can have very different dynamic ground pressures because their balance is different. To know the ground pressure when the tractor is pulling logs we have to know the size of the load and add its effect to the machine. This dynamic ground pressure is the one that matters and it is strongly influenced by machine balance. The tractor with a lower dynamic ground pressure will perform better on soft floor conditions. Dynamic ground pressure comparisons mean much more than those from simple spec sheet numbers.

In S.E. Arkansas on a soft, swampy jobsite a prototype Custom Skidder with a grapple was able to work alongside stripped (no blade or winch) conventional LGP crawlers and outproduce them. On this site the bare LGP's could only operate with labor-intensive log chains and skid pans due to the soft floor. Balance and ground clearance made the decisive difference.

(The operator of our prototype had some trouble convincing his wife that he had been at work since he didn't come home tired and covered with mud from setting the chain tongs. We hadn't anticipated this particular problem).

The roller frames on the Custom Skidders were located using engineering analysis. The requirements were good dozing capability, good uphill skidding and low dynamic ground pressures. Computer simulation evaluated the possible solutions and was instrumental in the final selection. Figure 4 shows the results. The predicted performance difference between a standard D4H and the Custom Skidder version is dramatic. This particular comparison is based on uphill skidding on strong soil with grapples. For this analysis we used our Tracked Vehicle Tractive Performance program. (Rohrbach and Jackson, 1982). On any given slope the Custom Skidder version of the D4H will theoretically pull more wood up the hill even though horsepower is the same. These predictions were confirmed with a prototype which was enthusiastically accepted by users on slope operations in the Pacific Northwest and the Inland Empire.

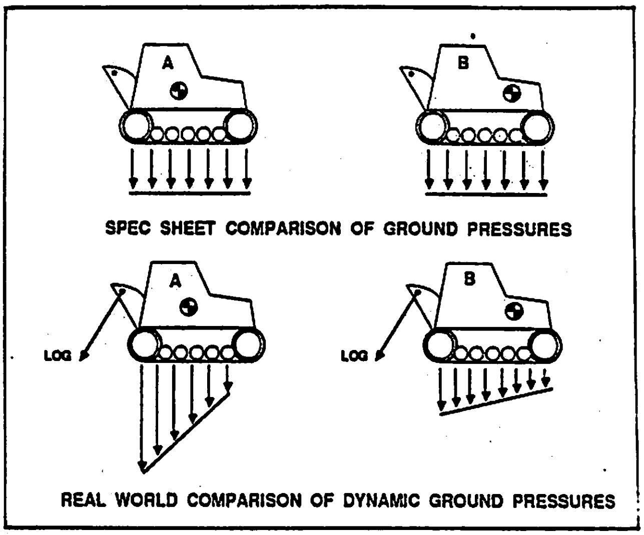


Figure 3--Possible differences in dynamic ground pressures between machines that may have the same static spec sheet ground pressures.

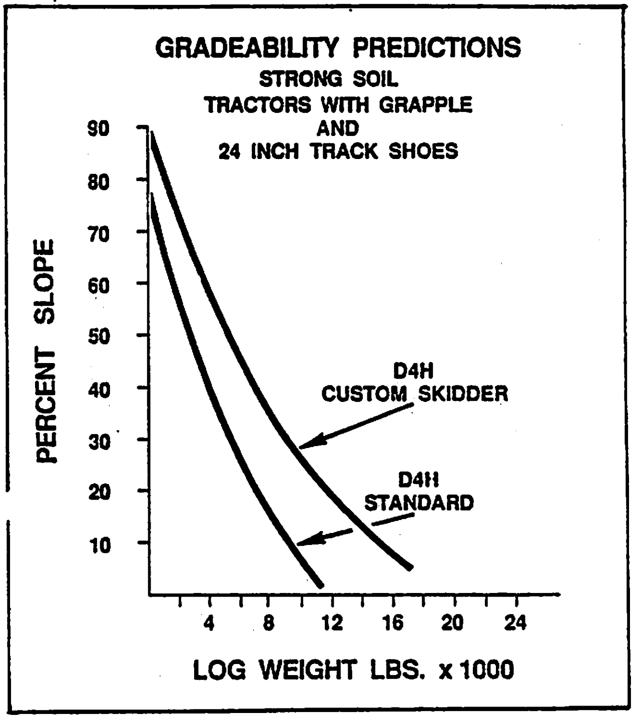


Figure 4--Predicted performance differences in uphill skidding on strong soil between Custom Skidder and standard versions of D4H tractors.

Ground Clearance:

The importance of ground clearance is well known to any skidder operator. It allows the vehicle to pass over obstacles such as stumps and debris, reduces turns and their resulting disturbance, shortens the skid distance, increases productivity and just makes the operators life a little easier in general. Ground clearance also determines how far the vehicle can sink on soft soil before it hangs up on its bellypan. The older conventional crawlers not only had marginal ground clearance for skidding in the woods but the diagonal braces would catch before anything else and mire the tractor. The elevated sprocket gave us the design freedom to position the roller frames for 22 inches of ground clearance on both the D4H and D5H skidders. The combination of really good ground clearance and the flat underbelly without diagonal braces makes an enormous difference in woods capability.

(One operator of a prototype Custom Skidder delimbed at the landing by straddling the bunch, using the inside track edges and the dozer blade as delimbing knives to cut off anything that projected. We didn't examine the economics of this system.)

GAUGE:

The track gauge of the Custom Skidders is increased from the standard tractor by 13 inches on the D4H and 14 inches on the D5H to 78.7 inches and 85 inches respectively. This extra gauge not only improves side slope capability for skidding but also allows wide shoe options for soft underfoot areas.

CABLE VERSIONS:

The cable version of the D4H Custom skidder uses the new redesigned CAT 54 winch. The D5H version uses the new CAT 55 winch. Both winches feature adjustment-free multiple disc oil-cooled clutches and brakes, full filtered hydraulics with pressure lubrication and single lever control. Reel-in and reel-out line control has been improved by larger clutch surface areas and better modulation of clutch actuation. Freespool drag was reduced by relocating the drum disconnect closer to the drum, reducing the number of rotating parts during freespool.

The 55 winch also has power out capability. This is available as an option on the 54 winch.

GRAPPLE VERSIONS:

The grapple versions have frame extensions mounted on the rear of the main case at the regular winch mount locations. These extensions mount the grapple arch, the arch cylinders and a smaller winch nestled between the extension frames. The D4H uses the CAT winch from the 508 wheel skidder. The D5H uses the CAT 518 winch. A fairlead for the winch is built into the grapple arches. The arches are designed to support a variety of AEM grapples from 75 to 100 inch tong openings. They are guarded to allow gate delimbing.

The location of the grapple pin joint will strongly affect the dynamic ground pressure of the vehicle while it is skidding. Pins that are too high or too far back give the load a larger lever to lift the front of the machine. This will raise the dynamic ground pressure. The Custom Skidder pin locations provide enough clearance for the 100 inch grapple while still being as forward and low as possible to minimize dynamic ground pressures.

Grapple actuation is provided by a single lever control. Fore/aft moves the arch, side/side opens or closes the grapple tongs and rotating the control rotates the tongs. The grapple motion parallels the operator's hand movement for a natural feel to the controls. The lever is at the operator's right.

Hydraulic power is provided by load sensing, variable displacement piston pumps. The D4H pump provides 25.5 GPM at 2200 engine RPM and destrokes to minimum displacement at 2700 psi. maximum pressure. The D5H has 30 GPM and destrokes to a minimum at 3000 psi. The load sensing system allows detenting the grapple tong control in the close position wihout excessive power loss and hydraulic system overheating. The logs get maximum tong squeeze without added crossover valves and accumulators and the operator doesn't have to keep snugging up the tongs during a skid.

QUAD-LINK TRACK:

Quad-link track is a Caterpillar exclusive which has many benefits for crawler tractors with wide shoes in tough applications. It will be an option on the Custom Skidders. On a conventional track, wide shoes can put higher twisting forces into the track chain since forces at the ends of the shoes have a longer lever arm. Forces can come from vertical loads (running over a stump at the edge of the track) or from snag loads (catching the end of the grouser during a hard pull). Wide shoe effects on chain life are well known and the user usually chooses the narrowest shoe which will still do the job. As a rule,though, the wider the shoe the better the performance of the tractor. Wider shoes increase flotation, reduce compaction and ground pressure, increase cohesive traction and widen the operating range of the machine. Quad-link lets the user have wide shoe performance with narrow shoe track life.

Quad-link adds single link strands close to the ends of the shoes. (Fig. 5) Tying the shoes to each other spreads the shoe edge loads through the track rather than forcing the center links to do all the resisting. Laboratory tests showed center chain loads on a D5E with 34 inch shoes reduced to those that the chain would see from 14 inch shoes. Field tests in stumping operations with D5E's and 34 inch shoes showed track life increased up to 5 times with quad-link. These benefits are very important for the logger who needs wide shoes in his applications.

BULLDOZER:

The Custom Skidders have a big advantage over other special built tracked skidders..They're still good bulldozers with the customary ruggedness and durability the user expects from a dozing tractor. Both the D4H and the D5H skidders come equipped with standard PAT (Power Angle and Tilt) dozer blades. These have full hydraulic control of lift, dig, angle and tilt. The blade is mounted close in to the tractor with push arms that are inside the roller frames. This gives steady blade control while reducing the overall length and width of the tractor for in-the-woods maneuverability. The blade is controlled by a single lever at the operator's right. The blade angling capability is really appreciated by operators decking logs on narrow landings.

The Custom Skidders give the logger true dual purpose machines. They can doze just as well as they can skid. This flexibility has many advantages. The set tractor at the landing or the utility dozer in the fleet can now be a productive skidder when it's not busy with dozer tasks. The Custom Skidders can punch out roads and skid trails, build landings and deck logs. The ability to use his equipment full time will help lower the logger's cost per unit production.

OTHER FEATURES:

The Custom Skidders have many other features that will be appreciated by the logger. Engine cooling is provided by a folded-core radiator, another CAT exclusive. These radiators have top and bottom tanks connected by narrow modular cores that are angled and separated from each other. A high fin density deflects debris past the cores where it passes thru the gaps between them. (Fig. 6) A folded-core radiator is much less prone to plug with debris and greatly extends the cleaning interval. They are also less costly to repair as individual core modules can be replaced.

The operator's compartment places him higher for a better view of the blade and the grapple or winch. Transmission, steering and brake controls are at his left and need only one hand to operate. Single lever dozer, winch and grapple controls are at his right.

The Electronic Monitoring System, another CAT exclusive, constantly monitors all critical functions (temperatures, pressures and fluid levels) and warns the operator by light and sound when something is not right. Gauges are also available as an option.

A single diagnostic connector can be used to troubleshoot the starting and charging systems quickly without removing sheet metal or making connections to individual components. A complete test of 15 areas from one location can be done in five minutes.

SUMMARY:

The new Custom Skidders from Caterpillar Inc. are unique. They combine traditional crawler tractor ruggedness and dozing capability with the balance and ground clearance necessary for good skidder performance. This combination is

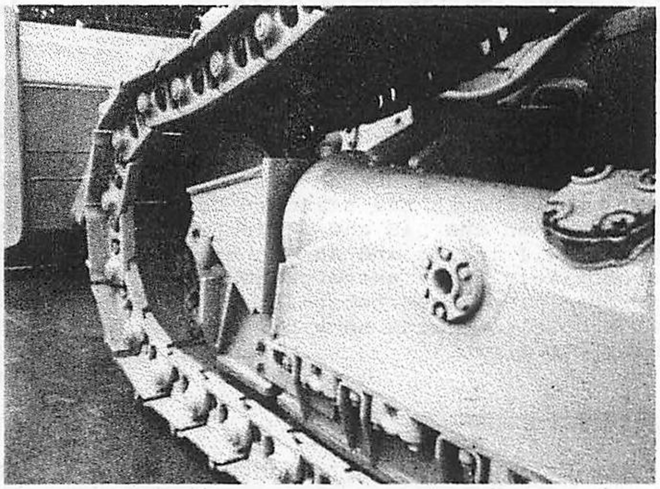


Figure 5--Quad-Link track arrangement available as an option on D4H/D5H Custom Skidders.

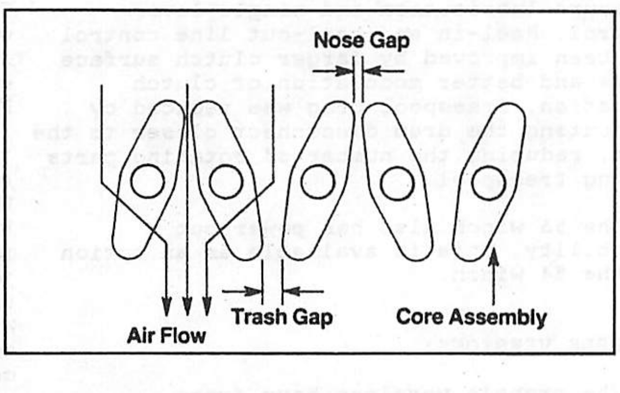


Figure 6--Folded-Core radiator arrangement. Individual high fin density cores are angled to let debris pass through gaps between them.

made possible by the elevated sprocket which let the roller frames be located for the application instead of being tied to the sprocket position.

A lot of field experience and engineering analysis went into the design of these machines. The dynamic ground pressure was kept low by optimizing machine balance and log load pull points. The correctness of this approach was proven by the high field acceptance of the initial prototypes. The Custom Skidders are an important addition to the Cat Timber Team.

D4H CUSTOM SKIDDER SPECIFICATIONS:

Winch Version:	
Operating Weight*	27,143 lb/12,310 kg
Ground Pressure*	5.68 psi/0.40 kg/cm^2
Winch	CAT 54
Grapple Version:	
Operating Weight*	30,650 lb/13,900 kg
Ground Pressure*	6.42 psi/0.45 kg/cm^2
Grapple	75 to 100 inch opening 1905 to 2540 mm
Winch	CAT 508
Both Versions:	
Power	90 FWHP/67 kw
Length of track on ground	103.8 inches/2636 mm
Gauge	78.7 inches/2000 mm
Ground Clearance	22 inches/559 mm
PAT Dozer Capacity	2.11 yd^3/1.62 m^3

* With 23 inch/590 mm shoes

D5H CUSTOM SKIDDER SPECIFICATIONS:

Winch Version:	
Operating weight**	33,870 lb/15395 kg
Ground Pressure**	6.53 psi/0.46 kg/cm^2
Winch	CAT 55
Grapple Version:	
Operating Weight**	36,150 lb/16,432 kg
Ground Pressure**	6.97 psi/0.49 kg/cm^2
Grapple	75 to 100 inch opening 1905 to 2540 mm
Winch	CAT 518
Both Versions:	
Power	120 FWHP/89.5 kw
Length of track on ground	108 inches/2740 mm
Gauge	85 inches/ 2160 mm
Ground Clearance	22 inches/ 563 mm
PAT dozer Capacity	3.27 yd^3/2.5 m^3

** With 24 inch/610 mm shoes

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