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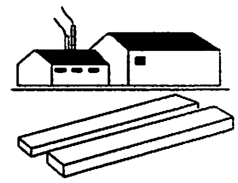

1989

IMPLEMENTING TECHNIQUES FOR SUCCESSFUL FOREST OPERATIONS

Proceedings of the
12th Annual Meeting
of the
COUNCIL ON FOREST ENGINEERING

August 27 to 30, 1989
Coeur d'Alene, Idaho

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College of Forestry, Wildlife and Range Sciences
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TABLE OF CONTENTS

PREFACE

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

COFE has three sub-chapters that carry out the stated objectives on a regional basis. These include NERCOFE (New England States of the U.S.), SRCOFE (Southern States of the U.S.), and WRCOFE (Western States of the U.S. and British Columbia).

COFE membership is open to anyone with an interest in forest engineering. Members receive a quarterly newsletter and a membership directory.

Each year the activities of COFE are highlighted by an annual meeting. The annual meeting brings members together to focus on forest engineering problems related to the conference theme and on the unique problems of the geographic region hosting the conference. This year's conference concentrated on "Implementing Techniques for Successful Forest Operations" and the unique conditions of the Intermountain Region. The conference was held in Coeur d'Alene, Idaho, with participants from all regions of the United States and Canada.

We owe special thanks to the many people who helped in the planning and conduct of the Annual Meeting. These include Sylvia Aulerich (COFE headquarters in Corvallis, Oregon) and Harry Lee, Richard Cleavenger, and Robert Stoker of the Forest Products Department at the University of Idaho. Special thanks also goes to the hosts and contractors associated with our field trip. These include Tom Davis of Louisiana-Pacific Corporation, Jerry and Jeff Miller and Bob Taylor of Harvester Logging, Paul Wagner of Inland Empire Paper Company, Dick Chatfield of Panhandle Logging, John Bruning of the U.S. Forest Service, and Bob Burlingame and Dick Thompson of Burlingame and Thompson Logging. Finally, special thanks go to the speakers and authors whose papers you will find in these proceedings. The time and efforts spent by all of these people are greatly appreciated.

These proceedings are available for $25 from the Council on Forest Engineering, 620 SW 4th Street, Corvallis, Oregon 97333-4428. Make checks payable to COFE.

Stephen P. Aulerich, Co-Chair
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Leonard R. Johnson, Co-Chair
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An Overview of Timber Harvesting in the Intermountain Region[1]

Leonard R. Johnson[2]

Abstract: Timber harvesting in the intermountain region is affected by large variations in piece size and terrain conditions. Logging systems developed for the region must accomodate this variation and must also be mobile to be effective with small landings and frequent moves.

Keywords: Intermountain, Logging

The intermountain region can generally described as the area between the northern Cascade and Rocky Mountains. This includes parts of western Montana and Alberta, Canada, Idaho, and eastern Oregon, Washington and British Columbia. It is characterized by variation. Tree sizes range from small, stagnated trees in stands started in response to fires in the early part of the century to large trees in virgin stands or left during earlier logging activity. Terrain ranges from very flat areas where the use of ground based systems is obvious to very steep ground where both road access and timber harvesting is difficult. The challenge with these terrain and timber variations is that they often occur in the same drainage or timber harvest planning area. Timber harvesting systems and timber harvest planning activities have evolved over the years to accomodate the wide ranges in timber and terrain conditions.

CHARACTERISTICS OF THE REGION

Although the average tree size has been steadily decreasing to a recent average of 13 - 14 inches, diameter breast height, on U.S. Forest Service sales, the variation of tree sizes within a single sale or harvest tract can be quite large. Should the logging plan call for equipment that can handle the largest trees or the average trees? Should two size classes of equipment be used? The challenge for area loggers and timber sale planners is to identify systems that can effectively move larger material, but still be efficient with trees in smaller diameter classes.

The range and type of harvesting operations are affected by the markets for processed logs. Most of the timber harvest goes to sawmills for the production of lumber. A secondary market exists in some parts of the region for plywood and veneer logs and these often command higher value than sawlogs. Timber from some non-federal lands can also go into an export market. A limited market has developed for pulpwood in the roundwood form. This material is either used directly in one of the region's four pulp mills or is debarked and chipped for delivery by barge to the west coast or export markets. There are very few opportunities for in-woods processes such as whole tree chipping, even with in-woods debarking, because of the low bark content allowances of area pulp mills.

Harvesting operations and the type of equipment that can be economically used is constrained by the length of the operating season. The operating season will generally range from 8 to 10 months, with down time coming in both the spring and fall. When snow and rain begin in the fall, but temperatures are not cold enough to freeze the ground, logging must be curtailed. The scenario is repeated in the spring, when the snowpack begins to melt. Many county and state roads will post load limitations during the spring and fall because of the freezing and thawing that typically occurs and the effect on subgrade stability. The shortened operating season reduces the number of hours available to pay for equipment investment and therefore, limits the amount of fixed cost most logging contractors are willing to incur.

EQUIPMENT AND SYSTEM CHARACTERISTICS

The topography of the region and general method of timber sale layout and design has dictated a high degree of mobility in the harvesting equipment. Landings are relatively small and are often restricted to the logging road used to access the area. As a result of the small landings, equipment is moved frequently and mobility is essential to harvesting efficiency. A typical operation might have the fallers with chainsaws working one to two weeks ahead of skidding or yarding. Tree length material is normally skidded downhill to a landing on gentle slopes. Log length material is yarded uphill to a logging road in steep terrain. Processed logs will be cold decked for loading and hauling at a later time.

Skidding and log processing usually work together on gentle ground. Tree length material is skidded to the landing. Landing sawyers delimb the tree and buck it into log lengths. The processed logs are pushed into cold decks for subsequent loading and hauling. Loading and hauling will generally be done after completion of skidding and processing in an area. One loader and the associated trucks might service several skidding and processing locations.

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[1]Presented at Council of Forest Engineering Meeting; Coeur d'Alene, Idaho; August 27-30, 1989.

[2]Leonard R. Johnson is Associate Dean for Academics in the College of Forestry, Wildlife, and Range Sciences, University of Idaho, Moscow, Idaho.

Cable yarding operations typically require felling and bucking in the woods. Log length material is yarded to the landing. The landing is usually limited to the width of the logging road and there is not room for processing tree length pieces into logs. The yarder will swing the logs onto the road and create cold decks oriented parallel to the yarding direction, but to one side of the yarder. The yarder generally begins yarding at the back of the setting and works progressively toward the front, plugging the road behind the operation with logs. Once yarding is completed, the loader and trucks begin loading from the front of the strip and unplug the road as they progress to the back.

The transition from ground based skidding systems to cable yarding generally occurs on ground with slopes in the range of 35 - 45 percent. The actual transition point will be affected by slope, the type of soil and the location of the haul road. Efforts are made to plan ground skidding with roads located at the lower edge of the slope to allow downhill skidding. Many cable yarding operations utilize two drum yarders that are limited to yarding material uphill. Roads for these systems must be located at the upper edge of the harvest strip.

Timber volumes and harvesting equipment sales within the region have never been large enough to justify development of equipment specific to the timber and slopes of the area. Most of the equipment used in the past was adapted from systems used elsewhere. When the necessary equipment could not be adapted, machines that could do the job were built in local machine shops. The result has been innovation in the type of equipment and methods of logging. Some of this innovative equipment has been commercialized and can now be found in use outside the region.

Equipment used in harvesting operations results from the needs for mobility and adaptability to a wide range in piece size. Wheeled skidders and crawlers in the 90 to 120 horsepower class are used in gentle and transitional terrain. Most of the wheeled skidders are now equipped with hydraulic grapples and a hydraulic powered winch. Crawlers are often used on the transition slopes (35% - 45%) when the road is located at the lower edge of the unit. The skidding distances planned for crawlers will generally be less than those of the wheeled skidders, however.

The types of cable yarding systems used in steep terrain have been influenced by the need for mobility and the limited landing areas. The high lead yarding systems and skyline towers of coastal areas are too large for intermountain conditions. In the past, even downsized versions of these yarders were not mobile enough for the most intermountain landings.

The intermountain solution has been to maintain the rigging configuration of the ground lead and skyline systems, but to provide for greater mobility. An example is the Idaho Jammer. The two-drum jammer is generally shop-built on the fram of a truck or crawler. It works like a highlead with a main and haulback line operating out to distances of 600 to 800 feet. Logs are dragged to the 40 to 50 foot boom of the machine and are then raised to be decked into decks located parallel to the haul road. This deck location keeps the yarding corridor clear and allows landing sawyers to work on a level deck. The machines are very mobile, often moving two to three times per day. Their yarding orientation perpendicular to the yarding corridor and the ability of the operators to deck material parallel to the road without swinging the boom of the machine allows them to work on very narrow roads and to keep machine investment requirements low.

Skyline systems have also been adapted from other equipment to provide for mobility and deck construction on the logging road. A typical two drum live skyline system in the intermountain region is based on modification of a construction crane. The boom is strengthened and increased in height to 45 to 50 feet. Capacity and speeds of the drums on the crane are modified to accomodate more cable and higher inhaul speeds. Yarding distances are generally limited to 900 to 1000 feet. One advantage of the crane is that the operator can swing the upper portion the the crane and boom to bring the logs alongside the yarder and perpendicular to the road. This allows construction of larger decks without the logs blocking the yarding corridor. The deck can also be developed on the level surface of the road.

There has been a gradual influx of commercial yarders in recent years. These have higher capacities and longer distance capabilities than the converted shovels. They can usually be rigged in a number of skyline system configurations. The influx has resulted from the development of yarders that are a closer match to intermountain needs and recent timber sales that have incorporated longer yarding distances.

The common use of a two drum skyline for yarding and the need to control the logs by locking the carriage to the skyline during lateral inhaul and logs to the carriage during yarding resulted in developments of the Maki and Christy logging carriages. Both manufacturers are located in Idaho. The simplicity and durability of the original carriages made them popular throughout the world. Newer carriage designs of the companies now allow radio control of the carriage locking mechanism and in some instances, mechanical slackpulling capability. The newer carriages extend the reasonable yarding distances of choker setters and complement the yarders with longer yarding distance capabilities.

FUTURE TRENDS IN TIMBER HARVESTING

The most noticable change in the region over the last five years has been the escallating use of mechanized harvesting systems. Use of feller bunchers and other mechanized equipment had been limited to very flat terrain and relatively small timber. Use of the systems was dependent on a market for pulpwood or wood fuel. Area sawmills did not like accepting the sheared wood as sawlogs.

The introduction of feller bunchers that could effectively work on steeper slopes and of felling heads that would saw rather than shear the tree addressed two of the factors that had limited mechanized systems in the intermountain area. Requirements for a mechanized system were completed when computer sensors and controls in mechanized delimbing systems allowed effective processing of sawlogs with slide boom delimbers and other delimbing/processing heads. The mobile delimbing and bucking systems can work effectively from cold decks and allow operators to use mechanized systems effectively with the small landings and cold decks that are common to the region. The number of operations utilizing a feller buncher with saw head and some type of mechanized processing has increased dramatically in the last three years. It has changed some methods of operation, but has also allowed economic harvesting and manufacture of smaller trees.

SUMMARY

Planning for future timber harvesting in the region will focus on several issues related to both first and second entries into harvested areas. Does the harvesting plan reuse skid trails and roads that may have been improperly located during a first entry? Areas that were accessed with an excessive number of skid trails and haul roads may now have stabilized. Second entries into these areas will probably leave those areas stabilized and may have to work around obstructions they create. As new areas are opened for timber harvest, land managers may be pressured to reduce the number of roads constructed to access these areas. New skidding and forwarding systems will then be needed to accomodate the increased distances between haul roads.

The primary timber issue in the region focuses on future timber supplies. The issue centers around the debate and political decisions that need to be made on the allocation and use of the roadless areas existing on public lands in the region. As some of these areas are opened to timber management, the design and layout of the corresponding timber sales may change. Timber harvesting operations in the intermountain region will continue to need innovative approaches to access, remove and replant the trees safely, effectively and economically.

Future Trends in Mechanized Harvesting in the Intermountain Area[1]

Joseph W. Gorsh[2]

Abstract: Driven by lack of skilled labor, increasing Workmen's Compensation rates, and continuing environmental pressure on all forest land managers, we will be seeing an increase in the number of two-operator, two-machine, "Cut-to-Length" harvesting systems to reduce costs and lessen environmental impacts.

Keywords: LOG-Forwarder, Harvester, B-Train

Currently, the most common method of harvesting small timber on mountainous terrain less than 40 percent is to tree-length log using a Feller-Buncher, two skidders, landing processor, and a log loader. This normally constitutes a cash outlay of approximately $800,000 and a five-man crew with two pickups. For this crew to maintain a production level of 10 to 12 loads per shift, skidding distances translate into road densities of approximately 10 miles of truck road per square mile of land managed for the production of wood fiber.

From the landowners perspective, such a transportation system removes approximately 40 acres of land per square mile from wildlife habitat and the future production of wood fiber (Table 1). On land capable of producing 8,000 board feet per acre under management, enough timber land would be lost to construct 32 average homes per square mile of land at the next rotation. In addition to the visual impact of 600 feet skidding and the accompanying road system, approximately 26,000 cubic yards of excavation would be required to construct the roads and landings, representing approximately 40 cubic yards or four 10-wheel dump truck loads per acre harvested. In areas with valuable fisheries, such excavation could represent significant erosion potential and expensive mitigation measures. The dollar cost of such a transportation facility ranges between $120,000 to $170,000 per square mile depending on the soil and terrain. In addition to this initial up-front investment, roads require some level of maintenance. Over a timber rotation period, road maintenance often exceeds the cost of the original construction. Alternatives to this conventional ground-based logging system, which are less disruptive to the ecosystem and less costly, now exist.

TABLE 1

EFFECTS OF SKIDDING DISTANCE

PER SQUARE MILE OF MANAGED MOUNTAINOUS LAND

AVERAGE EXTERNAL SKIDDING DISTANCE		APPROXIMATE MILES OF TOTAL ROADS[a]		ACRES OUT OF FORAGE, FIBER PRODUCTION		CUBIC YARDS EXCAVATION ESTIMATE[b]		ROAD COSTS AT $17,500/MI		ROAD COSTS AT $22,500/MI
500 FT.	-	11.6	-	45	-	37,600	-	$203,000	TO	$261,000
1000 FT.	-	5.8	-	23	-	18,680	-	101,500	TO	130,500
1500 FT.	-	3.5	-	14	-	11,270	-	61,250	TO	78,750
2000 FT.	-	2.6	-	11	-	8,370	-	$ 45,500	TO	$ 58,500

[a] includes permanent, spur, and temporary roads.
[b] does NOT include excavation for skid trails or landings.

Within the last 2 years, loggers and purchasers have begun to look at some different mechanized harvesting systems. One very promising method is commonly referred to as the "Cut-to-Length" or "LOG-Forwarder" method. This method is unique in several respects. First, the Feller-Buncher and Log Processor are replaced by a single machine called a Harvester (Fig. 1). This one-man, one-machine operation directionally fells, limbs, measures, bucks, and presorts logs as it works its way through the woods, in both partial cuts and clearcuts. The operator accomplishes this from within a protective, air-conditioned, stereo-equipped cab. Many of the log manufacturing tasks are preprogrammed to relieve the operator of repetitive tasks. In the process, logs are limbed to a 3-inch diameter and precisely cut to lengths of 16.5 and 25 feet for saw logs. Pulp wood, posts, and poles would be manufactured to different lengths. As a result of the high quality logs produced and the presorting that takes place in the woods, sawmill operators have reported both increased recovery and reduced milling costs. Due in part to the merchandising taking place in the woods.

Figure 1 -- Harvester

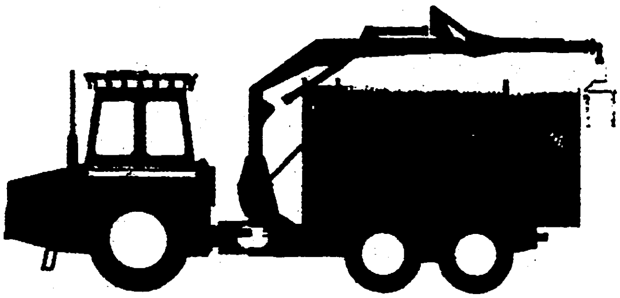
The LOG-Forwarder (Fig. 2), which picks up the cut-to-length logs, is equally impressive. In the woods, the operator in his air-conditioned protective cab picks up prebunched piles of previously sorted logs left by the harvester. In so doing, the 10- to 15-ton forwarder loads reduce the number of skidder turns by 50 percent, or more. Upon arriving at roadside, the LOG-Forwarder then offloads directly onto parked trailers waiting at roadside to be loaded and transported to a specific mill, be it a stud

[1]Presented at Council of Forest Engineering Meeting; Coeur d'Alene, Idaho; August 27-30, 1989.

[2]Joseph W. Gorsh is the Regional Logging Engineer for the USDA, Forest Service's Northern Region; Missoula, Montana.

mill, post and pole yard, or pulp plant. Transporting logs of a given sort to different parts of the same yard can also reduce the amount of yard handling that normally takes place in the mill yard.

Figure 2 -- LOG-Forwarder



More importantly, the LOG-Forwarder eliminates the need for two skidders and a log loader, each with their respective operator. Since the LOG-Forwarders carry short logs free of the ground, there is no skidding damage to the residual stand, and the mills receive clean logs which extends knife and blade life. Since LOG-Forwarders carry the load's center of gravity ahead of the rear load-bearing axel, the weight is shared by all three axels, thereby reducing both the ground pressure and resulting compaction, while increasing traction. With greater traction, less wheel slippage, and greater float, land managers have found this equipment to be capable of operating on softer and steeper ground without the environmental damage experienced from conventional equipment.

Having the capability of economically forwarding "cut-to-length" logs 1,000 to 2,500 feet and offloading them directly onto waiting B-Train trailers, two very important changes take place. First, one-half to two-thirds of the truck road system can be eliminated along with three-quarters of the constructed log landings. In Montana, timber sales designed for such harvesting systems have experienced a reduction of 4 to 6 miles of constructed truck roads per square mile of land managed for the production of wood fiber. This constitutes a 30- to 60-percent savings in road construction and maintenance costs. On mountainous terrain with slopes up to 40 percent, LOG-Forwarders can reduce the area taken out of the production of wood fiber, forage, and ground cover by 16 to 24 acres per section (1 square mile or 640 acres). Another translation of this would be a reduction of 10,000 to 25,000 cubic yards of excavation per section harvested, or the equivalent of 1.5 to 2.5 10-wheel dump truck loads per acre harvested. Refer to Table 1.

The LOG-Forwarder has some additional attributes that benefit both land managers and timber purchasers. For any given volume per acre that is to be silviculturally removed, a LOG-Forwarder can remove it with fewer turns and lighter loaded ground pressures (Table 2). With fewer turns and lower ground pressures, we have less soil compaction. Where desired, the silvicultural prescription can specify that the limbs and tops be placed ahead of the harvester, creating a mat for the tracked six-wheel drive machines to negotiate. This woody mat significantly reduces the potential for compacting soils and the need for designated skid trails. Since the LOG-Forwarder carries the turn of short logs ahead of the rear load-bearing axel and free of the ground, skid trails are not gouged out of the soil from dragging logs, nor are residual trees damaged by the drag of logs. In the process of forwarding, the LOG-Forwarder returns to the woods in reverse by rotating his seat, thereby eliminating the need to physically turn the machine around both at the landing and in the woods. This maneuver not only disturbs less ground, it makes for a much safer operation.

TABLE 2

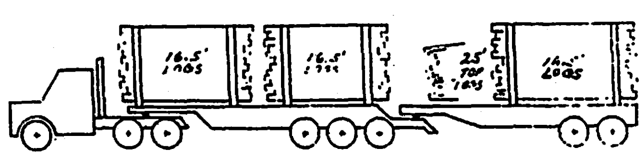
GROUND-BASED LOGGING

DISTURBANCE AND COMPACTION

PRIME MOVER	LOADED P.S.I.	TURNS/AC IN 50-100 BD. FT. TIMBER 6 MBF	9 MBF	10 MBF	12 MBF	14 MBF
130 H.P. RUBBER TIRE SKID	25	7.5	10.0	12.5	15.0	17.5
140 H.P. TRACTOR	15	5.5	7.3	9.1	10.9	12.7
12 TON LOG FORWARDER	9	2.9	3.8	4.8	5.7	6.6
15 TON TREE FORWARDER	10	2.4	3.2	4.0	4.8	5.6

Upon loading itself and maneuvering to roadside, the LOG-Forwarder pulls up alongside a preparked set of B-Train Trailers (Fig. 3) to offload directly onto the B-Train. This procedure eliminates the need for log-loaders in the woods along with the cost of landing construction and cleanup.

Figure 3 -- 108,000 #CVW B-Train



With specially designed B-Train trailers capable of negotiating 50 feet radius switchbacks with a legal GVW of 108,000 pounds, both haul costs and road maintenance costs (Table 3) are reduced since they make fewer trips with lighter axel loadings. They

TABLE 3

LOGGING ROAD

MAINTENANCE LEVEL

ROUND TRIPS PER ACRE

VEHICLE	SITE PRODUCTIVITY/ACRE 6 MBF	8 MBF	10 MBF	12 MBF	14 MBF	AXEL LOADING
CONVENTIONAL 80,000 #GVW	1.3	1.7	2.2	2.6	3.0	16,000 #/AXEL
B-TRAIN 103,000 #GVW	1.1	1.3	1.7	2.1	2.4	12,800 #/AXEL
B-TRAIN 108,000 #GVW	1.0	1.3	1.6	1.9	2.2	12,000 #/AXEL

also become a very attractive method of transportation on log hauls greater than 50 miles. Two truck tractors with three sets of B-Train trailers produce the daily equivalent of four conventional logging trucks.

About now, one has to ask about the cost of such a harvesting system. In Montana, land managers have experienced a savings of $150,000 to $200,000 per section in road and landing construction costs for land managed for wood fiber. In addition to the road savings, logging costs were reduced $82 to $117 per acre as compared to conventional ground-based logging. In a 3-day, side-by-side logging demonstration north of Missoula, one logger with a nine-man conventional crew and four pieces of heavy equipment produced 132.8 thousand board feet of timber, his daily labor cost including payroll assessments came to $1,597 per day. In the same unit, a LOG-Forwarder side harvested 155.7 thousand board feet with two operators and two pieces of equipment. With these operators working in an enclosed protected cab, the daily labor cost was $268. The difference in labor cost more than offsets the difference in equipment costs, which varies plus or minus 10 percent depending on the makes and models compared to produce an equal daily production. This same equipment with their enclosed protected cabs, 20 or more halogen lights, and internal communication system permits them to be double-shifted, thereby reducing their monthly fixed costs. The combination of this equipment being mounted on rubber with a road gear permits them to be economically moved on most road systems without permits, lowboys, or road damage. This is particularly useful when operating in small cutting units or ownerships within an hour or two of each other.

Recognizing that the "cut-to-length" Forwarding System has limitations working on slopes greater than 40 percent, forwarding logs over one-half mile in distance, and harvesting timber stands greater than 15 inches in average diameter, many land owners are still looking to this logging system to reduce the environmental impacts of timber harvesting without increasing the cost of logging. With much of the larger diameter material already harvested and more second-growth stands coming on line for thinning and intermediate cuts, I believe we will see more of this type of equipment. The lack of skilled labor, high labor costs, and the continuing pressure to lessen environmental impacts, will only accelerate the shift to these two-man, two-machine "Cut-to-Length" logging systems.

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Economics of Recovering Ponderosa Pine Thinnings Residues[1]

Dallas C. Hemphill[2]

Abstract: In 1987-88 Logging Engineering International, Inc. conducted a study of the economics of forest residue recovery operations owned by Kinzua Corporation in eastern Oregon. Residue treatments studied included piling and burning ponderosa pine thinnings; recovery of pine thinnings for fuel chips and for sawlogs; and recovery of small understory white fir trees for fuel chips in advance of the sawtimber logging operation. Relationships were developed between fuel production costs and stand variables. Recommendations for improving the economics of the operation include: using a larger size of feller buncher; adoption of an optimal utilization standard; using improved landings; and producing flail-debarked/delimbed pulp logs.

Keywords: thinning, chipping, feller bunchers, flail delimbers.

BACKGROUND

Kinzua Corporation and its affiliates own and operate a sawmill, a chipping plant, a wood residue-fired power plant, and timberlands at Heppner, OR. The power plant is a 9.7 MW cogeneration facility with a wood residue fuel requirement of 71,500 BDU/year. Up to 25 percent of this fuel requirement has been met with forest residues. In 1987 and 1988, Logging Engineering International, Inc. conducted a study of the economics of recovering forest residues on Kinzua operations, recommended operational improvements, and examined related policy factors[3].

Two classes of forest residue have been exploited by Kinzua for fuel: (1) thinnings removed from overstocked young growth ponderosa pine (*Pinus ponderosa*) stands, and (2) small understory trees removed from old growth white fir (*Abies concolor*) stands in advance of regular logging operations.

Recovery of thinnings residues performs a valuable forest management function. Many young growth ponderosa pine stands in eastern Oregon are overstocked, and the trees are stressed to the point of succumbing easily to insect attack, which can infest an entire stand. Recovery of the thinnings for fuel is a means of making thinning economic, thus relieving the overstocked condition and therefore susceptibility to insect epidemics.

EXISTING THINNINGS RESIDUE TREATMENT SYSTEMS

Systems Tested

The following residue treatment systems operated by Kinzua were studied in separate test areas:

1. French Pass test area: Pile and burn in a precommercial thinning; recover merchantable sawlogs in a separate operation.

2. Jackson Ranch test area: Recover all removed trees for fuel chips.

For both systems, three-wheeled Morbell and Morbark Superbuncher feller bunchers were used to sever and either bunch the trees in skidder bunches (Jackson Ranch) or pile them for burning (French Pass). Trees recovered for fuel or sawlogs were grapple skidded. In the fuel operation, a Morbark 30-inch portable chipper made 3/4-inch fuel chips, which were transported by "dry" (highway freight) van to Heppner. Sawlog trees were processed into logs by a Denis stroke delimber, and decked for loading and hauling.

Productivity and Costs

Stand descriptions, and standardized productivity and cost estimates, are shown for the two methods of residue treatment in table 1.

Table 1--Stand descriptions, productivities, and costs for test areas.

	French Pass Pile & burn	Jackson Ranch Fuel chips
Stand Description		
Mean tree dbh, inches	4.4	5.3
Take trees/acre	325	289
Productivity		
Feller bunch, trees/ 10-hour day	1001	844
Skid and chip, ODT/day	n.a.	108
Costs		
Feller bunch	$164/net ac.[a]	$14.33/ODT
Burn	13	n.a.
Skid and chip	n.a.	14.33
Haul--Heppner	n.a.	8.74
Total--gross	$177/net ac.	$37.40/ODT
Less credits		-14.77
Total--net	$177/net ac.	$22.63/ODT

[a]"Net" acres are those that are stocked and actually require thinning. On the test area, 25 percent of the area was understocked and was not thinned. Therefore, for the gross acreage thinned, the cost was $133/acre.

[1]Presented at the 12th Annual Council on Forest Engineering Meeting, Couer d'Alene, ID, August 28-30, 1989.

[2]President, Logging Engineering International, Inc., 3621 Vine Maple St., Eugene, OR 97405.

[3]Hemphill, D.C. 1989. Kinzua Forest Residues Utilization. Project Report. USDOE/BPA, Portland, OR.

The net delivered cost of fuel chips on the Jackson Ranch unit was approximately equal to the avoided cost of outside purchase of hog fuel: $23/ODT. Therefore, thinnings residues were an economically marginal source of fuel with this system.

The credit allowed in the net cost calculation for thinning for fuel was the avoided cost of precommercial thinning. The data collected in the study of the pile-and-burn area was used to derive an estimate of the avoided cost of thinning the fuel chip thinning unit, of $14.77/ODT. For the pile-and-burn unit itself, the $177/net acre thinning cost converted to $22.50 per ODT of biomass in the cull trees. Clearly, the thinning credit is a major component of residue recovery economics.

The relationship found between the pile-and-burn cost of precommercial thinning (and therefore the credit allowed against production costs where thinnings were recovered for fuel), and removed stocking and tree size, is expressed in figure 1.

The relationship found between the production rate for feller bunching into skidder piles, and tree size and removed stocking, is expressed in figure 2.

Sawlogs were produced from the pile-and-burn thinning area at a standardized cost of $102/Mbf gross short-log Scribner scale, net of credits. Stump-to-landing unit costs were found to be nearly inversely proportional to piece size, as piece-rate productivities in feller bunching and mechanical delimbing were nearly independent of piece size within the range studied.

Thinnings sawlog values were estimated by simulating lumber recovery for the Kinzua mill with the computer model SAWSIM, applying the lumber grade mix recorded on a mill study in similar material in the Black Hills, and using average published 1984-87 lumber values. By segmenting trees into logs on paper, estimates of merchantable tree values were developed. The "pond" (delivered log) value for trees in the study area, and the cost of producing

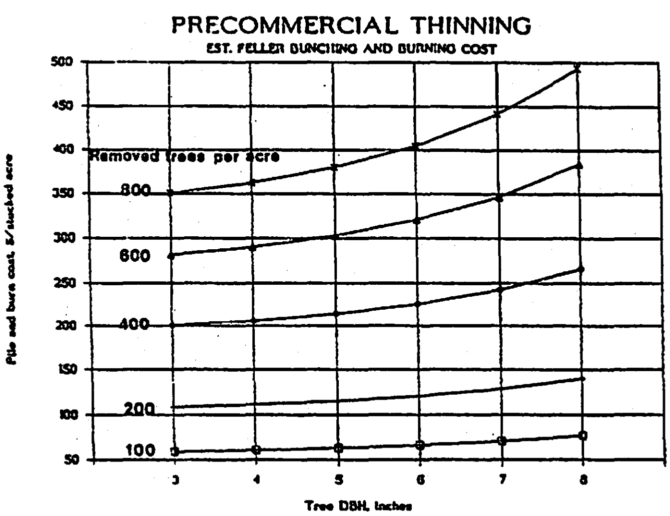

Figure 1--The credit allowed for thinning is a big part of fuel recovery economics. It depends partly on tree size, but mostly on removed stocking.

sawlogs, are displayed as functions of tree dbh in figure 3. The break-even tree size for producing sawlogs is seen to be about 10.5 inches dbh, in this case equivalent to a 38 bf tree.

It is emphasized that the value estimates displayed in figure 3 apply only for the set of assumptions made in this case. Values depend on variables such as mill configuration, tree form, and the set of product prices used.

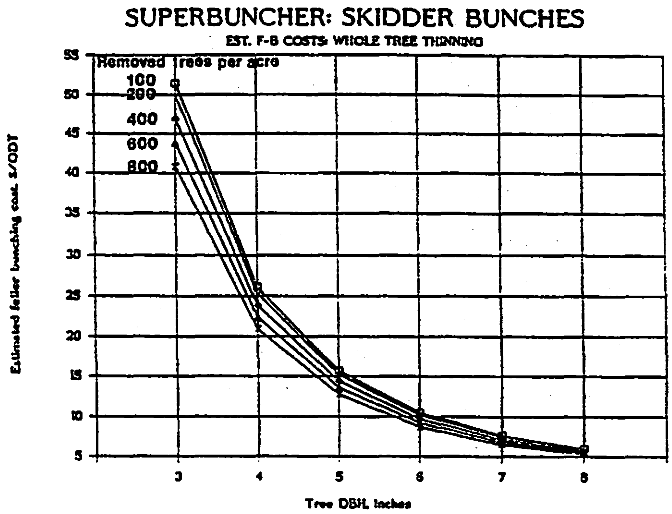

Figure 2--Estimated costs (whole tree basis) for Superbuncher making skidder bunches in thinnings.

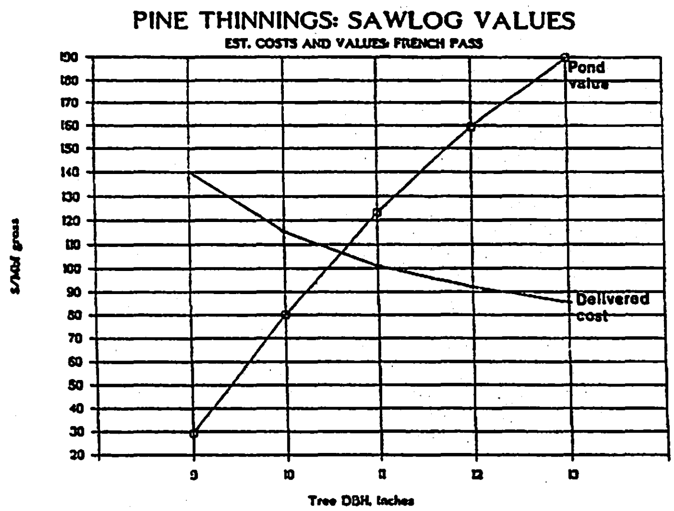

Figure 3--In this case, cost and value curves for ponderosa pine thinnings sawlogs show a breakeven point at about 10.5 inches DBH.

SYSTEM IMPROVEMENTS IDENTIFIED

Selection of Feller Buncher

Analysis of the test data showed that the larger Morbark Superbuncher feller buncher averaged a larger size of accumulation and was therefore able to cut more trees per day, than the smaller Morbell feller buncher. For the 5.3-inch dbh average tree recorded in the Jackson Ranch fuel recovery test unit, estimated accumulation sizes, productivities, and feller bunching costs are shown in table 2 for the two machines when building skidder bunches.

Table 2--Comparison of feller buncher productivities and costs.

Feller buncher model	Morbell	Superbuncher
Accumulation size, trees	2.7	5.1
Est. productivity, trees/10-hour day	840	1168
Est. feller bunching cost, $/ODT	14.33	12.78

The larger machine, in spite of its greater daily owning and operating cost, was able to feller bunch more economically. Its use in the fuel recovery operation, instead of the smaller Morbell, is therefore recommended, with an estimated savings of $1.55/ODT.

Landing Selection

"Good" landings are those with sufficient space for two chip vans and adequate ingress/egress for chip vans, permitting rapid van changes and therefore high chipper utilization. "Bad" landings lack suitable space and access. A comparison of landing situations on the fuel recovery study area showed that chips could be produced from "good" landings at a cost $8.15/ODT lower than from "bad" landings. "Good" landings are normally available in eastern Oregon thinning operations at little incremental cost, since the terrain is typically gentle and natural forest openings are generally utilized for landings. By using only "good" landings instead of a mix of "good" and "bad", fuel production costs on the Jackson Ranch test site could be reduced by $3.70/ODT.

Where "good" landings are not available, thinnings recovery for fuel may not be economic.

Utilization Standard

In the test areas, practically all trees not selected as crop trees were severed and recovered for fuel or piled for burning. A large proportion of the take tree count consisted of very small trees, with a high per-ton removal cost. Thinnings of 2 inches dbh cost over $100/ODT to recover as fuel.

Incremental costs (i.e. of feller bunching, skidding, and chipping optional trees that do not have to be bear their share of certain fixed elements of the production cycle) were analyzed, to determine the breakeven tree size for fuel recovery. It was found that trees under 4 inches dbh did not pay their way. Trees this small do not substantially impact stand development, and therefore it was recommended to cut only those take trees over 4 inches dbh.

The adoption of a 4-inch utilization standard was estimated to result in a $5.17/ODT cost reduction for fuel recovery on the Jackson Ranch test area. However, if a silvicultural prescription is adopted that permits all trees under 4 inches dbh to be left, the avoided cost of precommercial thinning is also reduced, by $4.44/ODT. Therefore, the net savings resulting from a 4-inch dbh utilization standard is estimated at $0.73/ODT.

These improvements to the existing system are simple, low-risk changes. The cost reduction resulting from optimal feller buncher and landing selection, and adoption of a 4-inch dbh utilization standard, is estimated at $5.98/ODT. The total delivered cost, net of the thinning credit, for the optimized system was then estimated at $16.65/ODT. This was clearly competitive with the outside purchase cost of $23/ODT for delivered hog fuel, realizing a margin of $6/ODT.

ALTERNATIVE SYSTEMS

Alternative residue recovery systems were investigated, that would employ a chain flail delimber/debarker to produce either:

- Debarked pulp logs, for chipping in the existing whole-log chipper at the Kinzua plant in Heppner.

- Pulp chips, using a portable chipper teamed with the flail.

For each system, the option exists of processing the whole trees either on the woods landing or at the mill yard.

The existing feller buncher/grapple skidder extraction system would continue to be used, with the improvements made as identified above.

For both systems, flail debris (bark, foliage, pieces of limbs) would be available in a readily conveyed and transported form. It would require further comminution to be usable as fuel in the Kinzua power plant. Comminution would be most economically achieved by using a suitably-configured mill yard waste shredder.

System Economics

System productivities and costs were projected from the analysis of the existing residue treatment systems.

Debarked Pulp Logs--Woods Processing

Productivity and cost projections for the production of debarked pulp logs from the woods landing for the Jackson Ranch test unit are presented in table 3. They are based on the assumption that the fuel (non-pulp-chippable) fraction of the tree is wasted.

Table 3--Productivity and cost projections for the production of debarked pulp logs from thinnings landings.

	Productivity, ODT/day	Cost, $/ODT
Feller bunch	42	13.66
Skid-flail-load	99	19.35
Haul	55	8.40
Road maintenance		0.34
Total gross cost to Heppner		41.75
Less: Thinning credit		-16.00
Total net cost to Heppner		25.75

The total net projected cost of $26/ODT compares favorably with the avoided cost of outside purchase of chip logs, which is estimated at $37/ODT for bark-free wood. Debarked pulp logs would therefore yield a margin of $11/ODT. Additionally, flail debris is available at a cost of $14 to $18/ODT delivered to Heppner.

Debarked Pulp Logs--Mill Yard Processing

In this system, whole trees would be hauled to the mill yard. Productivity and cost projections for the production of debarked pulp logs from the mill yard, for the Jackson Ranch stand, are presented in table 4. All of the flail debris would be recovered for fuel. Unit costs and the thinning credit are lower than those presented for woods debarking, since the whole tree is used.

Table 4--Productivity and cost projections for the production of debarked pulp logs from the mill yard.

	Productivity, ODT/day	Cost, $/ODT
Feller bunch	65	8.74
Skid-load	190	6.26
Haul to Heppner	46	10.96
Road maintenance		0.34
Debark	196	7.31
Total gross cost		33.61
Less: Thinning credit		-10.33
Total net cost		23.28

The product in this case would consist of 64 percent pulpwood and 36 percent fuel, with a composite avoided-cost value of $32/ODT. At a total net cost of $23/ODT, this method would therefore yield a margin of $9/ODT.

Pulp Chips--Woods Processing

Assuming the fuel (non-pulp-chippable) fraction of the tree is wasted, productivities and costs of the various components of the system producing pulp chips at the woods landing are estimated for the Jackson Ranch test unit as shown in table 5.

Table 5--Productivity and cost projections for the production of pulp chips from thinnings landings.

	Productivity, ODT/day	Cost, $/ODT
Feller bunch	42	13.66
Skid-chip	112	24.70
Haul	27	18.27
Road maintenance		0.34
Total gross cost to Columbia R.		56.97
Less: Thinning credit		-16.00
Total net cost to Columbia R.		40.97

The value of the chips produced by the flail and portable chipper, containing up to 1 percent bark, is conservatively estimated at $48/ODT, delivered to the Columbia River, for early 1989. On this basis, wood chips delivered at a total net cost of $41/ODT would yield a margin of $7/ODT. Again, flail debris is available at a cost of $14 to $18/ODT delivered to Heppner.

Pulp Chips--Mill Yard Processing

Productivity and cost projections are presented in table 6 for the Jackson Ranch stand, where whole trees are hauled to the mill site for debarking and chipping in a portable chipper. All of the flail debris would be recovered for fuel. Unit costs are lower than those presented above for woods debarking, since the whole tree is used.

Table 6--Productivity and cost projections for the production of pulp chips from pine thinnings, debarking and chipping at the mill yard.

	Productivity, ODT/day	Cost, $/ODT
Feller bunch	65	8.74
Skid-load	190	6.26
Haul to Heppner	46	10.96
Road maintenance		0.34
Debark-chip	196	11.06
Total gross cost		37.36
Less: Thinning credit		-10.33
Net cost f.o.b. Heppner		27.03
Haul to Columbia River		9.62
Total net to Columbia River		36.65

Chips would be delivered to the Columbia River at a total net cost of $37/ODT, yielding a margin of $11/ODT. Fuel would yield a negative margin: -$4/ODT. The composite margin, for 64 percent pulp chips and 36 percent fuel, would be $6/ODT.

COMPARISON OF RESIDUE TREATMENT SYSTEMS

Projected per-acre dollar margins generated by fuel, pulp chips, and sawlogs from an average Jackson Ranch acre carrying 8 ODT/acre of cull material and 650 bf/acre of sawtimber are presented in table 7. Costs for the fuel chip systems are modified from those quoted above to reflect the reduced annual woods fuel requirement now in effect at the Kinzua power plant, which has the effect of raising certain fixed costs per unit of fuel.

Table 7--Projected margins generated per acre by alternative thinnings residue treatment systems.

	Margin, $/acre
Waste--pile and burn all material	0
Fuel chips only--not optimized	-21
Fuel chips and sawlogs--optimized	69
Pulp logs--woods debarking	88-102[a]
--yard debarking	99
Pulp chips--woods debarking/chipping	66-79[a]
--yard debarking/chipping	74

[a]Margin depends on how much flail debris is recovered for fuel.

Clearly, the greatest margin may be realized by producing debarked pulp logs. The per-ton margin can be maximized by debarking in the woods, wasting the flail debis. However, the per-acre margin would be maximized through maximum utilization of the flail debris as fuel, either by hauling whole trees for debarking at the mill site, or by hauling all of the flail debris from the woods.

Debarking at the woods landing was recommended to Kinzua Corporation, since it would provide maximum or near-maximum profitability, without the risk involved in developing a highway hauling system for whole trees and without occupying valuable space at the mill site. It also would permit fuel production to be varied according to power plant requirements.

In the case of Kinzua, the production of pulp chips has a further important advantage over using the whole tree for fuel. The annual woods fuel requirement at the Kinzua power plant is limited to approximately 7000 ODT/year, and therefore only a limited area can be thinned per year for fuel. By producing pulpwood, by-product fuel production can be limited to that required by the power plant, without limiting the acreage thinned.

Figure 4 shows thinning margins that can be realized from the allocation of thinnings trees to various product types. It shows that trees under about 11.5 inches dbh are best allocated to pulpwood production. Trees larger than this, if suitably formed, are best allocated to sawlog production.

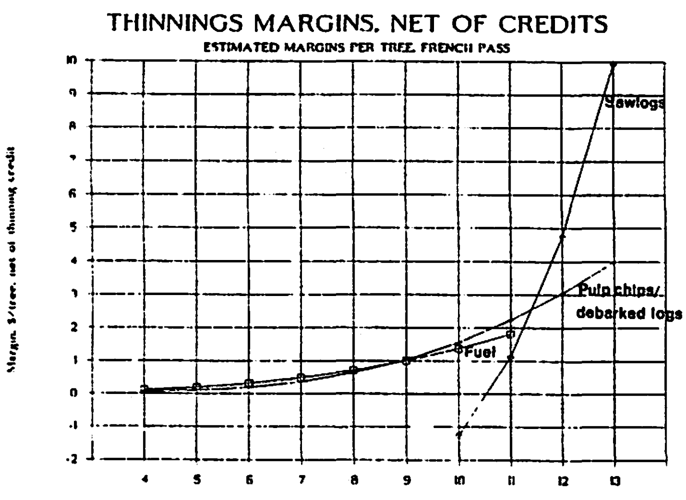

Figure 4--Margins compared for ponderosa pine thinnings used for sawlogs, pulp chips/pulp logs, and fuel chips.

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Field trials of a chain-flail delimber/debarker and a portable chipper processing small-diameter frozen wood.[1]

Björn O. Andersson, M.Sc.F.E.; E.A. Sauder, R.P.F.; A.W.J. Sinclair, P.Eng., M.B.A.[2]

Abstract: This report discusses the results of a trial that was undertaken in 1989 to determine the production ability of a chain-flail delimber/debarker processing frozen small-diameter conifers at a satellite location in central Alberta. An objective of the field trials was to maintain bark content at less than 1 percent on a green-weight basis. The delimbed and debarked logs were chipped with a portable chipper and samples of the chips produced were analyzed for bark content and size distribution. In addition, delimbed, small-diameter lodgepole pine pulpwood stems and spruce-pine tops, as well as fire-killed, delimbed, spruce-pine timber were processed through the system. This paper presents productivity, cost, and chip quality results determined by the field trial.

Keywords: Satellite processing, Chain flail, Chipping, Bark content, Frozen small-diameter conifers, Production, Cost

The objective of this study was to establish the production volumes and costs of using a portable chain-flail delimber/debarker and chipper system to process frozen small-diameter conifers while maintaining a bark content of less than 1 percent (green-weight basis).

BACKGROUND

Satellite whole-tree debarking and chipping operations in Alberta, Canada could supplement chip supplies from sawmills and replace or supplement pulp mill woodroom installations. Some of the timber in this area consists of small-diameter black spruce (Abies mariana (Mill.) B.S.P.) and lodgepole pine (Pinus contorta Dougl.) not suitable for sawlogs. These trees could be processed into chips at satellite whole-tree chipping operations.

An economic feasibility study undertaken by MacIntosh and Sinclair (1988) indicated that economic debarking and chipping of small-diameter stems could be achieved using a debarker that had multiple-stem processing capability. They estimated production rates and costs but cautioned that none of the multiple-stem debarkers had operated on small-diameter frozen stems. MacIntosh and Sinclair recommended that field trials be undertaken to prove or disprove their estimates for processing frozen small-diameter stems. Consequently, small-diameter frozen conifers were processed with a multi-stem chain-flail delimber/debarker and a mobile chipper in a field trial undertaken in February-March 1989. The project was financially supported by Forestry Canada and Alberta Forestry, Lands and Wildlife through a Canada/Alberta Forest Resource Development Agreement contract. This paper presents the only the results related to the chipping of frozen small-diameter conifer.

STUDY METHODS

Production and equipment performance were recorded using Servis recorders, work sampling, and a detailed diary. All van loads of chips produced were weighed and chip samples were obtained prior to dumping. Debris from the flail and chipper was loaded into a dump truck for weighing and disposal.

Stems within felled bunches were randomly sampled to note species and to measure butt and top diameters (inside bark) and length.

TRIAL DESCRIPTION

The equipment was set up in a logging landing 38 km northeast of Weldwood's pulp mill at Hinton, Alberta. Temperatures during the trial varied between -37°C and +5°C. All the trees were frozen, although outer bark sometimes softened during periods when temperatures rose above freezing for several consecutive afternoons. Figure 1 is a flow diagram of the system.

Logging was carried out by a company crew using a feller-buncher and a grapple skidder. Bunches skidded to the landing were normally placed in front of the flail. Whenever the stockpile at the flail was full, the bunches were stockpiled around the landing perimeter. Trees were recovered from the stockpile when logging production fell behind the demand for stems for chipping.

The trees were loaded into the flail with a hydraulic log loader equipped with a butt-and-top grapple. The loader was oversized for this application and the its grapple was awkward to use around the flail.

Delimbing and debarking was done with a Peterson-Pacific Model 4800 chain flail. Stems

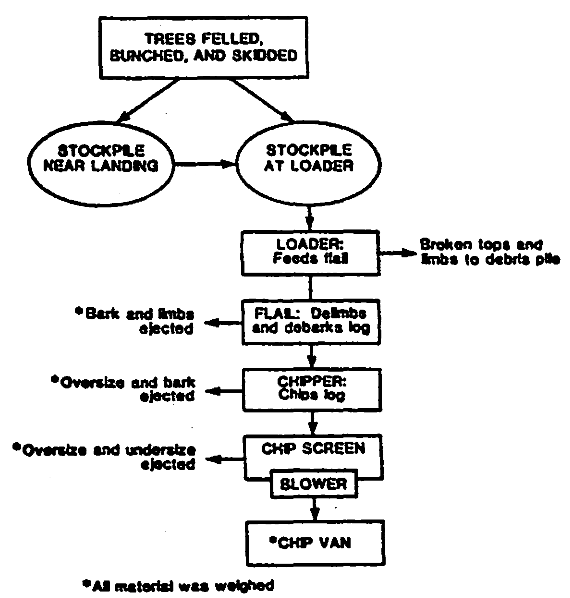

Figure 1. Flow diagram of system.

[1]Presented at the Annual Council on Forest Engineering Meeting, Coeur D'Arlene, ID, August 27-30, 1989.

[2](Respectively) Researcher, Group Supervisor, Manager; Forest Engineering Research Institute of Canada, Vancouver, B.C.

were fed directly from the Peterson chain flail into an older Morbark Model 22RXL Chiparvester equipped with a sliding-boom.

Chips were blown into 13.7-m (45-ft) enclosed vans that had been modified for chip hauling. Modifications included making two 929-cm² (1-ft²) openings in the trailer front to allow the discharge of air and the installation of half-doors of steel mesh. These doors swung from the trailer roof at the rear of the van to contain the chips during loading.

RESULTS AND DISCUSSION

Stem Sizes

Table 1 summarizes the average sizes of stems processed by the flail during the trial.

Table 1. Summary of Stem Dimensions

Trial	No. stems sampled	Avg stem diam (cm)	Avg length (m)	Avg volume (m³)
Mixed spruce pine[a]	101	13	11.1	0.152
Black spruce	159	12	8.4	0.094
Lodgepole pine	176	10	6.6	0.054

[a] White spruce, black spruce, and lodgepole pine.

Initially, logging was concentrated in areas of larger trees (spruce and pine) but then progressed into areas of smaller trees (nearly pure black spruce). The smallest diameter stems processed were two truck-loads of lodgepole pine pulpwood delimbed by a stroke delimber.

Production

The trial generated 1 264 tonnes (t) of chips and 316 t of debris (Table 2). The debris produced by the flail consisted of pulverized tops, branches, bark, and stem wood. The debris from the chipper consisted of oversized chips, dirt, bark, and knots.

Bark Content

The bark content (Table 2) of all chip loads was greater than 1 percent (green-weight basis). However, 75 percent of the spruce/pine and black spruce chip loads were between 0.20 and 1.50 percent. The bark contents obtained during this trial compared favourably with chip-production facilities in the area.

During the trial, the quality of flail debarking appeared to be affected by the number of stems being debarked simultaneously, the stem's angle or position at infeed, the air temperature, the number of limbs on the stem, the infeed speed of the flail, the tree species, and the diameter of the stems.

Chip Quality

Most chips were not cleanly cut on one side and many chips were less than 22 mm long but 2 cm or more wide. These features may have resulted when long stems reached the chipper knives while still being debarked. Vibrations caused by the flail and the mismatched feed rates may have prevented the stem from being fed at a constant feed rate to the chipper knives. To counteract feed-rate interference, the chipper and flail were separated as much as stem length would permit (Figure 2), and the engine speed was reduced by 150 rpm.

Production Rates

Overall equipment utilization (PMH/SMH) was only 50 percent. Much of this was related to the nature of the study, the lack of winterizing, and the lack of spare parts for the chipper. If these delays and wait-for-empty-van delays are removed from the shift-level summary, overall equipment

Table 2. Summary of Production Rates (with all delays greater than 10 minutes deleted)

	Spruce-pine	Black spruce	Lodgepole pine pulpwood
No. of vans	30	30	2
Percent oven dry weight	57.4	58.6	59.2
Summary of production			
No. of stems processed	7 752	8 514	880
Volume solid wood (m³)[a]	1 178	800	48
Chips produced (t)	617.0	609.3	37.9
BDU produced[b]	325	328	21
Flail debris (t)	94.6	168.8	5.1
Chipper debris (t)	16.6	27.8	3.1
Bark content (pct. green weight)	1.18	1.12	1.32
Production/van load			
No. of stems	258	284	440
Volume solid wood (m³)	39	27	24
Weight of chips (t)	20.57	20.31	18.93
BDU	11	11	10
Production/van load			
Total time to load van (min)	67	70	74
No. stems/min	3.9	4.1	6.1
Length of stems (m/min)[c]	43	34	40
Volume solid wood (m³/h)	36	23	20
BDU/h	10	10	9
Revised production/van load[d]			
Total time to load van (min)	57	59	67
No. stems/min	5.3	5.6	8.4
Length of stems (m/min)	59	47	55
Volume solid wood (m³/h)	48	32	27
BDU/h	13.7	13.7	12.3

[a] Number of logs x average log volume.
[b] Weight (kg) of chips ÷ 1000 x pct. oven dry weight x 0.919 BDU/t.
[c] Number of logs x average log length.
[d] Based on reduced delays, a continuous supply of stems to flail, and more operator experience.

Operational Comments

The cost of replacing chain has been generally reported as a concern at existing chain-flail operations. During these trials, the chains were upended between the 12th and 15th loads and completely replaced after every 30 to 35 van loads of chips.

Chain replacement was a two-man job and took 60 to 90 minutes. The rods holding the chains were changed halfway through the trial, although they were only slightly worn.

Chipper knives lasted between 11 and 16 van loads of chips. This was longer than expected, probably because the trees being chipped were free of dirt. Changing knives took between 20 and 40 min and could be done by one man.

The harvesting phase was able to maintain a continuous supply of trees to the loader and flail because trees were stockpiled during delays in the chipping phase, during repairs, and while waiting for chip vans. Without these delays in the debarking/chipping cycle, a single skidder and feller-buncher working only one shift per day would not keep up to chipping demand.

The loader was easily able to match the flail's production requirements. While waiting for the flail infeed to clear, the loader cleared debris that had accumulated around the flail infeed area. However, the loader had to wait for the skidder to drop turns in the decking area which directly affected the flail's production. Chipper production was limited because:

- The loader had to wait for the skidder to unload logs at the flail and could not load the flail.
- Full chip vans had to be replaced by empty chip vans.
- Empty chip vans were not always available at the chipping site.

The modified dry vans used as chip-hauling trailers were adequate for the trial period, but could not be fully loaded. The openings in the front for air escape were too small, and became plugged with chips and fines during loading. Once the openings became plugged, chips would begin to accumulate 3-5 m away from the van front. The void that was created was difficult to fill.

CONCLUSION

Results of this trial indicate that the chain flail, when processing frozen small-diameter stems, can consistently produce chips with a bark content of about 1.2 percent. This is acceptable to mills requiring a low bark content. While the goal of less than 1 percent bark (green-weight basis) was not achieved for all loads, a comparison with other chip suppliers indicates the chips were of the same quality being delivered to the Hinton mill. More than 75 percent of the loads are probably within 1 percent when the variation between samples is considered.

The study indicates the chain flail has the capability of processing up to 6 stems/min and maintaining bark content of less than 1 percent green weight. From the production recorded during the lodgepole pine pulpwood trial, a feed rate of 6.6 small-sized stems/min would result in a production of 9 BDU/operating hour. The data also suggest that larger stems (0.10 to 0.15 m^3/piece) could be processed at between 5 and 6 stems/min by ensuring an even flow of 3-4 stems/infeed unit. This would result in a production of 11-12 BDU/operating hour.

The production achieved during the trial was 10 BDU/h for mixed white spruce, pine, and black spruce and 9 BDU/h for lodgepole pine. Based on field observations, it was estimated that a fully operational system could produce 13.7 BDU/h for frozen white spruce/pine and black spruce, 12.3 BDU/h for frozen, delimbed, lodgepole pine pulpwood.

Production costs were $28.96/BDU for white spruce/pine and black spruce, and $31.53 for lodgepole pine. Based on field-test results, the study estimates that a production cost of $22.72/BDU for spruce, pine, and black spruce, and $24.59 for lodgepole pine pulpwood is achievable.

The satellite chipping operation that was tested seemed well suited to high production. However, the fast rate at which the flail/chipper equipment is capable of processing stems requires continuous skidding of trees to the infeed area and, if possible, a stockpile of trees. One feller-buncher and one skidder cannot adequately supply the system without working more hours than the debarker/chipping system.

The following operating factors should be considered to minimize bark content and to maximize chip production during sub-freezing temperatures:

- The loader and its grapple must be sized for the timber being debarked. It should be able to pick up 3-5 stems at a time without disturbing other stems, be able to pick through the log deck, and also be able to pick up large grapples of debris to throw on the waste pile.

- Stems should be fed into the flail at a rate that is as constant as possible; stems should overlap and be well spaced across the infeed rollers.

- A deck of trees to be debarked should be built up in front of the flail so that stems can easily be fed horizontally through the flail, and assistance from the loader is not needed to keep the stems horizontal.

- If the chipper infeed rate cannot be varied then the flail outfeed and chipper infeed should be separated as far as possible to minimize the time that the chipper is pulling logs through the flail at a rate that makes adequate debarking impossible.

- Worn chains should be replaced immediately.

- With the present infeed roll system on the Peterson flail, lower bark contents can be achieved when the branches are left on the stems.

- Modify the flail so that infeed rollers can close tightly against the tops of the small-diameter stems. An infeed roller system that could put the same pressure on different diameters of logs would be useful.

- The chipper supplied for the trials was an older model. Mechanical delays that occurred during the trial reinforced the need for the chipper to be in good operating condition and well maintained. There should be an adequate supply of spare hoses and fittings, the

Figure 2. Processing longer stems with flail and chipper separated.

utilization would increase to between 60 and 70 percent.

More than half of the delays over 10 min exceeded 30 min in length, and 20 percent exceeded 60 minutes. Long delays were related to cold temperatures and a lack of spare parts and repair supplies for the chipper. This illustrates the loss in production that can occur when working in cold temperatures without proper equipment winterization and with an inadequate supply of spare parts and repair supplies.

Table 2 summarizes debarking production for the flail trials. Production estimates are based on the time required to load and change vans and includes all delays less than 10 minutes.[3]

Flail production in the trials generally varied with timber size. However, production was also influenced by experiments to determine the time required to debark stems consistently to a known bark content. For example, lodgepole pine were debarked at 6.1 stems and 40 m combined length/total minute. Spruce-pine, which were nearly 70 percent larger than the former stems, were debarked at 3.9 stems and 43 m/total minute.

Flail production was smoothest when a deck of stems was accumulated in front of the flail so that the loader could slide a bunch of stems to the infeed roller. The deck allowed the stems to travel horizontally through the flail and reduced the need for the loader to align them during debarking. The loader operator tried to keep three stems in the infeed of the flail at all times but this was not always possible with the butt-and-top loading grapple. The grapple was too large and cumbersome to be positioned easily near the infeed without disturbing the logs being debarked.

Stem length affected the transfer and alignment of stems from the flail to the chipper. Short stems tended to shoot out of the flail and onto the chipper infeed deck. Long stems were pushed out of alignment with the chipper infeed when the skidder drove over, or the loader grapple hit, the stems being fed into the flail. Misaligned stems had to be repositioned into the chipper infeed with the chipper's sliding boom loader, thus slowing production. Additional guarding and deflectors between the flail and the chipper would have corrected alignment problems.

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[3]When using detailed timing data to estimate long-term productivity, it is normal to eliminate delays greater than 10 minutes.

Several grapple loads of 2- to 4-m-long conifer tops were inserted into the flail to determine if the flail had potential to debark logging residue. The tops jammed in the flail because they were not long enough to bridge the gap between the infeed and outfeed rollers, and the tops usually broke at 2-3 cm diameter. Also, the infeed rollers could not close tightly enough to hold the tops against the debarking action of the chains, so that tops were propelled through the flail at high speeds.

Satellite Chipping Costs

The machine costs are FERIC estimates based on results determined during the field trial. Interest costs and a ninth hour at overtime labour wage rates are included, but profit, company overhead, and supervision costs are excluded. Logging costs were not included.

The hourly costs were prorated against both the production recorded during the trial (excluding delays greater than 10 min) and a revised rate that estimated production for an experienced, operational, satellite chipping facility (Table 3). The revised rate was based on a 17 percent increase in production that occurs when delays associated with the study (5 percent), waiting for access to stems at the deck (6 percent), and waiting for an empty van to return to the chipping site to replace a full van (6 percent), are not incurred and the time is spent in production functions. Also, production was estimated to increase by 20 percent when the loader was able to feed a continuous supply of stems to the flail.

The equipment, as set up for this trial, was estimated to cost $231/SMH (Sauder and Sinclair, 1989) to operate, excluding operating supplies (Table 3).

Chips produced during the trial cost between $29 and $32/BDU for conifer, and were expected to decrease to between $23 and $25/BDU for conifer in a production operation. The cost of production was directly related to the volume/piece and number of pieces processed/minute. The use of a smaller, less expensive loader would reduce the hourly equipment cost by $11, and reduce chip costs by $1.00-1.25/BDU.

Table 3. Summary of Satellite Debarking and Chipping Costs.

	Recorded	Revised[a]
Spruce-pine ($/BDU)		
Equipment (at $231/SMH)	23.12	16.88
Operating supplies[b]	5.84	5.84
	28.96	22.72
Black spruce ($/BDU)		
Equipment (at $231/SMH)	23.12	16.88
Operating supplies[b]	5.84	5.84
	28.96	22.72
Lodgepole pine ($/BDU)		
Equipment (at $231/SMH)	25.69	18.75
Operating supplies[b]	5.84	5.84
	31.53	24.59

[a] Assumption based on reduced delays (17 pct.) and continuous supply of trees to flail.
[b] Operating supplies
Chain replacement $950 for 96 eight-link chains
Rod replacement $1000 for 8 rods
Knife replacement $75 for 4 knives

knives need to be changed regularly, the anvil must be properly adjusted, and the counterknives must be in good condition.

- All equipment needs to be fully winterized.

- An adequate supply of chip vans must always be at the outfeed of the chipper and they should be designed so that they can be filled to capacity. Landing size and configuration of chip vans with respect to the chipper outfeed must be such that system delay time is minimized when an empty van is exchanged for a full one.

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Analysis of Productivity and Availability of Two Operations Utilizing the Steyr KP-40 Grapple Processor[1]

Stephen J. Pilkerton, Loren D. Kellogg[2]

Abstract: The Steyr KP-40 is a relatively new entry into the North American mechanized delimbing market. Designed for European smallwood processing, it was unknown how well it would function in long log applications of the Pacific Northwest. A 6-month shift level study was conducted to determine long term productivity and mechanical availability. Productivity averaged 42.5 m^3 per productive hour processing log-length and tree-length materials from stems averaging 0.39 - 0.42 m^3. Mechanical availability averaged 76 - 78 percent on the two operations studied.

Keywords: Mechanized harvesting, delimbing

INTRODUCTION

The Pacific Northwest's forest products industry is faced with a rapidly changing raw material base. The conversion of privately held mature forests and increasing socio-political influence reallocating publicly administered timber are forcing the industry to gear up for dimensionally smaller second growth and previously shunned fiber resources. Harvesting costs, on a unit volume basis, increase exponentially with a decrease in piece size. Thus the industry is faced with lower productivity and higher costs in processing these resources.

Labor-intensive motor-manual limbing and bucking activities are a major cost component of traditional harvesting operations. Research has shown manual limbing and bucking activities to consume 50 to 70 percent of delay free felling and processing time in conventional small tree harvesting operations (Burrows, 1983; Kellogg, et al, 1986). Additionally, 27 percent of all logging injury accidents occur during these activities (Anon., 1984).

The logging industry in Canada, the Eastern and Southern United States, and Europe has had to deal with the problem of handling small timber in a safe and productive manner for years. Their solution has been to develop several delimbing and bucking-topping strategies for manufacturing precision length logs and/or tree length segments from whole trees. These can be functionally divided into stroke and roller/chain feed delimber-buckers.

All stroke delimbers secure the stem in stationary grapples and delimb by sliding grapple knives along the bole. There are essentially two types of stroke machines-- stroke-boom and stroke-deck units. Stroke-boom machines suspend the stem overhead, using sliding, telescoping, or knuckle booms to propel the grapple knives. Stroke-deck machines support the stem on a deck surface, and use chains or cables to slide carriage-mounted grapple knives along the bole.

Unlike the stroke machines, roller or chain feed delimbers pull the stem through stationary delimbing knives. Most of the European machines have incorporated computer microprocessors for pre-programmed, automatic precision length log merchandising. None of the stroke-boom machines currently have this automatic cycling capability. The European roller/chain feed delimbers are manufactured in two forms: grapple head machines, generally referred to as "single-grip" grapple processors; and "double-grip" bunk/chassis mounted units, where trees are placed into the feed mechanism by a loading boom. The "single/double-grip" terminology refers to the number of times the piece is grasped prior to processing.

The Austrian made Steyr KP-40 (Fig. 1) is an example of modern grapple processor technology. Since its 1985 introduction to the Pacific Northwest, the Steyr has been used to manufacture 9 - 15 meter log segments. As the Steyr was designed for production of log lengths up to about 7 meters in length, it was unknown how well the machine would hold up in long log applications. This study (Pilkerton, 1989) was undertaken to determine the long term productivity and mechanical availability of the Steyr KP-40 in Pacific Northwest conditions.

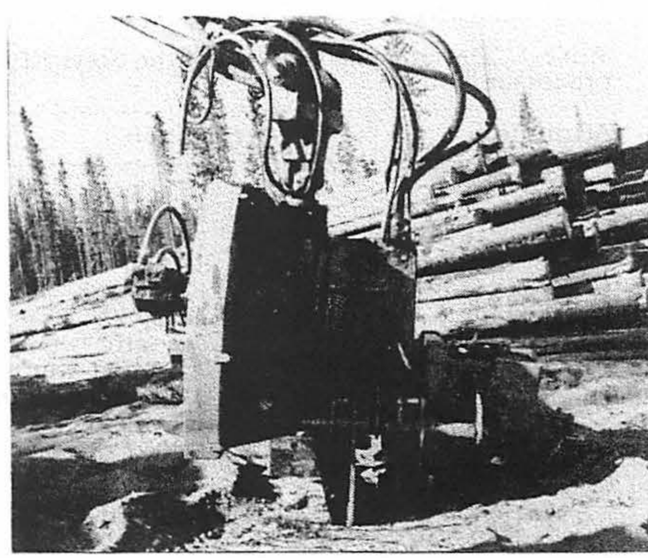

Figure 1. The Steyr KP-40 grapple processor.

[1] Presented at the 12th Annual Council on Forest Engineering Meeting, Coeur d'Alene, ID, August 27-30, 1989.

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PROCESSOR DESCRIPTION

The Steyr's single continuous feed chain pulls stems through five delimbing knives. Four grapple arms are powered by the carrier's variable displacement hydraulic pump to maintain constant pressure on the stem against the chain drive. One fixed and two wrap-around knives, which are pivot shaft mounted to allow for stem irregularities, function to delimb the upper bole. Knives mounted on the forward set of grapples delimb the lower bole. A hydraulically driven circular saw serves as the bucking device.

Operationally, the processor head grapples a stem and secures it against the chain drive. Log length information is gathered by a feed chain driven length encoder and sent to a cab-mounted digital display. Length measurement begins when the stem butt interrupts a light barrier positioned near the bucking saw. Upon reaching the desired length, and/or visually estimated diameter, the feed chain is stopped and the bucking saw activated. The severed log drops to the outfeed deck, while the remaining stem is retained in the grapples for further processing or disposal. Bucking saw activation resets the length encoder.

Although the operator can control all functions manually, a microprocessor and controller-programming unit mounted in the cab provides an automatic delimbing, length measurement, and bucking sequence. The operator may program up to seven desired lengths. Thereafter, pushing one of the seven programmed-controller buttons, corresponding to the desired length, activates the feed chain and bucking sequence. Manual override is possible at any time.

The unit by design is a single stem processor. However, multiple stem processing is possible if small, tightly bunched stems can be grappled simultaneously. Maximum delimbing diameter is 45 cm. Maximum bucking diameter is 35 cm. Table 1 summarizes additional operating specifications.

Table 1. Design specifications of the Steyr KP-40 processor.[a]

Attribute	Specification
Length	191 cm
Width	114 cm
Height	117 cm
Weight (with rotator)	811 kg
Log feed rate	1.5 m/sec
Log feed force	12-25 kN
Processing memories	7 length
Length accuracy	2.5 cm at 4 m, 0.5 pct. over 4 m
Carrier power (net)	90-105 kW

[a]Source: Manufacturer's brochure

STUDY DESCRIPTION

The two Steyr units studied belonged to Mid Columbia Forest Systems of Hood River, Oregon and the S & H Timber Company of Bend, Oregon. Both Steyr processors studied were mounted on used John Deere 690-B tracked excavator undercarriages. The JD 690-B's engine is rated at 97 kW. Although neither operator had prior grapple processor operating experience, both primary operators were experienced log loader operators.

The Mid Columbia Steyr operated primarily on timber sales in the Mount Hood National Forest during the shift level study. This mixed-conifer stand contained lodgepole pine [Pinus contorta (Dougl.)], grand fir [Abies grandis (Dougl.) Lindl.], western larch [Larix occidentalis Nutt.], and associated species. The preharvest stocking of 815 trees per hectare had approximately 318 m^3 per ha. Slopes ranged from 0 to 20 percent. The sale contained clearcut and partial cut units. All but the largest trees were mechanically felled and bunched by two Clark Bobcat 1080-B feller-bunchers (30 cm shear capacity). Two John Deere 640 (90 kW) grapple skidders skidded the whole trees to roadside landings where they were immediately processed. The Steyr manufactured random length stud-logs to a minimum 15 cm top diameter and pulpwood.

The S & H Timber Steyr operated on fiber salvage timber sales in the Deschutes National Forest for the duration of the shift level study, producing tree length chipping material. The stand was infested with the mountain pine beetle [Dendroctonus monticolae]. The pure lodgepole pine stand had a preharvest stocking of approximately 1482 trees per ha. Volume in 15 cm plus dbh dead and dying material was approximately 119 m^3 per ha. Terrain was flat with occasional slopes to 10 percent. One Hydro-Ax feller-buncher with a 51 cm shear head capacity felled timber. Whole tree skidding was accomplished with a single Caterpillar 518 (90 kW) grapple skidder. Stems were immediately processed into tree-length segments at the roadside landing, to a 10 cm minimum top diameter or a 15 m maximum length.

STUDY METHODS

A six-month shift level study was conducted to determine the productivity and mechanical availability of the Steyr Processor. A detailed time and motion study was conducted in addition to the shift level study for analysis of production characteristics and system level interactions. A cab mounted 24-hour model DSR Servis Recorder and a daily report form were used to monitor utilization. The operator recorded piece count production and the cause of each non-productive period (duration greater than 10 minutes) which occurred during the shift.

The model DSR Servis recorder is a dual track monitor, utilizing a motion-activated pendulum recorder and an electro-magnetic recorder. The electromagnetic recorder was wired to the circular saw power switch. This allowed for differentiation of processing time from non-productive time. The Steyr operators were responsible for rewinding the clock mechanism and installing a new recording chart at the beginning of each shift.

RESULTS

Both Steyrs required replacement of the main structural frame due to fracturing during the study period. These repairs are reported as prototype repairs as the original frame was replaced with a sturdier frame provided by the manufacturer. The Mid Columbia operation was down 12 shifts (nominal shift - 9 hours) and the S & H Timber operation was down 8 shifts (nominal shift - 8 hours) due to these repairs. These hours are excluded from the following reported values as they are considered prototype anomalies.

Due to operator turnover and sporadic shift level reports, Mid Columbia's Steyr activities are reported for a continuous 50 shift period totaling 449 scheduled operating hours. Production averaged 119.6 pieces per productive hour from trees averaging 1.2 pieces. Average piece size was 0.35 m^3 for a total of 42.3 m^3 per productive hour.

A total of 914 scheduled operating hours covering 126 shifts were reported on the S & H Timber operation. Production during this period averaged 110.8 pieces per productive hour. There were only 1.02 pieces per tree due to tree length processing. Average piece volume was 0.38 m^3 for a total of 42.6 m^3 per productive hour.

Long term utilization, the percent of time spent in productive activities, averaged 58.2 and 59.7 percent over the reporting periods for the Mid Columbia operation (Fig. 2) and the S & H Timber operation (Fig. 3), respectively. Mechanical availability; defined as the ratio of productive time to the sum of productive, active repair, and service time; averaged 78.3 and 75.9 percent for the respective operations.

Based on a machine rate of $ 50.06 per scheduled operating hour and a long term utilization of 60 percent, a processing cost of $1.97 per m^3 is calculated for both operations based on their reported shift level production. Production per scheduled operating hour averaged 60 and 65 trees for the Mid Columbia and S & H Timber operations, respectively. The contractors and timber purchasers were all satisfied with delimbing and bucking quality, which generally consisted of flush knots and minimal slabbing (longitudinal splitting of the log).

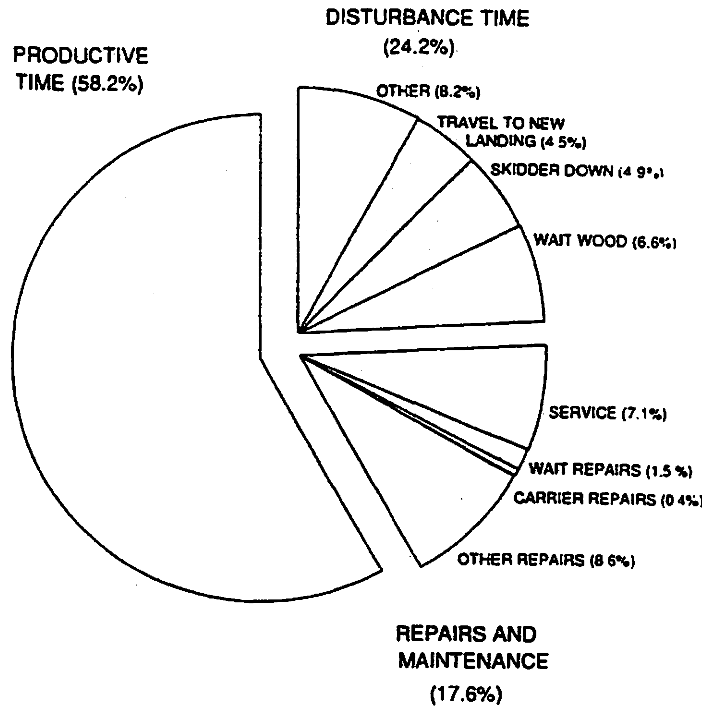

Figure 2. Long term Steyr activities - Mid Columbia operation.

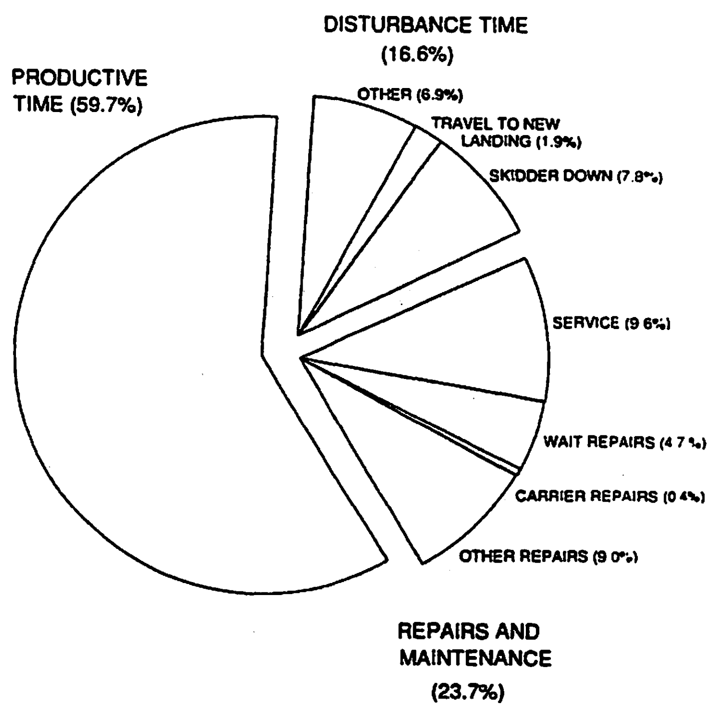

Figure 3. Long term Steyr activities - S & H Timber operation.

DISCUSSION

Observed Steyr production is comparable to reported production of two stroke-boom machines delimbing tree-length materials of similar size. A Roger delimber (18 m boom) produced 26.6 m^3 per productive hour from a throughput of 92 trees averaging 0.29 m^3 (McMorland, 1984). A Denis delimber, working in a central processing yard, produced 49.3 m^3 per productive hour on a throughput of 107 trees averaging 0.46 m^3. The Steyrs studied processed 103 (log manufacturing) and 109 (tree-length) trees per productive hour. Additionally, Powell (1981) reports a Hahn Harvestor (stroke-deck) processing 43.3 m^3 per productive hour from stems averaging 0.38 m^3.

Utilization, which is a system dependent measure, could be improved. More than 40 percent of the total reported hours on both Steyr operations was spent in non-productive activities. Disturbance delays, which consist of all non-productive activities excluding repairs and service, accounted for 24.2 and 16.6 percent of the total reported hours on the Mid Columbia and S & H Timber operations, respectively.

Approximately one-quarter of the Mid Columbia Steyr's disturbance time was caused by a lack of wood for processing while one or more skidders were operating. During an additional 4.9 percent of the total reported hours the Steyr was out of wood due to skidder downtime. This operation processed from a small infeed deck, tying production to that of the skidder (Fig. 4).

This landing layout created skidder-Steyr interference and system imbalance. The Steyr operator would process stems from a fixed location, building up the processed deck to a maximum height before it would move backwards and begin decking upwards against the previously decked logs. Processing in this fashion created a number of production hindering effects: "dead" infeed space beyond the Steyr's operating position which limited decking area for newly skidded stems and perpetuated "hot" processing through the lack of an adequate "cold" deck; it forced the skidder to travel out in the direction of the incoming skidder; incoming skidder delay to allow the Steyr to complete processing of current stem; and alternately Steyr delay to allow skidder to deck logs and/or clear slash.

Conversely, the S & H Timber landing layout minimized interference and promoted system balance. The Steyr utilized the whole landing, processing in a circuitous route (Fig. 5), incrementally increasing deck height with each pass. As the Steyr processed stems, it created an opening in the feed deck for newly skidded logs. The skidder would deck stems on the opposite side of the opening created, away from the Steyr. The skidder removed slash from the processing path without interfering with the Steyr. The Steyr usually had a one to two hour supply of decked stems, which buffered long skids or minor skidder delays. However this operation still incurred half of its disturbance time due to skidder repairs and operator absence. Reported Steyr mechanical availability is low in comparison to reported values of 86 and 90 percent for Harricana and Roger delimbers, respectively (Giguere, 1981); 85 percent for a Denis delimber (McMorland, 1984); and 86 percent for a Hahn Harvestor (Powell, 1981). Carrier repairs amounted to only 0.4 percent of the total reported operating hours, thus validating the decision to mount the Steyr on used carriers.

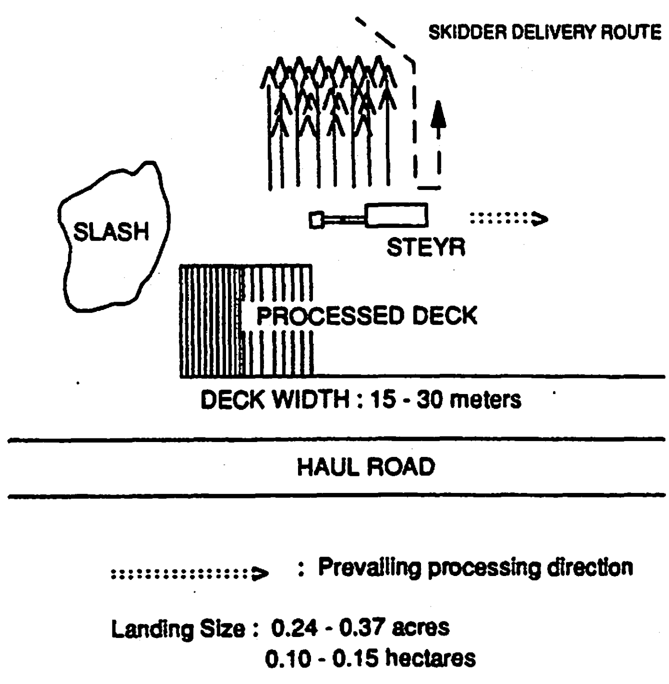

Figure 4. Typical roadside landing of Mid Columbia operation.

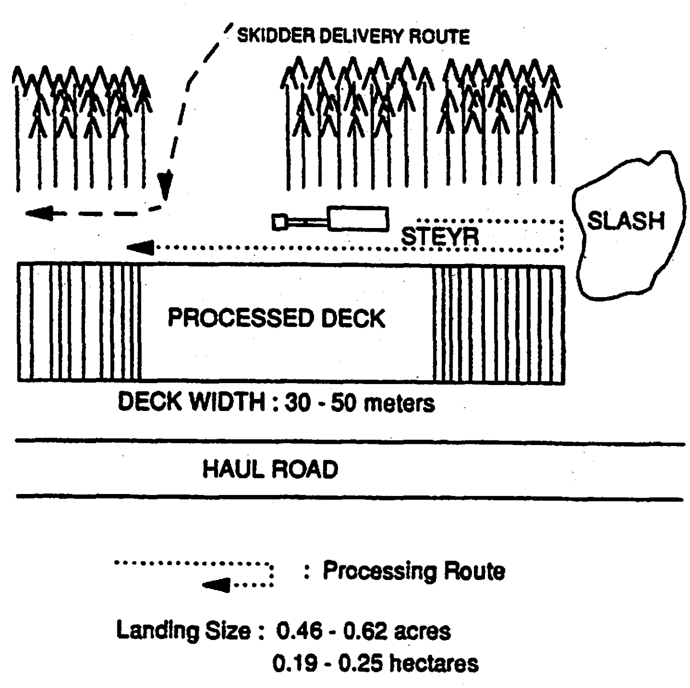

Figure 5. Typical roadside landing of S & H Timber operation.

Approximately 60 percent of the reported active repair time on both operations was attributable to design or installation inadequacies. One should note that there been Steyr KP-40 design improvements incorporated into the newer version, referred to as the Steyr KP-40 Series II, which include: a stronger rotator - mounting unit, a redesigned frame - a second modification to the replacement frames on the two operations studied, a modified microprocessor - not subject to the voltage spikes of the studied Steyrs which eventually utilized isolated 12 volt batteries for its power source, a modified length encoding system which can display english and metric units, automatic oiling of the chain feed drive, and redesigned saw guides to improve blade life by reducing wobble which caused both operations to modify the blade shrouding. Upon inspection of the Series II, it also appears that the hydraulic hoses have been protected, and overall it appears to be structurally better than its predecessor.

The Steyr's unit costs are comparable with other reported mechanized delimbing-bucking costs. Greene and Lanford (1985), reporting on a Valmet 940 grapple processor operating in a loblolly pine plantation, had processing costs of \$8.21 per cord. Using a conservative factor of 1.28 cunits per cord, this results in a processing cost of \$2.27 per m^3. Peterson (1986) projects a processing cost of \$3.17 per m^3 for a Hahn II Harvestor operating in a central processing yard.

SUMMARY

The Steyr KP-40 grapple processor effectively delimbed tree-length fiber material and manufactured sawlogs from lodgepole pine and mixed conifer stands of Central Oregon. Long term productivity averaged 42.5 m^3 per productive hour at a cost of \$1.97 per m^3, which is competitive with other mechanized delimber-buckers.

Recorded mechanical availability is in the 75 - 80 percent range, however, with recent design changes the potential for increased availability exists. Utilization averaged 60 percent, however harvest planning and system balance among the components can increase this system dependent measure.

The Steyr KP-40 grapple processor thus appears to be an acceptable alternative to current stroke delimber-bucker technology in the mixed conifer and lodgepole pine types common to Central Oregon and the intermountain region.

ACKNOWLEDGEMENTS

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An Electronic Machine Monitor for Long-term Time Studies[1]

Bob Rummer and Bryce Stokes[2]

Abstract: Equipment utilization data for forest engineering production studies is difficult to obtain, requiring extended field observations to monitor a sufficiently representative period of time. Current methods of obtaining utilization data entail costly field study or daily attention to chart recorders. An electronic monitoring system has been developed to collect machine utilization data for extended periods without intervention. The electronic system was used along with conventional stopwatch time study and tachographic monitoring to quantify the utilization of a drive-to-tree feller/buncher in a field study. The estimates of utilization rate given by the three methods did not significantly differ.

Keywords: feller/buncher, instrumentation, utilization

INTRODUCTION

The purpose of time study is to improve productivity of man-machine systems through careful evaluation of how system time is spent. Total machine time can be broken down into several distinct categories (fig. 1). Scheduled machine hours (SMH), for example, can be separated into productive machine hours (PMH) and delays. Delays can be further subdivided into specific classes. Similarly, productive time can be broken down into individual work elements. Through analysis of the time attributed to each category, system inefficiencies and performance characteristics can be identified for subsequent improvement.

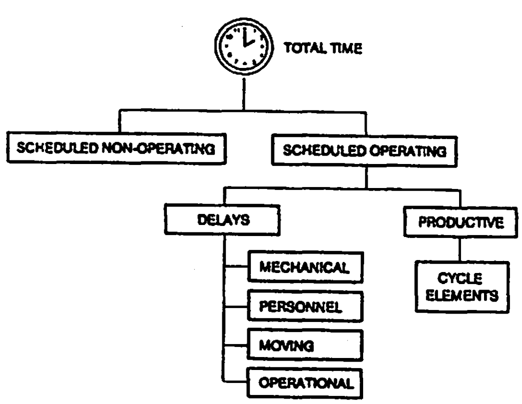

Figure 1--Breakdown of machine time (after Rolston 1972).

1 Presented at the 12th Annual Council on Forest Engineering Meeting, Coeur d'Alene, ID, August 28-30, 1989.

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Most forest engineering production studies measure productive time using an elemental time study. Such studies examine a machine's performance on a cycle basis. Each cycle is broken down into distinct activities, or elements, and the time to perform each element is measured. Because of the cost and effort of data collection and analysis required for detailed time study, most production studies are completed in a few days. Such a short duration, however, is insufficient to sample the occurrence of many types of delays and irregular productive elements. Thus, production is usually defined on a productive machine hour (PMH) basis assuming a utilization rate (the ratio of productive time to scheduled time). Because the true production rate is production per PMH multiplied by the utilization rate, the assumption of a "standard" utilization rate obscures differences in productivity.

The necessary complement to the short-term detailed time study is a long-term utilization study. Long-term study covers a sufficient period of time to record delays and irregular elements. Combining the utilization rate obtained from the long-term study with the production data from the detailed time study can provide a more accurate estimate of actual machine productivity.

Collecting long-term time study data by current methods, however, involves costly field time when stopwatches or tachographic recorders are used. New electronic data recorders are being applied for field data collection in forestry applications. Application of this technology to machine monitoring to provide an improved method of long-term time study is considered in this study.

OBJECTIVE

The aim of the present study was to evaluate the concept of using an electronic data acquisition system for long-term unattended time study on forestry machines. Initial design criteria included the ability to discriminate between several machine activities and to operate for extended periods without operator intervention. The data recorded by the electronic device were compared to data collected by standard stopwatch and tachographic procedures.

LITERATURE

Two of the most common methods of obtaining long-term utilization data are work sampling and tachograph recording. Work sampling, also known as ratio-delay study (Niebel 1982), is a classic industrial engineering technique that consists of taking discrete observations at specific points in time. At each observation time, the activity of the system is classified and tallied. Observation times should be random and unannounced to avoid possible bias. Work sampling studies generally require a time study person to be assigned to the project, although a single observer can easily collect data on more than one machine.

Marsh (1969) used work sampling to analyze the effect of stand variables on harvesting system productivity. Several crews were observed while working in good, fair, and poor operating conditions. Based on approximately 3,000 work sampling observations, the work activities of the felling and skidding functions were analyzed to examine variations in productivity. Miyata, Steinhilb, and Winsauer (1981) described work sampling for logging production studies. In addition, they compared the work sampling technique with continuous stopwatch time study for determining machine utilization. Comparison of the field data showed that the work sampling data closely agreed with the utilization rate determined from continuous time study.

Tachographic recording is an alternative method used to obtain utilization data over a long time period. Tachographic recorders consist of a mechanical drive, indicating pens, and a paper chart. In a typical service recorder, for example, the working machine vibrates a pen over a rotating circular chart, leaving a wide mark. When the machine is idle, the pen is stationary and the resulting mark is narrow. The charts can be examined to determine idle and productive times. Some tachographic devices also record machine parameters such as engine rpm on the recorder chart. Compared to work sampling studies, tachographic recording requires little data collection time and is therefore less costly.

Everts (1975) described the use of tachographs for monitoring site preparation operations in New Zealand. Operators were required to change charts and to note the causes of idle times that exceeded 5 minutes. Analysis of the tachograph data determined the current equipment utilization rate and identified actions to increase utilization. Baumgras (1971) illustrated the use of tachographs for monitoring logging truck utilization. He noted that the chart data could be used to locate system inefficiencies, improve crew supervision, and analyze system performance.

Tachographs, however, have three distinct shortcomings--they require chart handling, offer limited time resolution, and limited activity discrimination. Depending on the type of recorder used, the circular charts may need to be replaced every shift. Some types may run up to nine days without changing. Proper labeling and protection of the charts are necessary to insure usable data. The charts must also be carefully read to develop the time study data.

Closely related to the length of the recording is the problem of event resolution. On a 24-hour service recorder chart, the scale is divided into 5-minute increments. On a 9-day chart, the resolution is considerably coarser. This makes it difficult to identify short-duration delays.

Finally, tachographic recorders are limited in their ability to discriminate between machine activities. A service recorder, for example, will identify a machine as either moving or sitting still. There are instances, however, when machine vibration may not be an acceptable indicator of productive time. A cable skidder, for example, could be sitting still during the choking phase of the machine cycle. This would be incorrectly identified on a tachograph chart as idle time. Although tachographs may have optional inputs, their ability to categorize is limited to a few classes of machine activity.

In the present project, electronic technology was used to combine the activity discrimination of work sampling with the stand-alone operation of the tachographic recorder.

METHODOLOGY

Hardware

The data acquisition system developed in this study was based on the Omnidata Polycorder[3] Model 700. Rummer and Ashmore (1987) described the capabilities of an earlier Polycorder model and its application in forest engineering studies. The Omnidata is an electronic data recorder able to measure and condition input signals, manipulate the data through programmed algorithms, generate output control signals, and store data in battery-backed memory. As many as 10 analog input channels and 8 digital input lines can be configured. There are 448K bytes of random access memory (RAM) available for program and data storage. The unit is contained in an environmentally sealed case with a membrane keyboard for operation in harsh conditions.

For this study, the Omnidata was connected to six sensors that were installed on a rubber-tired, drive-to-tree feller/buncher. The sensors were:

(1) Engine On--A relay was connected to the vehicle electrical system that closed when the engine was on (digital input).
(2) Maintenance switch--A toggle switch was mounted near the instrument panel with an associated indicator light. The operator was instructed to activate the switch during maintenance activities (digital input).
(3) Engine rpm--A tachometer generator (Servo-Tek Type SN-763A-2) was mounted on the engine (analog input).
(4) Driveshaft--A detector circuit utilizing two magnetic switches and flexible magnets was attached to the driveshaft. The magnetic switches generated a pulse signal that was processed through the circuitry to indicate driveshaft rotation on two digital channels. If both channels are low, the driveshaft is not rotating. If either channel is high, it indicates forward or reverse rotation (i.e., 10=forward, 01=reverse).
(5) Shear pressure--A pressure transducer (Paine Instruments Series 212) was installed in the hydraulic line going to one of the shear cylinders (analog input).

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3 Mention of trade names is solely for the information of the reader and does not constitute endorsement by the U.S. Department of Agriculture.

(6) Cab temperature--A thermistor was placed in the cab to monitor cab ambient temperature (analog input). This parameter was included as a matter of interest and was not used to classify machine activity.

Software

Data acquisition was controlled by a program running in the Omnidata under the Autolog mode. Autolog operation wakes up the recorder at specified intervals and executes the data acquisition program. At the completion of the program, the Omnidata powers down until the next sample time.

The data acquisition program logic is illustrated in Figure 2. Although the Autolog function cycled continuously throughout the day, the program checked the time and only collected data between 6 am and 6 pm. If the maintenance switch was set, or if the engine was off at the sample time, the program recorded the appropriate values and terminated. If the maintenance switch was off and the engine was on, the Omnidata measured values of engine rpm, cab temperature, and shear hydraulic pressure. The software required 780 bytes of RAM storage. Figure 3 illustrates an example of the data file created by the data acquisition program.

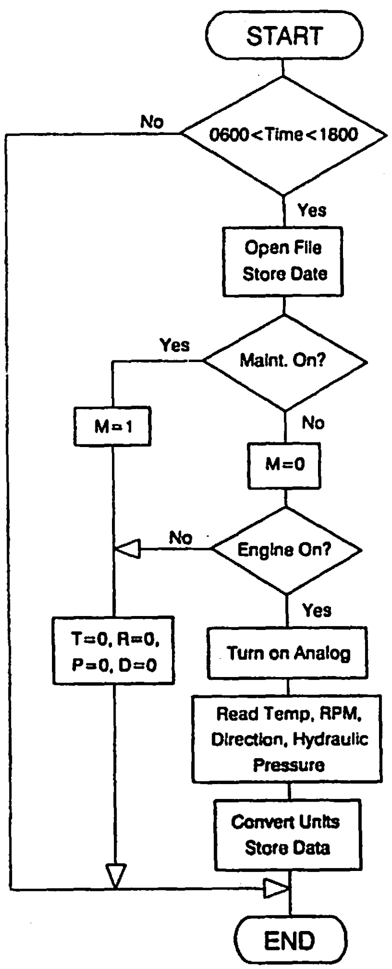

Figure 2--Flowchart of the electronic monitor's data acquisition program.

Date	Maint.	Engine RPM	Cab Temp.	Shear PSI	Driveshaft Forward	Driveshaft Reverse
216	1	296.8888	18.7153	-100.7125	0	0
216	1	1211.2982	19.0609	-120.8556	0	0
216	0	1045.0348	19.7525	362.5684	0	0
216	0	1121.3620	20.0976	956.7867	0	0
216	0	1022.9604	19.4053	755.3614	0	0
216	1	1031.4360	19.0589	-55.3934	0	0
216	1	1223.1258	19.4045	-50.3579	0	0
216	1	929.6374	18.7121	-55.3939	0	0

Figure 3--Excerpt from a data file created by the Omnidata program.

Field Test

After the data acquisition system was assembled, programmed, and tested in the laboratory, its performance was validated in a field study. The system was installed in a Hydro-Ax 511B feller/buncher that was operated by an independent contractor near Auburn, Alabama. After installation, the electronic machine monitor was operated for several weeks to verify functionality of the transducers and sampling program. During this period, the tachometer generator failed as a result of vibration and was replaced by a similar unit.

After the system was checked out, a production study was conducted on the feller/buncher using three data collection methods: (1) the electronic recorder, (2) two Servis Model T tachographs with 12-hour clocks, and (3) continuous stopwatch timing. For this test, the sampling interval of the Autolog program was set at two minutes and the electronic recorder was left unattended for the two-week period of the study. Tachographs were mounted on each door. A trained technician used continuous stopwatch timing to record productive and delay times.

The data from all three methods were summarized to determine daily and overall utilization rates. Utilization rates recorded by the three data collection methods were compared, and the ability of the electronic recorder to discriminate between different machine activities was subjectively evaluated by comparison with data from the stopwatch time study.

Both the tachograph charts and the stopwatch time study data provide continuous data. Theoretically, they should yield the true utilization rate by observing the entire study period. The electronic recorder, on the other hand, has some sampling error associated with taking discrete observations to estimate machine activity. Using work sampling theory, 95% confidence intervals were calculated for the electronic recorder utilization values using the equation:

$$CI = 2.037 * \sqrt{\frac{p * (1-p)}{n}}$$

where: CI = one-half the confidence interval width,
p = observed utilization rate, and
n = number of work sampling observations.

RESULTS

The electronic recorder operated continuously for 21 days, the comparative time study occurring during the last 14 days of the period. The data file created during 21 days of sampling filled 404K bytes of RAM. About one week into the sample period, just prior to the initiation of the three-part time study, the driveshaft rotation sensor was disabled by a severed sensor cable. The time study continued without the driveshaft sensor. Because of wet weather, only five days were suitable for working.

At the end of the field study, the equipment was removed from the machine and data in the electronic recorder were downloaded to a personal computer for analysis. A frequency distribution of engine rpm (fig. 4) was developed to subjectively establish a breakpoint for productive activity. Based on the recorded data, values above 700 rpm were considered productive. A similar analysis of hydraulic pressure to the shear (fig. 5) was used to evaluate shearing activity. Based on the field data, pressures above 550 psi were arbitrarily considered shearing.

Actual scheduled time for each day was calculated by subtracting the time of crew arrival in the woods from the time the crew left the woods, minus lunch. Daily scheduled times varied during this study from 6 to 9 SMH depending on weather conditions and equipment availability. The actual scheduled time was used as the common divisor for calculating utilization rates for all three data collection methods.

Total observed time reported by the electronic monitor started when either the machine or the maintenance switch was first turned on in the morning and ran until the last recordable activity at the end of the day. Total observed time from the tachographs was taken from the noted "Chart In" and "Chart Out" times. The stopwatch time study covered total time from the first productive activity until the last productive activity of the day.

With all machine activity defined from the field data, the results of the three time study methods were compared on a day-by-day basis. Figure 6 illustrates a comparative timeline for a selected day. Tachograph data identified machine time as either idle or productive. The electronic recorder identified shearing, productive, idle, and maintenance activities. The stopwatch study identified the specific causes of delay time with written remarks.

The summarized productive times and daily utilization rates are shown in Table 1. Overall utilization values averaged 65 percent for the entire study period. The electronic recorder and the tachograph were within 3 percent of each other for all of the daily utilization estimates. The stopwatch time study generally showed lower utilization values, although always within 10 percent of the other two methods.

DISCUSSION

Performance

The electronic machine monitor generally provided a reliable estimate of machine utilization during the course of this study. Engine rpm was an accurate indicator of productive activity except when the machine became stuck in the mud on March 2. High engine rpm during this delay was classified as productive time by the electronic recorder, but properly identified as idle time by the stopwatch and tachograph studies.

The maintenance switch on the electronic recorder correctly identified all repair activities that occurred during the study, but was also inconsistently used to identify daily

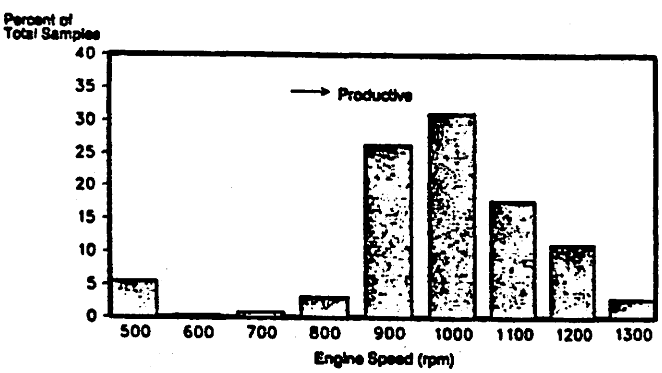

Figure 4--Frequency distribution of engine speed observations.

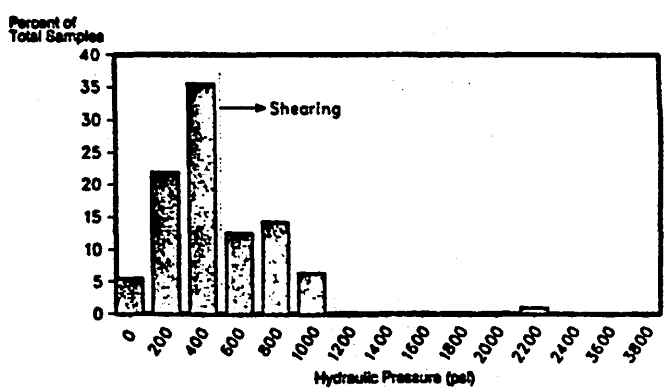

Figure 5--Frequency distribution of hydraulic pressure distributions.

Table 1--Comparison of time study data from the three collection methods.

Parameter	2/24	3/1	3/2	3/8	3/9	Overall
	Date					
Scheduled Minutes[a]	435	540	360	540	510	2,385
Total Observed Time						
Stopwatch	388	521	338	508	493	2,348
Tachograph	417	527	328	508	501	2,281
Electronic Recorder	408	532	338	530	502	2,310
Productive Minutes[b]						
Stopwatch	230	384	189	403	261	1,467
Tachograph	254	430	218	423	250	1,575
Electronic Recorder	254	428	218	438	252	1,590
Utilization						
Stopwatch	0.53	0.71	0.53	0.75	0.51	0.62
Tachograph	0.58	0.80	0.61	0.78	0.49	0.66
Electronic Recorder	0.58	0.79	0.61	0.81	0.49	0.67
95% confidence limits	± 0.06	± 0.05	± 0.07	± 0.05	± 0.06	± 0.03

[a] Scheduled minutes based on crew arrival and departure at job site.
[b] Productive minutes/scheduled minutes.

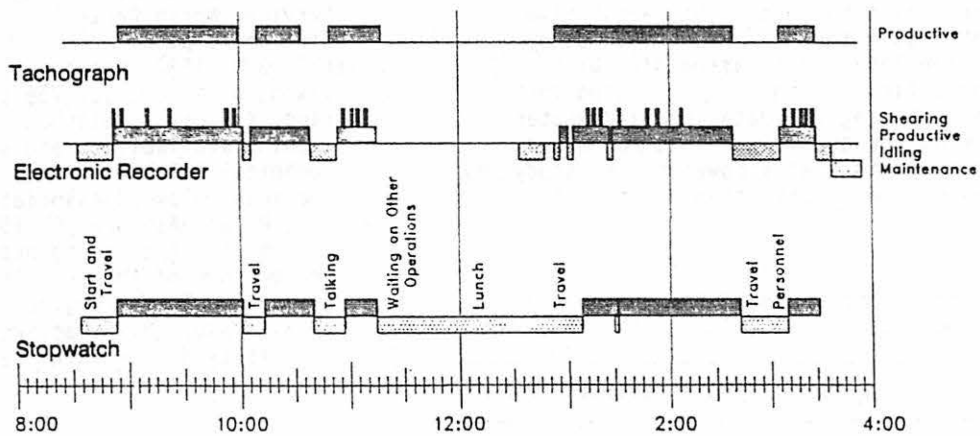

Figure 6--A comparative timeline for the three data collection methods.

fueling, lubrication, and cleaning the head. For such a self-reported activity, careful instructions need to be given to the operator as to what constitutes the activity. Even when an operator is give proper instructions, this type of data will be subject to errors when the operator neglects to set the switch during legitimate maintenance activity or forgets to turn the switch off at the end of the activity. One day during this study, for example, the operator set the maintenance switch while conducting end-of-the-day activities and left it on. This obscured the actual ending time and the starting time of the next day.

The electronic recorder also monitored pressure in the shear hydraulic line to detect shearing activity. The stopwatch time study, however, did not record individual shearing elements. Thus, the shearing activity recorded by the electronic recorder could not be corroborated by the other method.

The utilization values recorded by the tachographs used in this study were very similar to those recorded by the electronic monitor, but some mechanical problems in the tachographs showed up in the data. Because the two tachographs did not record the same elapsed times, it appears that the clock movements were out of adjustment. The tachograph times presented in Table 1 were selected from the charts closest to the other two methods. An additional problem developed when a faulty pen mechanism produced barely legible charts in one of the tachographs.

Of the three methods, the stopwatch time study method provided the most complete data. Job-related conversations, for example, were distinguished from personnel breaks. The stopwatch time study generally yielded lower utilization values than the other two data collection methods. For most days, the discrepancies between data from the electronic recorder and from the stopwatch were small amounts of time spread across the day, rather than any large differences in a single element. However, several problems with stopwatch data collection also became apparent during the study. On one day, the crew started operations before the data collector arrived at the site. The electronic recorder picked up the correct starting time, but the other two methods missed the beginning of the day. There were also several places where the remarks in the stopwatch data did not adequately identify machine activity. For example, at one point a lunch break was lumped in with some maintenance activity.

Costs

The three data collection methods vary not only in their performance capabilities, but also in the associated costs. Table 2 illustrates a possible set of cost assumptions based on 1600 hours of time study per year and a 3-year hardware life. Tachographic study requires the equipment, charts, mailing, and labor for chart analysis. The electronic recorder costs include the expense of the recorder and sensors, labor for installation and removal, and labor to download and print the data. Stopwatch time study is obviously the most expensive method because of the labor costs associated with maintaining a field technician, reducing the field data, entering the data into a computer, and performing the analysis. This rough cost comparison suggests that stopwatch time study may be 15 times more expensive than electronic monitoring.

Table 2--A cost comparison of the three data collection methods.

Cost Item	Tachograph	Electronic Recorder	Stopwatch
Purchase Price	$240.00	$4600.00	$175.00
Hourly costs ($/SMH)			
Depreciation	0.05	0.96	0.04
Expendables	0.02	---	---
Labor (collection)	---	0.25	20.00
Labor (analysis)	0.94	0.94	10.00
TOTAL ($/SMH)	1.01	2.15	30.04

CONCLUSIONS

The study demonstrated that an electronic machine monitor can effectively record machine activity for extended periods of unattended operation. With appropriate sensors, such a device can identify a variety of work elements. For long-term studies, such as those necessary to determine machine utilization, the use of an electronic monitor can be a cost efficient.

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Cable Thinning: An Effective Balance of Equipment And Personnel[1]

Martin T. Wozich[2]

Abstract: An equipment and personnel mix for efficient cable thinning of young, low volume stands is described. Practical application of whole tree yarding and processing is discussed.

INTRODUCTION

In eight years, our commercial thinning operation has expanded from two owner-operators and one Koller K300 yarder, to eleven woods personnel, two small yarders, a track-mounted loader, a swinging-grapple skidder and a crawler tractor. Our monthly production rates have gone from producing 30-60 loads and covering 16 to 20 acres to producing 100 to 150 loads and covering about 40 acres. In this paper, I will discuss how our operation evolved and why I feel it works effectively.

MARKET FACTORS

As a Forest Engineering (FE) graduate, fresh out of Oregon State University, I saw a challenge to carve out a niche as a thinning contractor who could do a quality job under tight financial constraints. The feedback I received then, and now, is that private and government landowners have an increased need for thinning contractors. Many small log mills are relying on thinning to provide part of their log supply. The mill we contract for takes about 25 percent of its log supply from thinning.

I observed that the number of thinning contractors did not seem to be keeping up with the number of thinning jobs available. With less competition between contractors for thinning jobs, I felt that if I expanded beyond a simple Mom and Pop operation, I would be able to better meet the demand for the service and reap a greater profit.

Once our company was in operation, I began to see an increased number of thinning sales with smaller trees (8 to 12 inches average dbh.) These smaller trees from younger stands can be harvested more efficiently with whole tree processing, but whole tree processing requires higher production to justify the extra processing equipment. For our company, this meant we would need to add another yarder in addition to adding processing equipment in order to stay profitable.

MATCHING THE EQUIPMENT TO THE JOB

While every thinning contract has its quirks, most of the jobs we bid tend to have some characteristics in common. Stands range from 20 to 70 years old with low volume per acre, from 1 to 4 loads per acre (26 to 104 tons per acre). Logs are shipped down to an 8 foot length and 4 1/2 inches small end diameter . A typical 26 ton load contains 70 to 80 pieces of wood. The ground is usually steep, often with broken topography. Yarding distances range from 300 of 2000 feet. Twelve out of 17 of our last timber sales had reaches greater than 1000 feet. Because these are thinning contracts, landing size is limited to avoid removing leave trees. To thin such stands, we need an efficient way to yard, process and load a large number of pieces from over a large area. Production always has to be balanced against damage to the residual stand.

Since we must keep the landings small and remove as few leave trees as possible, advance layout of the thinning sales is crucial. We need an adequate number of landings and skyline roads to cover the sale area and facilitate production. Corridor spacing is typically 150 feet. This avoids 200 foot sidepulls, uphill pulls, etc.

Advanced selection of landings is the key to effective job layout. While a clearcutter may log a whole job from one landing, a thinner uses many small landings. The landings must hold several turns in the landing chute without sliding. The landing must provide sufficient room away from the yarder to cold deck 1 to 2 loads in preparation for loading and have sufficient width to process whole trees into logs. This is a lot to ask of an area that may be only two truck-widths wide.

Another important part of advance layout is selection of guyline anchors, intermediate supports, tailtrees, and tailholds. These are flagged prior to felling. It's hard to rig a jack when the tree it was supposed to hang in has been cut down. Having an experienced crew member choose rigging trees in advance cuts down on production loss at machine set-up time.

Every job we have done has used some intermediate supports, either because of low tower height or because of broken terrain. Even with the 40 foot tower, we use intermediate supports 80 percent of the time. With a small diameter skyline (3/4 inch) on jobs with long reaches over 1400 feet, intermediate supports are almost always necessary for adequate payload capability.

Keeping these job conditions in mind, we have found our current equipment mix and system of operating to be effective. Most of our yarding is done with two small yarders. The larger is an AgroForst Technik V600. This is a two-drum yarder with a 40 foot telescoping tower. It has a 120 hp Perkins engine that powers a hydraulic transmission. The skyline and mainline drums hold 2000 feet of 3/4 inch and 7/16 inch line respectively.

Our other yarder is a Koller K300 with a 23 foot hinged tower. It has an 80 hp Iveco engine that powers a hydraulic transmission. The skyline and

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[1]Presented at the Annual Council on Forest Engineering Meeting, Coeur d'Alene, ID, August 27-30, 1989.

[2]Logging contractor, Commercial Thinning Systems, Inc., Pleasant Hill, OR.

mainline drums hold 1150 feet of 5/8 inch and 3/8 inch line respectively.

Both machines are narrow enough that when set against a bank, a loaded log truck can pass. Trucks have to be able to drive by when both yarders are set up on the same haul road. These yarders have the operator controls on the ground. Each is equipped with a Koller SKA1 multispan clamping carriage. The carriages have been reinforced to withstand heavy use and are equipped with T-bar hooks for ring chokers. We run 6 to 10 chokers depending on the piece size and the opportunity for presetting. Both machines are fairly simple to operate.

The AgroForst yarder, with greater horsepower, pulls about 30 percent more logs than the Koller yarder. The extra line strength and line capacity allows us to do logging jobs with reaches over 1000 feet. We can thin sales we couldn't do with just the Koller by putting the AgroForst on the long corridors and the Koller on the short corridors. The extra pulling capacity of the AgroForst is better matched to whole tree logging as well. Its increased operating costs are more than offset by its higher productivity.

We chose these two small yarders over domestic yarders, because we feel their size matches the thinning jobs. A 717 Skagit may produce 6 loads per day on a thinning where a Koller K300 or AgroForst V600 can produce 4 loads per day, but the smaller yarders will be more cost effective. Our yarders have lower operating and maintenance costs and fewer employees are required to operate them. With the yarder controls on the ground, we eliminate the need for a chaser to unhook turns at each yarder. Smaller line sizes mean fewer workers are needed just to pull line.

In the stands we thin, a larger machine could not accumulate a payload that would fully utilize its size and power. Small timber means smaller, weaker rigging supports and anchors that may be undersized for a domestic tower. The disadvantage of the small yarders is that they are unable to overcome a lack of deflection with tower height and require more intermediate supports and higher tail holds.

Once we began operating two yarders, our truck-mounted loader no longer met our needs. Last year we purchased a tracked Hitachi EX200 log loader with a Pierce boom and grapple. This machine is in constant operation. It loads six trucks per day at about 20 minutes per load. With small landings, we have to have a way to move logs out the chute. Since most land managers will not allow skidder swinging on rock roads, the Hitachi works well to swing and sort logs from under both yarders. We also use it for roadside logging and shovel logging after normal work hours. It is an integral part of the system when we process whole trees. Its mobility allows us to reach logs after bucking, move rapidly between two yarders to process, pile slash, and push trucks out of muddy landings.

With our initial operation, we used self-loaders to haul our logs. Most of our jobs are within a 90 mile radius of the mill. For a ninety mile, five hour round trip, the haul cost per ton increases 71 percent with self-loaders. This is a function of lower payload capacity and higher hourly rates for a self-loader. In addition, if we used a skidder to swing to a truck-mounted loader as in the past, we would be paying for two machines and two men versus one loader and one loader operator. The disadvantage of the tracked loader is its high ownership cost. We could not justify the expense of this machine with production from one yarder.

We do use a John Deere 540B skidder with an Esco 112 swinging grapple in our operation. The hitch that attaches to its blade allows us to move both yarders between landings. The skidder costs about $35 an hour to run as opposed to about $100 per hour for the loader and a truck. Since the maximum loader speed is 2.7 miles per hour, the grapple skidder works faster and cheaper accumulating clean-up logs. When allowed, we use this skidder for back-up swinging when both yarders are plugged up.

We keep a John Deere 450C Crawler as a utility machine. It has served as a guyline anchor, a tailhold, a road cleaner, and a snowplow.

MATCHING PERSONNEL TO THE JOB

With our current equipment mix we run an eleven person crew, including cutters. Labor is our greatest expense, running about 60 percent of our total costs. With our expanded and relatively specialized operation, we found it was important to put extra effort into hiring and training our crew. This extra effort is paying off in our ability to retain a work force that is safe, productive and conscientious. One frustrating aspect of the hiring process is that we gain about one permanent employee every fourth hire.

Management comes from a manager and a hooktender. As manager of our operation, I am directly involved in most business decisions. I estimate costs and production levels, negotiate with the mill, and argue with sale administrators. I am also responsible for arranging for repairs and adjustments to the machinery as needed.

I provide training, supervision, and feedback to the entire crew. I find it beneficial to periodically fill-in for absent crew members, since it helps me keep in touch with all phases of the operation. I view these times as opportunities to reinforce work techniques and check on equipment operation.

I think an effective manager has to have the ability and willingness to do any task within the operation. If I want to train the crew to do specialized jobs, I need to know firsthand what each job entails. As a manager, I have to set standards of production and balance productivity with proper techniques, quality work, and safety. I have to think ahead as to how preplanning affects production. And I need to continually evaluate and update our operating system to match the logging conditions.

With two yarders, two complex carriages, a skidder and a loader all working in a harsh environment, I expect frequent breakdowns. When machines are down, I have to find alternate work for the crew that will maintain production. At the same time, I may be hustling to get a machine running again. While my FE degree and nine years of logging experience help, I find the ability to think on my feet comes in most handy.

As our operation expanded, I added another management position. This individual spends about 3/4 of his time as a hooktender and about 1/4 of his time as a layout engineer. This position is currently filled by an FE graduate with 3 years logging experience. Ideally, the hooktender/engineer should be able to take my place when I am not at the job site. He also might fill-in for an absent crew member, train and supervise employees, and coordinate road changes and processing systems.

One of the hooktender/engineer's most important responsibilities is job layout. In addition to walking the whole sale and flagging corridors, rigging trees, and anchors, he reports back to me on the production potential of prospective sales, points out contract areas that need close examination prior to bidding, and provides input as to whether whole tree logging would be beneficial.

Most of our crew starts out as choker setters. Our new hires have little or no logging skills, have previously held minimum wage jobs, and tend to be men in their early twenties who know how to work hard. I'd rather train the individual for commercial thinning, than pay the going rate for experienced loggers that have to be retrained. It is my observation that a small percentage of the population is able to accept and withstand the adverse work conditions of logging. As mentioned, about 25 percent of new hires stay, and after 2 to 3 years they can consistently work independently and maintain production.

Our equipment operators have been trained and moved up from the ranks. I think they view their positions as a reward for staying with the company. We try to train each employee to do as many jobs as possible. Having knowledge of how the entire system works together makes them more productive, and they can fill in for another employee in a pinch. We base paid vacation and pay raises on productivity and longevity.

Our felling is currently done by a subcontractor (an owner and one employee). He had previous thinning experience, both cutting and yarding. This background helps him choose where to drop trees so they can be yarded with minimal stand damage. In the three years he has cut for us, our cutting quality has improved greatly.

Fallers cost most on an hourly basis. At approximately $34 per hour per faller, they need to spend time doing what they do best--felling trees. When possible, we yard whole trees and delegate limbing and bucking to landing personnel.

MATCHING THE SYSTEM TO THE JOB

We choose whole tree logging over bucking in the stand except in older stands of large trees with high volume per acre. A full payload turn can be hooked rapidly in these older stands. Very long trees are difficult to remove without scarring leave trees. These long trees throw a bottleneck in the system if they have to be processed on a small landing. In older stands with high volume per acre and large trees, the decrease in cutting cost for whole tree harvesting would be offset by lower production.

Whole tree logging works when there is less than an average of 60 lineal feet of logs per tree or when stand volume is lower than 10 Mbf per acre. These are the conditions found in most thirty to forty year old thinning stands in western Oregon. In these young stands, whole tree yarding increases our efficiency by decreasing felling costs and increasing yarder production. Two fallers can drop six loads of logs in whole trees per day. If they buck in the brush, this decreases to about four loads per day. Bucking, done by a chaser on the landing, costs about half as much as bucking in the brush.

With whole trees, we attain full payload capability with fewer chokers per turn. Less time is spent hooking logs and turn times are faster. Whole tree logging also reduces the average lateral yarding distance. There are fewer hang-up delays, since hang-ups increase with lateral yarding distance. Turn times improve when the choker setters don't have to pull as far to the side to hook the short top log.

An organized system of processing is essential for whole tree logging to work. We use the grapple skidder or the tracked loader to remove the trees from the chute to a landing area where they can be bucked into logs. In the past we bucked tops on the deck and rehooked them; this was time-consuming and dangerous for the yarder operator.

Stand damage is not necessarily greater with whole tree yarding since the probability of scarring will increase as more turns are pulled past a given leave tree. Whole tree yarding reduces the number of turns that have to go out. When yarding whole trees, the skill of the crew has a great affect on the amount of scarring. Fallers can drop the trees where they can be removed without rubbing hard on leave trees. Proper spotting of the carriage reduces rubbing, and the choker setters keep a saw handy to buck logs when needed.

PROBLEMS WITH OUR OPERATION

As we acquired more pieces of equipment, we gained an increased probability of breakdown. The AgroForst had some design and structural flaws that we have had to correct. It still has hydraulic problems that have not been corrected to my satisfaction.

In whole tree logging, when one machine fails, the whole system can fall apart. We're in a position where we can not afford to park either yarder. On jobs with only long reaches (greater than 1000 feet), the Koller is unproductive. The AgroForst can not put out enough wood by itself to keep the loader busy, so we stay away from those thinning jobs with predominantly long reaches.

In general, I am concerned about future labor availability, since logging appears to be unattractive to the quality work force we need. I am not convinced that higher pay will attract quality individuals to logging. We always seem to be doing a balancing act between labor availability and equipment availability. As we expanded and hired more people, we acquired an increased probability of human failure. We seem to have more problems with tardiness and absenteeism than when our operation was small.

As a manager, I usually feel like I'm spread too thin. I've found it difficult to develop a second in command who can keep things running smoothly when I'm not at the job site.

SUMMARY

Our current commercial thinning operation has evolved over eight years. After much trial and error, we have implemented a system of whole tree logging that utilizes two small yarders, a tracked loader, a grapple skidder and eleven crew members. This system is adapted to the logging conditions of younger, low volume stands available for thinning in western Oregon. Our operation is not problem-free, and it requires a great deal of management attention to run smoothly.

MATCHING CABLE YARDERS TO THE JOB: INTERPRETING EQUIPMENT SPECIFICATION SHEETS

John Sessions and John W. Mann

Abstract

In order to properly predict logging feasibility, harvest planners must know if yarding equipment can spool enough line to reach the logs, can develop sufficient lift to raise the logs, and at what speed the logs can be brought to the landing. Manufacturers' equipment specification sheets provide some of this information, but communication could be improved. Technical content in common specification sheets is reviewed and suggestions are made to improve communication.

Keywords: cable yarding mechanics, equipment productivity, harvest planning.

Introduction

Manufacturers' specification sheets for cable yarders are often used as a source of information during timber sale planning to help identify equipment that is capable of doing the necessary job. Traditionally, harvest planners have used static calculations of wire rope payload capacity as a test of physical feasibility in evaluating harvest project layout. The principal use of equipment specification sheets has been to determine if a yarder could spool a sufficient quantity of a large enough line to support a given payload under a set of topographic conditions. With the development of running skylines, it was observed that a check of line size and capacity was not sufficient (Darling 1985). For some machines and topographic conditions, yarder mechanical capability, not line capability, determines payload capacity (Hartsough et al. 1987).

Although payload capability has been used as a physical measure of feasibility, there is also an interest in using yarder simulation to improve estimates of economic feasiblity. Being able to support a load does not guarantee that it can be brought to the landing at an economically feasible rate. Wilbanks and Sessions (1985) demonstrated the relationships between load capacity and speed for several running skylines. Simulation models for skidders (SKID PC, OSU 1986) and trucks (Balcom et al. 1988) incorporate equipment mechanics to predict production as well as physical capacity.

This paper reviews the information typically found on manufacturers' specification sheets and how it can be used. We will identify information which will help answer the questions, (1) can the rigging reach the logs, (2) can the yarder lift the logs, and (3) how fast can the logs be brought to the landing?

Unfortunately, information from equipment specification sheets can often be misused or misunderstood. Misinterpretations have included estimating production using line pull at stall, using line speed with no load, confusing line pull with line retarding ability, or trying to derive line speed from engine output horsepower using estimated line pull. Such mistakes can lead to overestimating production, improper comparisons between yarders, and unreasonable expectations.

Specification Sheets

Yarder specification sheets are frequently set up similarly to Table 1. Data includes engine model, torque converter model, drum dimensions, and line size and capacity. Often a measure of line pull and line speed are also provided. Sometimes information on clutches and brakes are available, including manufacturer, model number, and type of clutch or brake. Let's first consider the line capacity, load capacity, and line speed information we can derive from such a specification sheet.

Drum Dimensions

Drum dimensions provide information that is important in two ways; 1) to calculate the amount of wire rope of a given line size that can be stored on the drum, and 2) to calculate the effective drum radius at any time during inhaul. Effective radius is important in determining the line pull and speed.

Often, line capacity for a range of line sizes is also given on specification sheets. If this information is not provided, the amount of line which can be stored on the drum can be calculated from the formula;

$$L = .2618\ W\ [(b_r + nd)^2 - b_r^2]/d^2$$

where,

- L = length of line on the drum, feet
- W = width of drum, inches
- n = number of layers of line on drum
- d = diameter of line, inches
- b_r = radius of the drum core, inches

If the number of layers of line on a drum is not known, it can be estimated by subtracting the drum barrel radius from the radius to the outside layer and dividing by the line diameter. If, instead, the amount of line on the drum, L, is known, the formula can be rearranged to solve for the number of layers on the drum as follows:

$$n = [\ -b_r + \sqrt{b_r^2 + d^2 L/.2618\ W}\ ]/d$$

Once the number of layers of rope on the drum is known, the effective radius, R_e, can be calculated by:

$$R_e = b_r + nd - d/2.$$

This information will be used later when we want to calculate line speed and pull at different points along the span.

TABLE 1. Typical specifications from a yarder manufacturer brochure.

PERFORMANCES AND CAPACITIES (sea level @ 60°F)

Pulls at stall or clutch slip--speeds at no load

Mark 21 Engine: G.M. 8V71N-N65 Torque Conv. T.D. 10,000 MS470

DRUM	DIMENSIONS		OPERATING CAPACITY		LINE PULL (LBS)*		MAXIMUM LINE SPEED (F.P.M.)	
MAIN	flange	33"	3150'	5/8"	bare	56,450	bare	784
	core	14"	2180'	3/4"	mid	32,585	mid	1358
	core length	21"	1600'	7/8"	full	25,500	full	1735
HAULBACK	flange	38"	6880'	1/2"	bare	49,650	bare	777
	core	14"	4400'	5/8"	mid	25,040	mid	1540
	core length	21"	3045'	3/4"	full	19,200	full	2010
STRAW & TAG	flange	26"	4800'	5/16"	bare	17,000	bare	1110
	core	9"	3340'	3/8"	mid	8,185	mid	2310
	core length	12"	1880'	1/2"	full	6,090	full	3100
SKYLINE	flange	40"	1930'	1"	LINE PULL			
	core	14"			1st layer	87,900	2nd layer	77,550
	core length	21"			3rd layer	69,400	4th layer	62,800

*Based on smallest cable size specified.

Load Capacity

Load capacity will depend upon the rigging configuration of the yarder, line strength, deflection, and the tensioning capability of the yarder. Lifting the load at a given location on the skyline profile requires tensioning one or more operating lines. Estimates of these tensions can be obtained from reference tables or by using a number of computer programs, such as LOGGERPC (OSU 1987). After this process, harvest planners refer to specification sheets to determine if the yarder can actually develop the anticipated line tension. The ability of the yarder to provide the needed tension will depend on the maximum torque which can be applied to the drum by the yarder either in pulling or retarding as required.

Driving Torque

Let's consider line pull. Most yarder specification sheets provide some information on maximum line pull. For example, Table 1 shows maximum line pull at bare, mid, and full drums at full throttle. What does this mean? Line pull is the amount of tension the yarder can develop for a specified amount of line on the drum and line speed. Often, line pulls are stated at stall or clutch slip. This is maximum pull with a line speed approaching zero. The yarder can develop this pull, but it cannot bring in the line, or perhaps can pull it in very slowly. This might be appropriate for raising a skyline using a "flyer", but using the maximum pull at stall for the mainline would be inappropriate for estimating production. Unfortunately, little information is usually available on the specification sheet to adjust the maximum pull at stall to a maximum pull at some desired speed. Most manufacturer specifications include information on line speed, but it is the maximum line speed at no torque, or very low torque. Using these line speeds would be inappropriate for loaded lines.

To select the maximum torque for a desired speed requires information on the power transmission efficiency as a function of the output speed from the torque converter or transmission. This information can be obtained from engineering offices of manufacturers, but is not available on typical yarder brochures. Figure 1 gives an example of how this information would look for a typical torque-converter output chart. Input torque and input horsepower refer to engine input to the torque converter. Output torque and output horsepower refer to output from the torque converter to a gear transmission or drum.

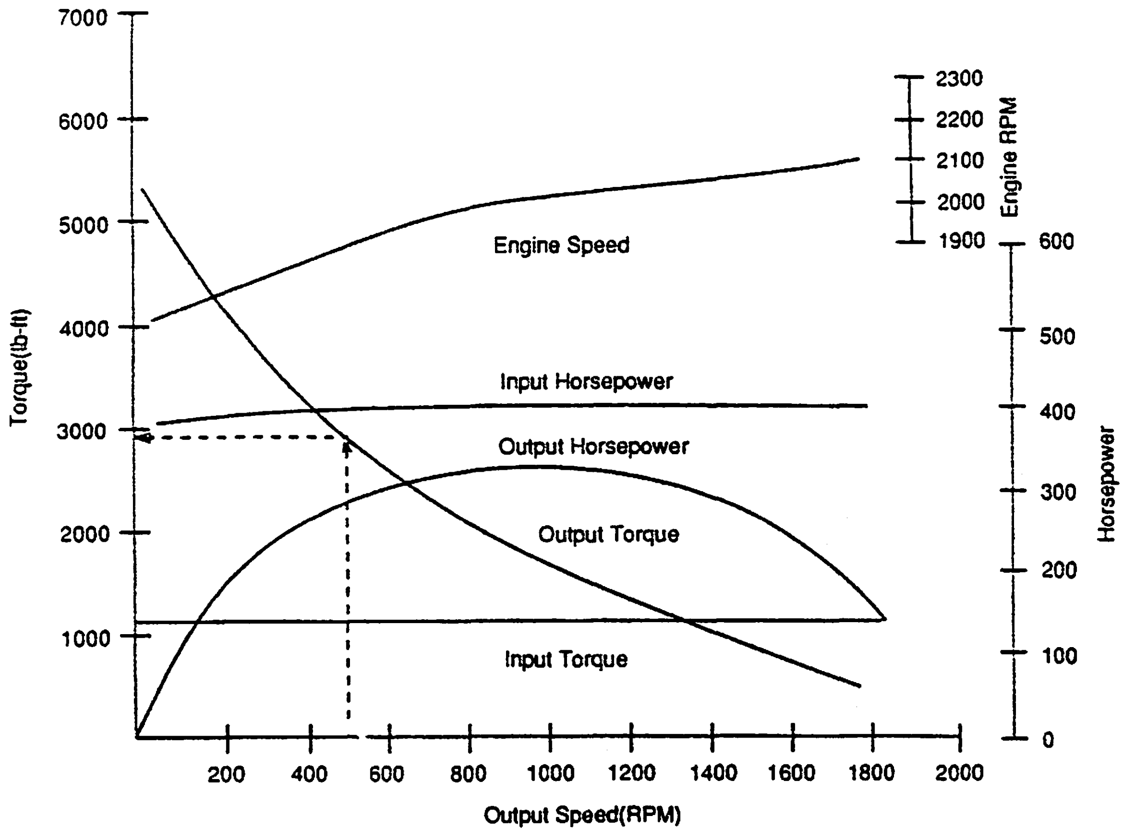

Figure 1. Output from a torque converter as a function of output speed for a typical cable yarder engine - torque converter combination.

Notice in Figure 1 that maximum torque occurs at zero output speed from the torque converter. Horsepower into the torque converter is relatively constant as a function of output speed of the converter, but horsepower out of the torque converter is not. At the point of maximum torque, horsepower output is zero. This means that all power is being used to heat the torque-converter fluid.

If Figure 1 were available, an appropriate maximum torque output could be selected based upon a reasonable line speed. For example, using Figure 1 and assuming we have a gear reduction, GR, of 10.0 between the torque converter and the drum, a transmission efficiency, E, of 0.9, and an effective drum radius, R_e, of 20 inches, then at a converter output speed, RPM, of 500 the line speed would be;

$$V = \frac{\text{effective drum circumference} \times \text{RPM}}{\text{gear reduction}}$$

$$V = 2 \times 3.14 \times R_e/12 \times \text{RPM} / \text{GR}$$

$$= \frac{2 \times 3.14 \times 20 \text{ in} / 12 \text{ in per ft} \times 500 \text{ rpm}}{10}$$

= 523 feet per minute.

Line pull could be determined by finding the output torque, OT, for an output speed of 500. From Figure 1 this is approximately 2900 ft-lb. The line pull, P, is now calculated by;

$$P = \frac{\text{converter output torque} \times \text{gear reduction} \times \text{E}}{\text{effective drum radius}}$$

$$P = \text{OT} \times \text{GR} \times \text{E} / (R_e/12)$$

$$= 2900 \text{ ft-lb} \times 10 \times .9 / (20 \text{ in}/12 \text{ in per ft})$$

= 15,660 lb.

These figures are useful for estimating what the harvest planner wants to know, e.g. feasible line pulls and production potential. For a given payload, line tensions are estimated by using LOGGERPC, or other methods. Knowing the location of the carriage on the span allows us to estimate the effective drum radius which determines the torque demand at the drum and consequently the torque demand at the converter. Knowing the torque demand at the converter yields the upper limit of line speed (full throttle) at this point in the span. This process can be repeated at various points along the span to obtain a line speed profile. Of course, such a speed profile must be viewed as an upper limit, since speed reductions for safety due to potential hangups must be considered.

Some harvest planners attempt to estimate line speed at a given line tension using engine output horsepower from the specification sheet. Although it is true that power is equal to force multiplied by velocity, the appropriate measure of power to bring in the load is that power which reaches the drum, not the power leaving the engine. From Figure 1, we can see that input power from the engine to the converter at full throttle is fairly constant as a function of output converter speed, but output horsepower from the converter is quite variable, particularly at low output speeds.

Braking Torque

Often a drum must provide retarding (braking) force rather than a driving torque to tension the lines. For example, in a running skyline, a haulback drum develops pull to return a carriage to the yarding area during outhaul. However, the same drum must develop a retarding force to maintain system lift when the loaded carriage is being brought to the landing during inhaul. The retarding force is provided by a retarding torque. This torque can be applied by a brake, such as a stand-alone slipping clutch, or by an interlock device using a slipping clutch or hydraulic regeneration system. Haulback lines being used to help support the load in other applications, such as slacklines, also require a retarding torque rather than a driving torque. Information on retarding torques is usually not provided in yarder brochures.

Substituting line-pull information for line-retarding information is not appropriate. If the model of clutch is supplied on the yarder brochure, the clutch manufacturers' brochure can be referenced to determine the maximum number of inch-pounds that the slipping clutch can maintain. Knowing the retarding torque, the corresponding line tension can be calculated using the effective radius. If this is less than the safe working tension of the line, this becomes the limiting factor. If the retarding torque is being applied by a slipping clutch, then the power dissipated by the clutch depends on the amount of slip and the retarding torque. Slipping clutch manufacturers provide the minimum rate of cooling fluid which must be supplied to prevent overheating of the friction surfaces for a given torque and drum speed.

Improving Communication

For a number of years, manufacturers of ground vehicles have provided figures showing rimpull or drawbar pull plotted as a function of gear, speed, and size of tire (Fig.2). A graphical display of such information for ground vehicles is relatively simple because the tire radius does not change appreciably during the skidding cycle. Similar charts could be prepared for cable yarders. For example, at one time the Skagit company provided yarder line pull - line speed data as shown in Figure 3(a) and Figure 3(b). Here we can easily see the relationship between line speed and line pull. If we want to reference the maximum load at stall, or the maximum speed at no load, we can read them directly from the graph.

At a minimum, however, a single graph of full throttle torque to the drum versus drum speed for one gear, transmission gear ratios, and drum dimensions provides sufficient information for a harvest planner to derive the rest of the information needed to predict equipment performance.

Concluding Remarks

Harvest planners often look to cable yarder specification sheets to help identify equipment capable of logging specific timber sales. The principal concerns are line capacity, load capacity, and line speeds. Typical specification sheets include drum dimensions, maximum pull at stall, and maximum line speed at no load. These values may provide a benchmark for the machine, but are not useful for harvest planning. Information provided in a format such as Figures 3(a) and 3(b) for both pulling and retarding modes would permit harvest planners to better estimate equipment payload capability and production rates.

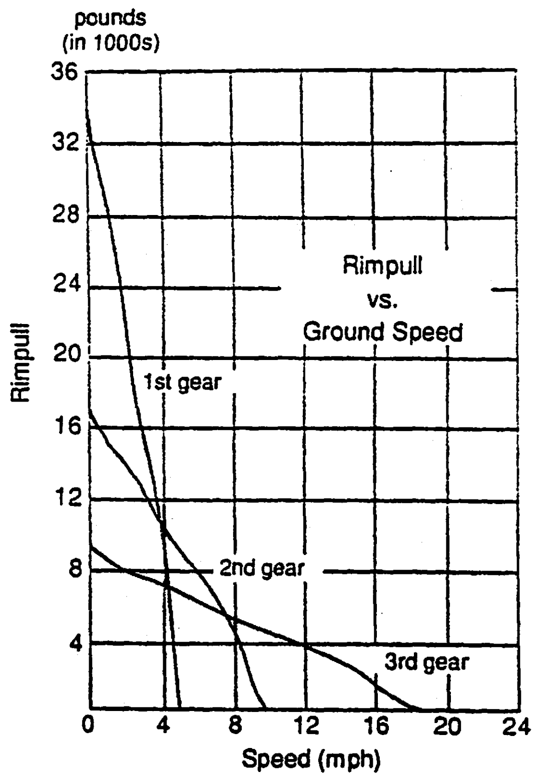

Figure 2. Rimpull as a function of speed and gear for a skidder using 24.5-32 tires. (courtesy of Caterpillar, CAT Handbook 18)

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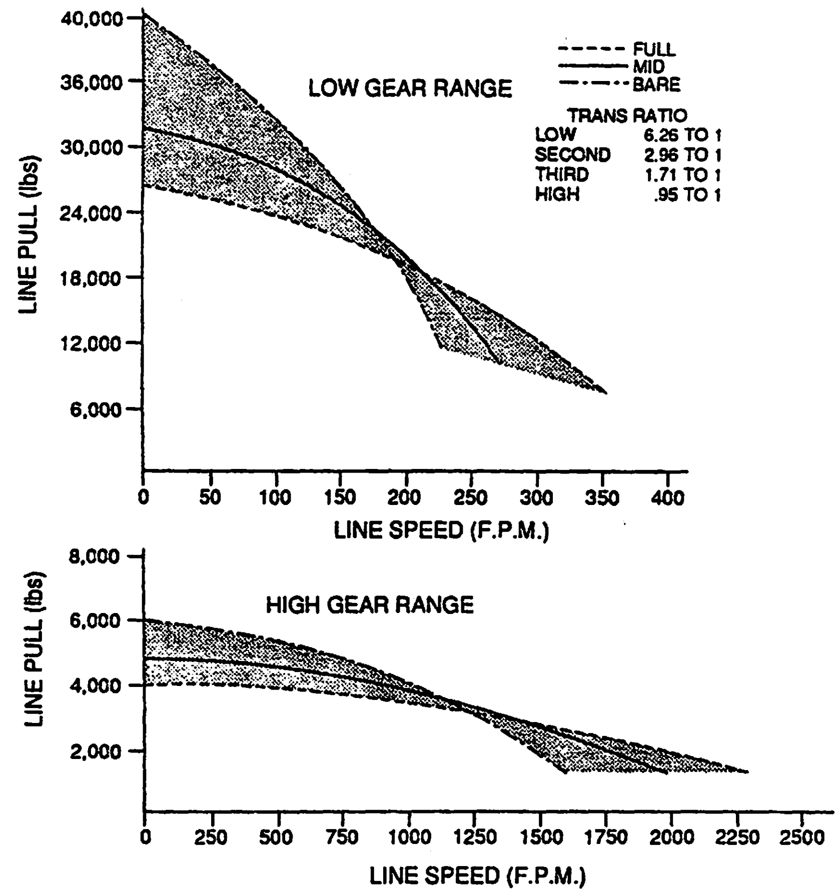

Figure 3. Line pull as a function of line speed, adapted from a brochure of the Skagit Corporation. Figure 3(a) is low range, Figure 3(b) is high range.

Shift Level Analysis of Cable Yarder Availability, Utilization, and Productive Time[1]

James R. Sherar and Chris B. LeDoux[2]

ABSTRACT: Decisionmakers, loggers, managers, and planners need to understand and have methods for estimating utilization and productive time of cable logging systems. In making an accurate prediction of how much area and volume a machine will log per unit time and the associated cable yarding costs, a reliable estimate of the availability, utilization, and productive time of the cable machine must be known. This study analyzes the important estimators for the Christy SWY III cable yarder operating in the southern Appalachian Region of the Southeastern United States. Shift data were collected on 12 logging units of timber sales on the National Forests in North Carolina from April 1986 through August 1987. The Christy SWY III is a small cable yarder and the results can be generalized to similar cable yarders and applications to estimate better the yarding costs for small cable systems.

KEYWORDS: Cable logging

INTRODUCTION

Cable logging technology is again being applied in the Eastern United States (Paul, 1980; Virginia Polytechnic Institute, 1982; Sherar, et al, 1986; LeDoux, 1985; Baumgras and LeDoux 1986; Lombardo, 1987). Numerous time and motion studies have been conducted (Fisher and Peters, 1983; Rossie, 1983; Baumgras, 1984) and generalized stump-to-mill computer packages have been developed (LeDoux, 1985). Although much work has been completed and reported, decisionmakers, loggers, managers, and planners need to understand and have methods for estimating the availability, utilization, and productive time of cable logging. Particularly in Eastern cable operations, this data often must be estimated from work completed in other parts of the country or in other countries. Errors in estimating equipment utilization or system productive time can result in incorrect estimates of logging production and costs, causing detailed time-study data to be less useful. In many cases, utilization data are collected concurrent with time-study data, then used to estimate productivity and costs. Data collected in this short period rarely represent the true availability of the logging equipment or the utilization and productivity of the logging crew.

In this study, the availability, utilization, and productive time of the Christy SWY III cable yarder are analyzed over a long and continuous period of time.[3] The Christy SWY III is a small, low-priced cable yarder and the results can be generalized to other yarders of the same class in similar applications. The results can be used to assist decisionmakers, loggers, managers, and planners in understanding the availability, utilization, and productive time of cable logging and in more accurately predicting logging costs of eastern cable harvesting systems. The data also contribute to the body of cable logging knowledge.

STUDY AREA

Data were collected on three timber sales of 12 logging units on the National Forests in North Carolina from April 7, 1986, through August 19, 1987. The data collection period was continuous and included logging throughout a winter season when normal operations must be severely curtailed. The logging units were typical of skyline units in the Southern Appalachian region of the Eastern U.S. with ground slopes averaging 50-60 percent in ridge-cove hardwood-type terrain.

LOGGING EQUIPMENT DESCRIPTION AND OPERATION

Gilkey Lumber Company has owned and operated the Christy SWY III since July, 1984. It has logged almost exclusively on National Forest land in Western North Carolina since that time. The company logging crew has worked together on this yarder for several years and has achieved a high degree of consistency not often found in Eastern cable logging crews. Although the Christy yarder is equipped with a haulback drum, the drum was rarely used except to log a limited amount of sidehill timber where the haulback was needed to return the Mini-Christy carriage to the choker-setting point. During almost all of the data collection period, the machine used only the skyline and mainline drums in a gravity ("shotgun") outhaul logging configuration.

DATA COLLECTION

The shift data were recorded by the logging crew using the activity descriptions shown below. Data was recorded by the logger to the nearest 1/4 day. The foreman recorded daily the activity(ies) that had occurred during the course of the scheduled work day.

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[1]Presented at the 1989 Annual Council on Forest Engineering Meeting, Coeur d'Alene, ID, August 27-30, 1989.

[2]Regional Logging Engineer, National Forest Systems Southern Region, USDA Forest Service, Ashville, NC; and Industrial Engineer and Project Leader, Northeastern Forest Experiment Station, USDA Forest Service, Morgantown, WV, respectively.

[3]The use of trade, firm, or corporation names in this paper is for the information and convenience of the reader. Such 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.

Definition of Activities

Scheduled Days -- Scheduled operating time for the equipment and logging crew. Normally five days per week. Sometimes a Saturday was worked to make up for a lost day during the week.

Move-in/out and Set-up/take-down Days--The time required to move the machine in and out of the sale area, or move between sales, and the time to set up and take down the machine after and before moves.

Change-Landing Days--The time required to take the machine down, move to the next landing on the same sale area, and set the machine back up again.

Machine-Not-Available Days--The time that the crew could not cable log because the machine was down for repairs. Does not include scheduled maintenance time for the machine.

Machine-Available/No-Work Days -- The time that the crew could not or did not work, although the machine was available for work.

Yarding Days -- The time that the machine and the crew spend yarding logs, changing roads, and performing routine maintenance.

DATA SUMMARY

Data were summarized for each unit logged, as shown on the Unit Data Summary Form (Fig. 1). Days were summarized as recorded in each activity, and availability, utilization, and productive time were calculated for each unit. Figure 1 also shows additional data summarizing the physical attributes of the logging unit, timber stand, and logging operation. The data has been summarized to estimate the average daily production of the Christy SWY III over the data collection period, but is not presented in this manuscript. Table 1 displays the summary of the logger-collected data by unit.

AVAILABILITY, UTILIZATION,AND PRODUCTIVE TIME

For the twelve logging units on which data were collected, calculations of the machine availability, utilization, and crew productive time were made. Calculations were based on the following definitions:

Availability--Total time the machine was mechanically available to the crew for yarding of timber (includes moves/set-up, landing-changes, machine-available/no-work and yarding days).

$$((2) + (3) + (5) + (6))/(1)$$

Forest: NFSNC
District: Grandfather
Sale Name: Mitchell Creek

Unit Number: 6
Unit Acres: 33

Unit Data:

No. of sawtimber trees	1288	Total Mbf	214	Pct. stems	100
No. of pulpwood trees	0	Total cunits	141	Pct. stems	0
No. of landings used	4	AYD*	450 feet		
Silviculture presc.	CC	Total turns	1563		

Equipment descriptions: Christy SWY III
Rigging configuration: Live Skyline, gravity
Logger: Mickey Conner
Dates of data collection: August 8, 1986 through October 17, 1986

Logging Data:

(1) Scheduled days	53.0
(2) Move-in days	0.5
(3) Change-landing days	1.5
(4) Machine-not-available	0.0
(5) Machine-available/no work days	17.0
(6) Yarding or skidding days on skyline volume	34.0

Production summary per yarding day:

Sawtimber trees per day	38	Mbf per day	6.3
Pulpwood trees per day	0	Cunits per day	4.1
Acres logged per day	.97	Turns per day	46

*AYD = average slope yarding distance from map.

Figure 1.--Data Summary Form.

Table1.--Logging data recorded in each activity, by unit.

Activity	MC9	MC8	MC3	MC5	MC4	MC6	IC1	IC2	JM4	JM5	IC5	IC6
	Unit											
1. Scheduled days	10.0	12.5	14.0	24.5	30.5	53.0	21.0	17.0	50.0	21.0	38.0	55.0
2. Move in/set up	0.5	0.75	0.5	0.5	0.5	0.5	1.5	0.5	1.0	0.5	0.0	1.0
3. Change landings	0.5	1.0	1.25	0.5	1.0	1.5	1.0	0.5	1.0	0.0	0.5	1.5
4. Machine not avail.	0.0	0.5	1.25	4.25	1.5	0.0	0.0	0.0	1.5	1.5	7.0	3.5
5. Machine available (no work)	0.0	0.5	0.5	1.0	0.0	17.0	4.0	8.0	15.5	5.5	1.5	5.0
6. Yarding days	9.0	9.75	10.5	18.2	27.5	34.0	14.5	8.0	31.0	13.5	29.0	44.0
7. Average turns per day	NA	NA	NA	NA	NA	46	43	49	48	42	51	49

Table 2.--Availability, utilization, and productive time by logging unit in percent.

	MC9	MC8	MC3	MC5	MC4	MC6	IC1	IC2	JM4	JM5	IC5	IC6
	Unit											
	Percent											
Availability	100	96	91	83	95	100	100	100	97	93	82	94
Utilization	100	96	88	79	95	68	81	53	66	67	78	85
Productive time	90	78	75	74	90	64	69	47	62	64	76	80

Utilization--Total time the machine was used by the crew, (including moves/set-up, landing-changes, and yarding days).

((2) + (3) + (6))/(1)

Productive time--Total time the crew and machine spend yarding timber.

(6)/(1)

The results for availability, utilization, and productive time are shown by logging unit in table 2.

SUMMARY AND CONCLUSIONS

The average machine availability for all units was 94 percent throughout the data collection period. Only two units, MC5 and IC5, show low availability, 83 percent and 82 percent respectively. The machine downtime on these two units was due to transmission repair, shaft and bearing repairs on the skyline drum, and repairs to the communication system. Over the study period, the machine lost 21 days due to mechanical repairs. During some of those days while waiting for parts, the crew maintained production by ground skidding areas near the roads and landings.

The average machine utilization rate for all units was 77 percent. The average productive time for all units was 72 percent. As expected, the utilization and productive time of the machine and crew was low during the winter logging season. Units IC2, JM4, and JM5 were logged from November 15 through April 3. In addition, MC6 was logged from August 11 through October 17 and had 12 days of missed work due to extremely wet weather. In most cases, landing sizes were not adequate to cold deck more than several days production, so when the haul road was in poor shape for hauling, the crew worked at other jobs. Move-in/set-up time averaged approximately 3/4 of a day for all units. Landing changes averaged about one day for all units.

As more information is collected on the availability, utilization, and productive time of Eastern cable operations, better estimates of system production and costs can be made. This study summarized data for the Christy SWY III small cable yarder operating under typical conditions of the Southern Appalachian mountains in Western North Carolina.

ACKNOWLEDGMENTS

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Analysis of Multiple Anchor Bridling Alternatives[1]

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Ronald L. Copstead, and
Robert J. McGaughey[2]

Abstract: Multiple anchor bridling remains a matter of concern because of uncertainties about anchor strengths and other problems related to installation and configuration. We modeled several bridling concepts in conjunction with various anchor arrangements and found that, with respect to bridle system performance, installation geometry is at least as important as method of bridling. If anchors are collinear with the direction of applied force, and all anchors seat uniformly, then perhaps no alternative is preferable to the fixed bridle. Otherwise, systems capable of performing like the hybrid parachute rigging described herein may provide sufficient advantage to warrant further research and development.

Keywords: logging, cable, guyline, anchor, bridle.

The Forest Service has been conducting research and development on anchors for use with timber harvesting equipment during the past decade or so. These efforts are described elsewhere (Copstead 1984, 1988, Cook and Simonson 1986) and have culminated in design methods and installation procedures for tipping plate and rock anchoring systems. The need for efficient anchor bridling systems was recognized early when it became clear that multiple anchors would have to be used to withstand the high forces in the guylines and skylines of cable logging systems (Anon 1984).

The design methodology for installing anchors has been based on the assumption that bridling systems are 100 percent efficient; that is, the strength of the bridled system is assumed to equal the sum of strengths of the individual anchors. In practice, of course, this is not generally true.

Specifically, there are concerns about the "rigid" bridle (Studier 1988), in which straps from several anchors are joined so that the unstretched length of each remains constant. (Indeed, such a bridle is not rigid in space, but moves freely in response to applied forces.) With a rigid bridle, nonuniform seating and deflection responses of individual anchors (due to nonhomogeneous soil conditions and installation anomalies) may result in sequential anchor failures, and thus lead to failure of the bridled system at resultant forces substantially less than might otherwise be expected.

[1]Presented at the 12th Annual Council on Forest Engineering Meeting, Coeur D'Alene, ID, August 27-30, 1989.

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OBJECTIVES AND PROCEDURES

Our objectives were to formulate anchor bridling concepts and assess their performance in conjunction with various anchor arrangements. Moreover, we were concerned with performance in circumstances wherein yield characteristics and failure loads of some anchors differ from those of others.

We derived mathematical models for several bridling concepts, which were used to predict the resulting bridle trajectories and corresponding anchor loads for various anchor characteristics and configurations. For ease and convenience, we restricted our models and analyses to two-dimensional representations. Space limitations prohibit description of our models here.

In our models, we used two distinct parabolic (second-degree polynomial) load versus displacement relationships derived from previous anchor field tests (Copstead 1988), one "strong" and the other "weak" (fig. 1). These relationships were based on test data from identical tipping plate installations in weathered rock of pyroclastic origin overlaid with silty sand. The depth of installation was about 5 feet. Standard penetration test (N) values in the area ranged from 76 to 100 blows per foot at the depth of installation. Each anchor had a bearing area of approximately 70 square inches. The difference in anchor characteristics shown in figure 1 is typical of results that have been observed in the Forest Service soil anchor testing program.

We analyzed both spread and collinear installations (fig. 2), which we distinguish from each other by their relationship to the direction of load application. In each, anchors are installed generally (but not necessarily) in a row. In a spread installation, the resultant force is applied approximately perpendicular to the row of anchors; whereas in a collinear installation, the resultant force is applied in line with the anchors.

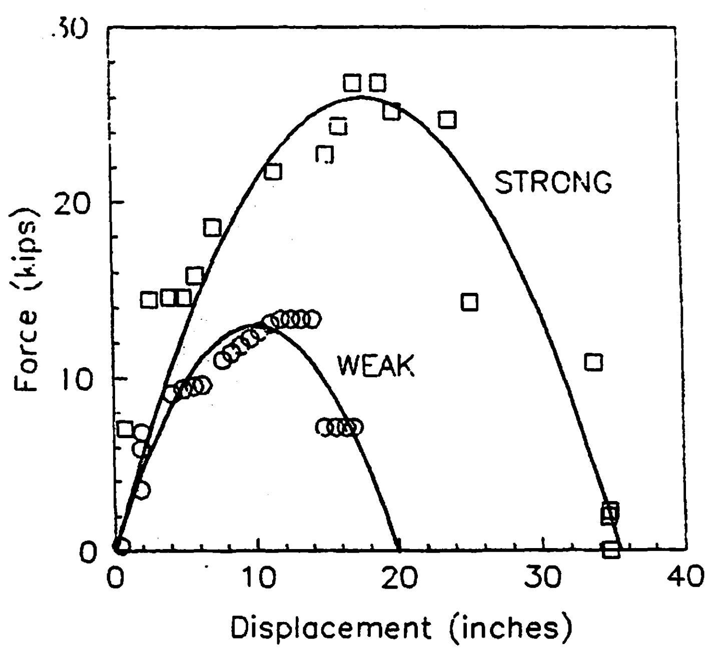

Figure 1--Load versus displacement relationships for strong and weak anchors.

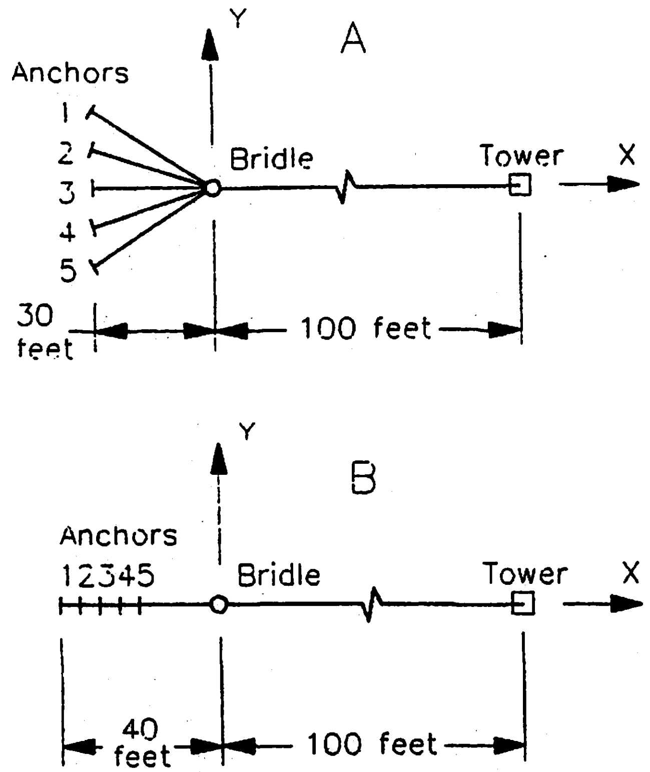

Figure 2--(A) Spread and (B) collinear installations, showing dimensions and coordinate systems. (Anchors are evenly spaced 5 feet apart.)

Figure 2 shows symmetry of bridle and tower positions with respect to the anchor rows. As will be seen later, a principal focus of our analyses is on the consequences of departure from this symmetry. Figure 2 also shows the coordinate system and key dimensions for the particular installations we analyzed. Our choice of straight rows of 5 evenly spaced anchors was arbitrary.

We analyzed both rigid and non-rigid bridle systems (Studier 1988). The former we call the fixed bridle, and the latter we represent by "parachute rigging" (Anon 1984) (fig. 3).

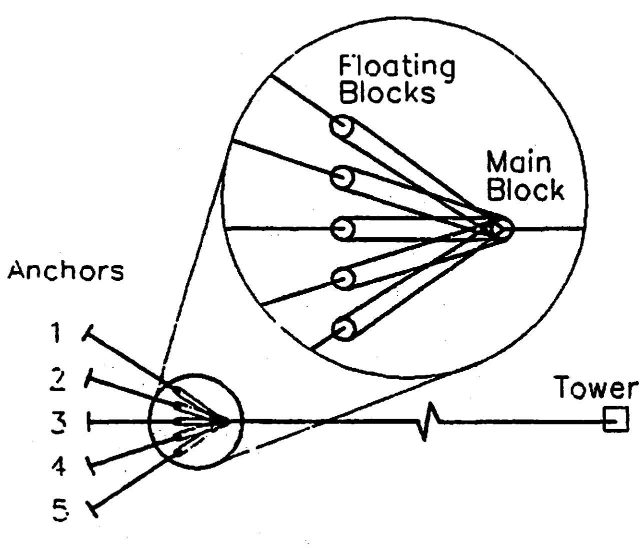

Figure 3--Parachute rigging.

In addition, we conceptualized and analyzed variations of the parachute rigging to accommodate yield or failure of weak anchors without incurring complete system failure. Only one of these variations will be dealt with here. We call it the hybrid parachute rigging. It equalizes individual anchor loads at low load levels, after which all sheaves in the main block are seized. Thereafter, it performs like a fixed bridle. This concept presumes sufficient friction between main block sheaves and the rigging cable to withstand ensuing tension differences.

RESULTS

We begin by considering performance of a fixed bridle in spread anchor installations (fig. 2A). Five examples will be discussed in detail, in which anchor 5 is weak and the remaining four anchors are strong (as defined in figure 1).

Consider first a situation of perfect initial symmetry, as shown in figure 2A, wherein the bridle is initially well-centered with respect to the anchor and tower positions. As the bridle is pulled toward the tower, it moves in the positive y-direction (fig. 4A) because the weaker anchor (5) yields more rapidly than the others. A peak resultant of about 100,000 lbs (100 kips) is reached when the bridle's x-coordinate has moved about 1.1 foot toward the tower and its y-coordinate has moved

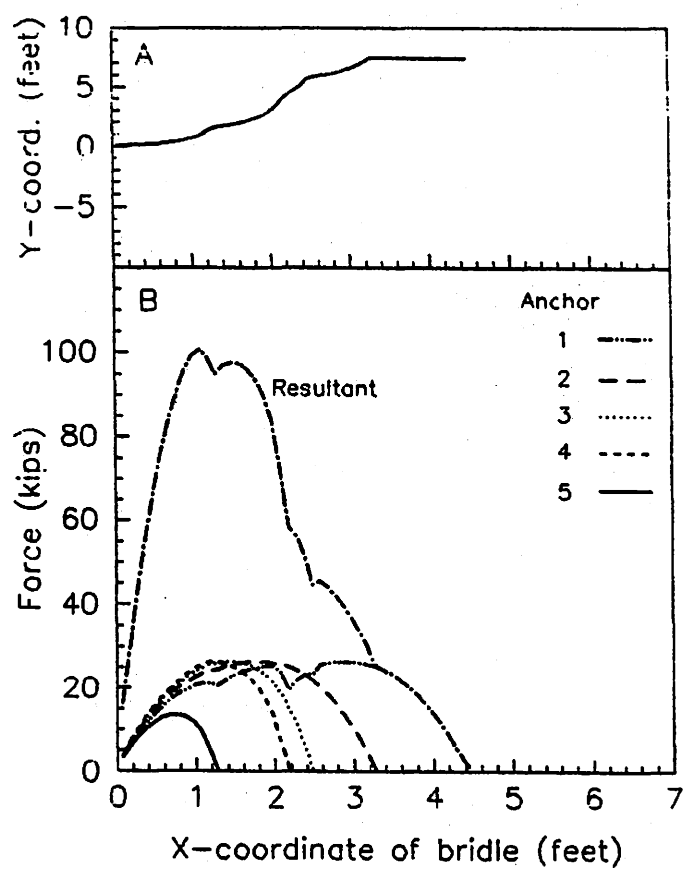

Figure 4--(A) Bridle trajectory and (B) anchor loads and resultant, fixed bridle in spread installation (fig. 2A); anchor 5 is weak; tower at x = 100 feet, y = 0; bridle initially at x = 0, y = 0.

about 0.8 foot in the positive y-direction from its initial position. This occurs after the maximum strength of anchor 5 has been reached, but before maximum strengths of the remaining anchors are attained (fig. 4B). Subsequently, the anchors fail progressively in reverse numerical order.

The graphs of figure 4 (and later similar graphs) are mainly of academic interest after the peak resultant is attained, because anchor system integrity has been compromised. We provide them, however, for their additional utility in assessing credibility of our model.

Initial bridle position in the preceding example was symmetric with respect to the tower and anchors. Suppose, instead, that the bridle's initial y-coordinate is -5 feet -- or the same as that of anchor 4 (fig. 2A). Then the peak resultant is reduced substantially (fig. 5B) -- nearly 40 percent less than that attained in the previous example (fig. 4). The peak resultant is reached after anchor 5 fails and somewhat after the peak strength of anchor 4 is reached (fig. 5B). Anchor 1 receives no load until after anchors 5 and 4 have failed and anchor 3 is near failure.

Alternatively, if the bridle's initial y-coordinate is +5 feet -- or the same as that of anchor 2 (fig. 2A) -- it results in the anchor loads and bridle trajectory shown in figure 6. In this example, the weak anchor (5) receives no appreciable load until after the peak resultant occurs and anchors 1, 2, and 3 (in that order) have failed (fig. 6B). This peak is about 10 percent less than that attained in the first example (fig. 4).

Next, consider an example wherein the initial position of the bridle is well-centered with respect to the anchors, as in figure 2A, but the y-coordinate of the tower is -10 feet -- or the same as that of anchor 5. The consequences of this asymmetry, shown in figure 7, are favorable when compared with those in figure 4. That is, strong anchors 1, 2, 3, and 4 act more in concert with each other and with the weak anchor (5), so that the peak resultant is about 10 percent greater than that attained in figure 4.

But if the y-coordinate of the tower is +10 feet -- or the same as that of anchor 1 (fig. 2A) -- then the anchors fail progressively, beginning with anchor 5 (fig. 8A), resulting in load versus bridle movement patterns similar to those in figure 5B. In this example, a peak resultant of about 74 kips is reached just before failure of the weak anchor (5); and thereafter a second peak of about 81 kips is attained (fig. 8B). As the bridle moves toward the tower, its y-coordinate migrates relatively steadily from its initial value of zero to its final value of +10 feet (fig. 8A), where it becomes aligned between the tower and the last surviving anchor (1).

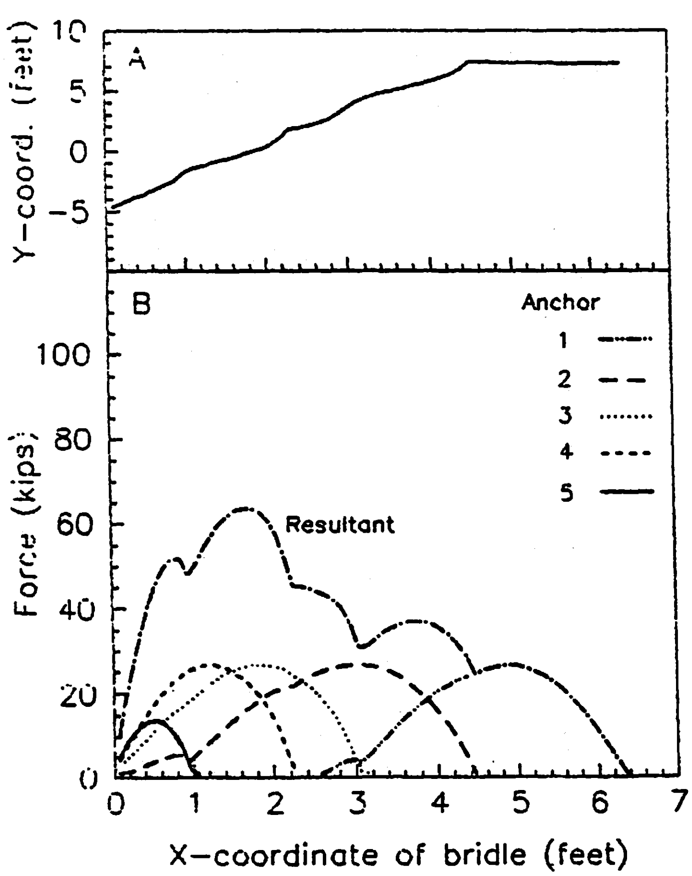

Figure 5--(A) Bridle trajectory and (B) anchor loads and resultant, fixed bridle in spread installation (fig. 2A); anchor 5 is weak; tower at x = 100 feet, y = 0; bridle initially at x = 0, y = -5 feet.

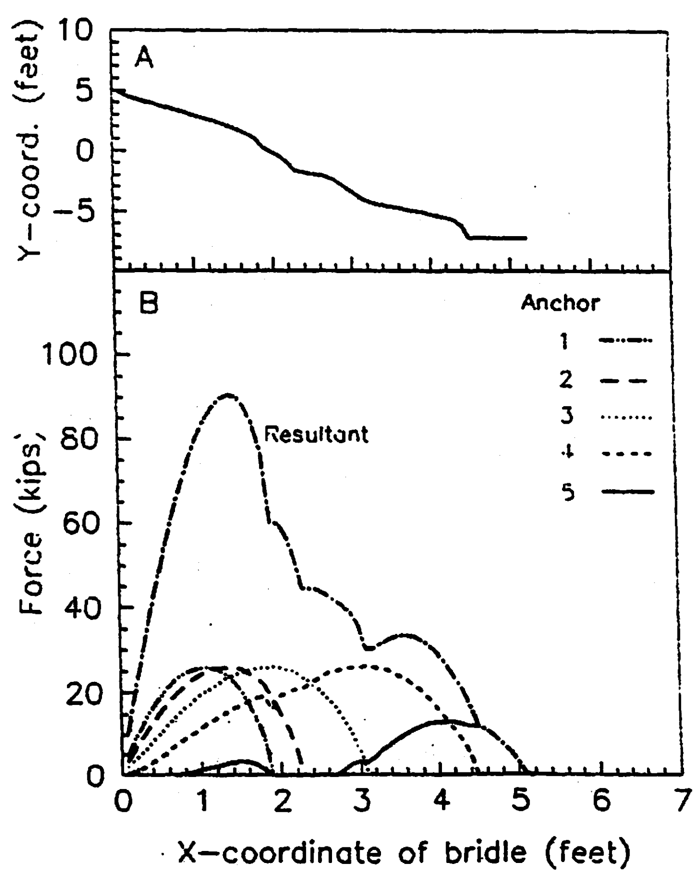

Figure 6--(A) Bridle trajectory and (B) anchor loads and resultant, fixed bridle in spread installation (fig. 2A); anchor 5 is weak; tower at x = 100 feet, y = 0; bridle initially at x = 0, y = +5 feet.

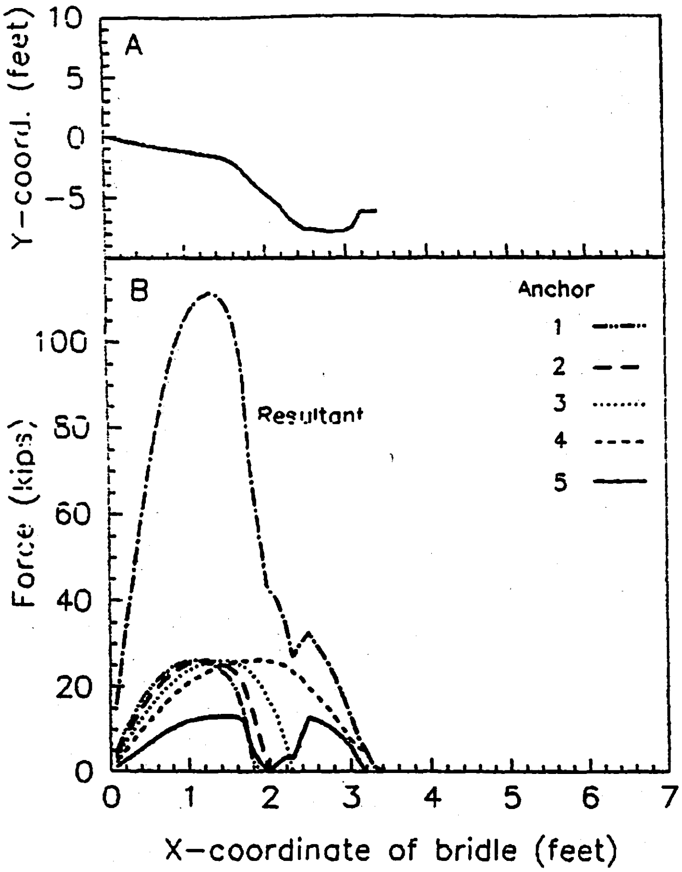

Figure 7--(A) Bridle trajectory and (B) anchor loads and resultant, fixed bridle in spread installation (fig. 2A); anchor 5 is weak; bridle initially at x = 0, y = 0; tower at x = 100 feet, y = -10 feet.

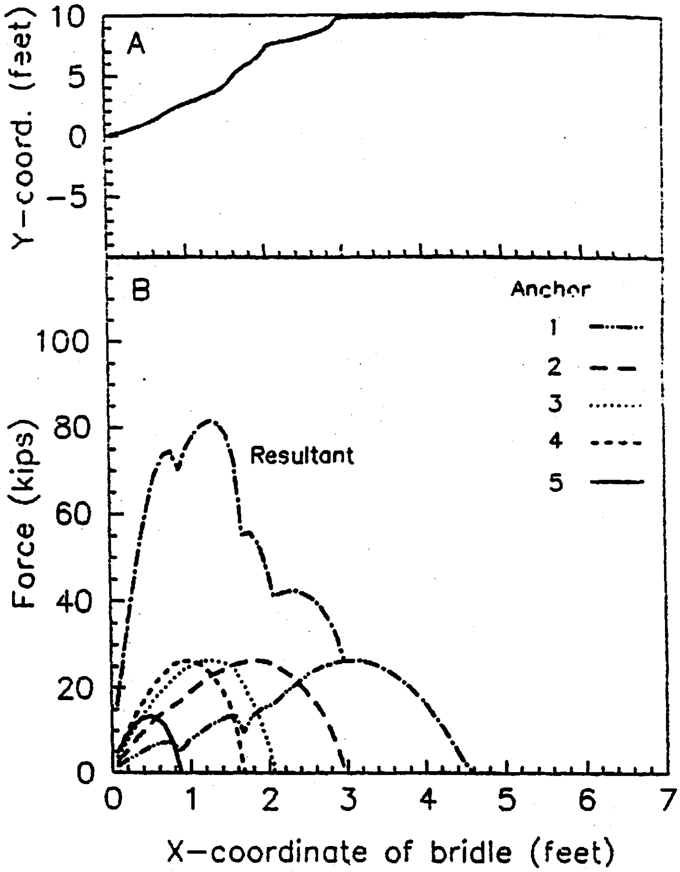

Figure 8--(A) Bridle trajectory and (B) anchor loads and resultant, fixed bridle in spread installation (fig. 2A); anchor 5 is weak; bridle initially at x = 0, y = 0; tower at x = 100 feet, y = +10 feet.

The foregoing examples show that, in spread anchor installations, a fixed bridle's performance strongly depends on initial positioning of the bridle and tower with respect to anchor layout. Table 1 summarizes results of these and other fixed bridle cases, some where the weak anchor's position is in the center of the group, some where all anchors are equally strong, and all based on the spread arrangement of figure 2A. The highest peak in table 1 is 127 kips; it occurs when there is perfect initial symmetry (as depicted in figure 2A) and all anchors are identically strong.

If a parachute rigging is used in spread installations (fig. 3), then results are as shown in table 2. Here the peak resultant loads are limited by the weakest anchor in the group, as anticipated by Studier (1988).

With the hybrid parachute concept, if all sheaves in the main block are seized at an anchor load of 2 kips (i.e., a tension of 1 kip in the parachute rigging cable), then results are as shown in table 3. These results show the advantage of initial load equalization, which causes the bridle (i.e., the main block) to move to a position following which the hybrid parachute rigging performs as would a fixed bridle in installations of perfect initial symmetry. Following pretensioning and seizure of main block sheaves, and until attainment of peak resultant, the main block trajectories and corresponding anchor and resultant loads in cases 7-9 of table 3 (in which anchor 5 is weak) are comparable to those in case 7 of table 1 (and as illustrated in figure 4). Similarly, after pretensioning, performance of the hybrid parachute rigging in cases 1-3, 4-6, and 10-12 of table 3 approximates that of the fixed bridle in cases 1, 4, and 10 of table 1, respectively. Of course, with slippage of the parachute rigging cable about seized sheaves in the main block (due to excessive tension ratios caused by declining load resistance of failing anchors), relationships like those in figure 4 would become invalid for the hybrid parachute rigging soon after attainment of peak resultant. We did not incorporate such cable slippage phenomena in our models.

The foregoing illustrates that, in spread installations, initial positions of the tower, bridle, and anchors are important determinants of performance, especially for a fixed bridle. Next we show the advantage of collinear installations (fig. 2B).

Table 4 summarizes results for a fixed bridle in collinear installations (fig. 2B). It shows that departures from initial symmetry or collinearity are relatively unimportant. The major cause of differences in peak resultant loads among the cases in table 4 is presence or absence of a weak anchor, regardless of its position in the group.

Table 1--Summary of results for fixed bridle in spread installations (fig. 2A).

Case	Anchor type[a] by number 1 2 3 4 5	Tower coords. x	Tower coords. y	Initial bridle coords. x	Initial bridle coords. y	Bridle coords. @ peak load x	Bridle coords. @ peak load y	Peak load
		feet						kips
1	S S S S S	100	0	0	0	1.5	0	127
2	S S S S S	100	0	0	5	1.4	2.1	91
3	S S S S S	100	10	0	0	1.3	2.1	114
4	S S W S S	100	0	0	0	1.3	0	108
5	S S W S S	100	0	0	5	1.3	2.4	81
6	S S W S S	100	10	0	0	1.2	1.8	99
[b]7	S S S S W	100	0	0	0	1.1	0.8	100
[b]8	S S S S W	100	0	0	5	1.4	2.1	90
[b]9	S S S S W	100	10	0	0	1.3	3.4	81
[c]10	W S S S S	100	0	0	0	1.1	-0.8	100
[c]11	W S S S S	100	0	0	5	1.7	0.4	63
[c]12	W S S S S	100	10	0	0	1.3	1.6	111

[a]Type S = strong, type W = weak (fig. 1). Each anchor's x-coordinate is -30 feet, and the y-coordinates of anchors 1, 2, 3, 4, and 5 are 10, 5, 0, -5, and -10 feet, respectively (fig. 2A).

[b]Complete results for cases 7, 8, and 9 are shown in figures 4, 6, and 8, respectively.

[c]Complete results for cases equivalent to 11 and 12 are shown in figures 5 and 7, respectively.

Table 2--Summary of results for parachute rigging in spread installations (figs. 2A and 3).

Case	Anchor type[a] by number 1 2 3 4 5	Tower coords. x	Tower coords. y	Initial[b] bridle[b] coords.[c] x	Initial[b] bridle[b] coords.[c] y	Bridle[b] coords. @ peak load x	Bridle[b] coords. @ peak load y	Peak load
		feet						kips
1	S S S S S	100	0	0.1	0	1.5	0	127
2	S S S S S	100	0	0.5	0	2.0	0	127
3	S S S S S	100	10	-0.1	2.4	1.4	2.5	127
4	S S W S S	100	0	0.1	0	0.5	0	63
5	S S W S S	100	0	0.5	0	1.0	0	63
6	S S W S S	100	10	-0.1	2.4	0.4	2.4	63
7	S S S S W	100	0	0.1	0	0.5	0	63
8	S S S S W	100	0	0.5	0	1.0	0	63
9	S S S S W	100	10	-0.1	2.4	0.4	2.4	63
10	W S S S S	100	0	0.1	0	0.5	0	63
11	W S S S S	100	0	0.5	0	1.0	0	63
12	W S S S S	100	10	-0.1	2.4	0.4	2.4	63

[a]See footnote a, table 1.

[b]Bridle here refers to main block of parachute rigging.

[c]These are coordinates of main block after initial pretensioning to nominal load. Before pretensioning, the main block's coordinates were the same as the initial fixed bridle coordinates in table 1, each floating block's x-coordinate was -5 feet, and y-coordinates of the floating blocks were 1 foot apart with that of the middle block (associated with anchor 3) matching that of the main block (fig. 3).

Table 3--Summary of results for hybrid parachute rigging in spread installations (figs. 2A and 3).

Case	Anchor type[a] by number 1 2 3 4 5	Tower coords. x	Tower coords. y	Initial[b] bridle[b] coords.[c] x	Initial[b] bridle[b] coords.[c] y	Bridle[b] coords. @ peak load x	Bridle[b] coords. @ peak load y	Peak load
		feet						kips
1	S S S S S	100	0	0.1	0	1.5	0	127
2	S S S S S	100	0	0.5	0	2.0	0	127
3	S S S S S	100	10	-0.1	2.4	1.4	2.5	127
4	S S W S S	100	0	0.1	0	1.3	0	108
5	S S W S S	100	0	0.5	0	1.8	0	108
6	S S W S S	100	10	-0.1	2.4	1.2	2.5	108
7	S S S S W	100	0	0.1	0	1.1	0.8	100
8	S S S S W	100	0	0.5	0	1.6	0.8	100
9	S S S S W	100	10	-0.1	2.4	1.0	3.3	100
10	W S S S S	100	0	0.1	0	1.1	-0.8	100
11	W S S S S	100	0	0.5	0	1.6	-0.8	100
12	W S S S S	100	10	-0.1	2.4	1.1	1.7	100

[a]See footnote a, table 1.

[b]See footnote b, table 2.

[c]See footnote c, table 2.

Results for a parachute rigging in collinear installations, corresponding to those of table 4, are not sufficiently different from those in spread installations (table 2) to warrant separate tabulation. Bridle (main block) coordinates at peak load nearly equal -- and peak loads are only about 2 percent greater than -- corresponding values in table 2. These minor differences are attributable to geometric differences between the spread and collinear arrangements.

Table 4--Summary of results for fixed bridle in collinear installations (fig. 2B).

Case	Anchor type[a] by number 1 2 3 4 5	Tower coords. x	Tower coords. y	Initial bridle coords. x	Initial bridle coords. y	Bridle coords. @ peak load x	Bridle coords. @ peak load y	Peak load
		feet						kips
1	S S S S S	100	0	0	0	1.5	0	130
2	S S S S S	100	0	0	5	1.9	0	129
3	S S S S S	100	10	0	0	1.4	2.3	130
4	S S W S S	100	0	0	0	1.3	0	111
5	S S W S S	100	0	0	5	1.7	0	110
6	S S W S S	100	10	0	0	1.2	2.3	112
7	S S S S W	100	0	0	0	1.3	0	111
8	S S S S W	100	0	0	5	1.8	0	114
9	S S S S W	100	10	0	0	1.2	2.4	111
10	W S S S S	100	0	0	0	1.3	0	111
11	W S S S S	100	0	0	5	1.7	0	108
12	W S S S S	100	10	0	0	1.2	2.2	112

[a]Type S = strong, type W = weak (Fig. 1). Each anchor's y-coordinate is 0, and the x-coordinates of anchors 1, 2, 3, 4, and 5 are -40, -35, -30, -25, and -20 feet, respectively, (fig. 2B).

Finally, table 5 summarizes results for a hybrid parachute rigging in collinear installations. These results are not appreciably different from those for corresponding fixed bridle cases in table 4. They differ from those in table 3 partly because of geometric differences between the spread and collinear arrangements, and partly because hybrid parachute rigging performance is hardly affected by weak anchor position in collinear installations.

CONCLUSIONS

In collinear installations, the fixed bridle and the hybrid parachute rigging perform equally well. However, if collinearity cannot be provided, if the tower location is unknown when anchors are installed and bridled, or if several tower locations are to be served by a single anchor installation, then a system that emulates the hybrid parachute rigging described herein may be preferred.

The hybrid parachute rigging concept may also find application in situations where it is desired to bridle several small stump anchors whose placement is predetermined.

Table 5--Summary of results for hybrid parachute rigging in collinear installations (fig. 2B).

Case	Anchor type[a] by number 1 2 3 4 5	Tower coords. x	Tower coords. y	Initial bridle[b] coords.[c] x	Initial bridle[b] coords.[c] y	Bridle[b] coords. @ peak load x	Bridle[b] coords. @ peak load y	Peak load
		feet						kips
1	S S S S S	100	0	0.1	0	1.5	0	130
2	S S S S S	100	0	0.6	0	2.0	0	130
3	S S S S S	100	10	-0.1	2.2	1.4	2.3	130
4	S S W S S	100	0	0.1	0	1.3	0	111
5	S S W S S	100	0	0.6	0	1.8	0	111
6	S S W S S	100	10	-0.1	2.2	1.2	2.3	111
7	S S S S W	100	0	0.1	0	1.3	0	111
8	S S S S W	100	0	0.6	0	1.8	0	111
9	S S S S W	100	10	-0.1	2.2	1.2	2.4	111
10	W S S S S	100	0	0.1	0	1.3	0	111
11	W S S S S	100	0	0.6	0	1.8	0	111
12	W S S S S	100	10	-0.1	2.2	1.2	2.2	111

[a]See footnote a, table 4.

[b]See footnote b, table 2.

[c]These are coordinates of main block after initial pretensioning to nominal load. Before pretensioning, the main block's coordinates were the same as the initial fixed bridle coordinates in table 4, each floating block's y-coordinate was the same as that of the main block, and the x-coordinate of each floating block was -5 feet.

Lastly, according to Studier (1988),

> "Even the most careful preadjustment of tieback line lengths on a rigid bridle will result in some slack lines since anchors tend to set in slightly different distances."

Thus, even in collinear installations, there may be circumstances in which a hybrid parachute rigging would be advantageous.

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Simulating Tree-Length Log Processing with SIMFACTORY[1]

Thomas J. Corcoran, Ph.D.[2]

POSTER ABSTRACT

Discrete computer simulation is one in which only discontinuous events occur. Animated simulation can be defined as viewing of a simulation utilizing user-chosen shapes moving under user control. The two- or three-dimensional shapes mimic real-life objects and are typically in color.

SIMSCRIPT II.5's SIMFACTORY is a menu-driven PC-software that allows a simulation model to be easily animated. Results can be continuously viewed and also printed when specified. With SIMFACTORY the need to formally program in code is non-existent. Animation has progessive value to the five stages of simulation modeling: debugging, verification, validation, analysis, and presentation.

A tree-length processing system has been animated in Version 1.6 of the SIMFACTORY software on a Zenith Model Z-248 microcomputer. The system bounds tree-length truck delivery activities to a scaling station with two unloading service areas, a slashing area, a debarking area, and conveyor area for storage or chipping.

Icons that represent viewed objects in the animated system have been specifically drawn to represent real-life objects in the modeled system. The objects can be color-coded corresponding to their natural color or to represent by color changes a current physical status of the objects. Objects can be stationary or can move to portray spacially the activities that occur within the system. Movable objects include trucks, tree-length logs, slashed bolts, and debarked bolts. Stationary objects include a scaling station, unloading equipment, slasher, debarker, and conveyor (or chipper). As the simulation executes the movable objects change their positions in a life-like way. The physical status as to the availability of the stationary objects would be color coded, e.g. awaiting wood resource flow, actively processing or servicing, down, etc. Color changes imply changes in status. The queue areas would have dynamic "windows" of numerical values representing, for example, their current queue contents. (See figure.)

Experimental simulations, which reflect altered designs/layouts, additions of equipment and/or production rate changes, can be performed to facilitate a decision as to whether an alteration improved the operation of the system. A viewing over time of the animation will lead to the recognition of design errors, layout inadequacies, improper equipment balances, unplanned collisions, and other problems that need to be corrected before an approved configuration is actually put in place and activated.

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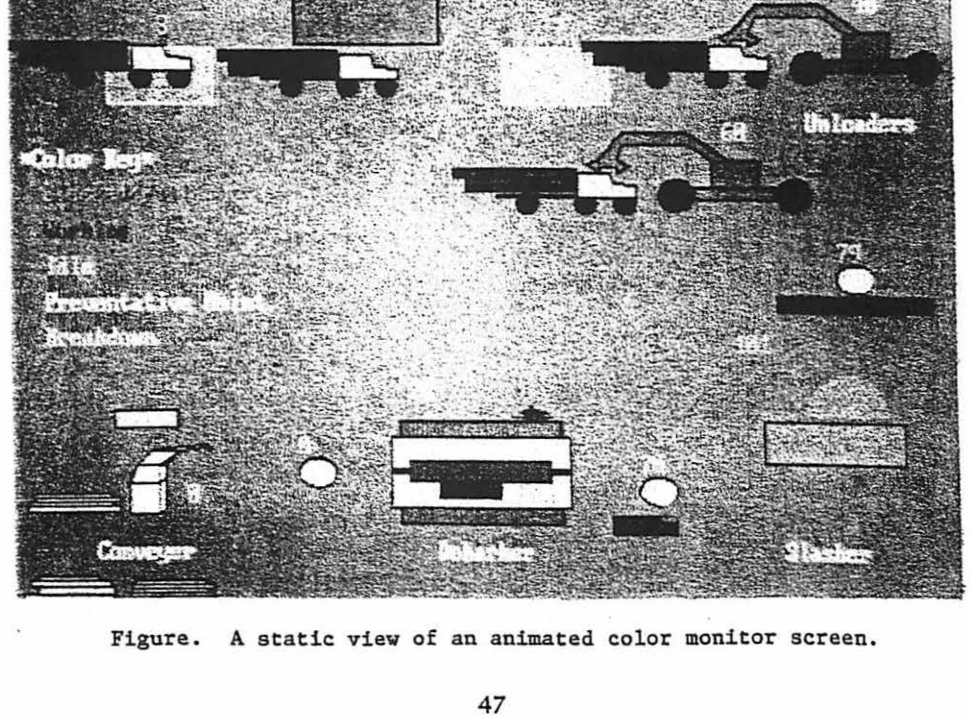

Figure. A static view of an animated color monitor screen.

Using The Global Positioning System For Forestry Applications[1]

David and Linda Dean[2]

Abstract: The NAVSTAR Global Positioning System (GPS) is a satellite navigation system designed to provide accurate position information. When GPS is used in conjunction with portable receiver systems, as the GPS Pathfinder[3], many of the tedious field recording and locating tasks adherent to natural resource management are simplified. With the aid of the user friendly control display unit (CDU), the user can navigate to known waypoints and record positions. The data can then be uploaded to a computer and plotted onto a map or used in Geographic Information System (GIS) databases.

Keywords: GPS, Satellite, Navigation, Position Location and Recording, GIS.

The NAVSTAR Global Positioning System (GPS) is a satellite navigation system designed to provide accurate position information. When the U.S. Defense Department fully deploys GPS, it will provide world-wide, 24-hour, 3-dimensional, continous position fixes accurate to better than 25 meters. In differential mode, the accuracy will be better than 5 meters, and for surveying applications, the errors will be in the millimeter range.

When GPS is used in conjunction with portable receiver systems, as the GPS Pathfinder, many of the tedious field recording and locating tasks adherent to natural resource management are simplified by taking advantage of the space technology. The GPS Pathfinder can be used for forestry applications including area location, point location and recording, as well as aircraft guidance for fires and search and recue. For GIS applications, the GPS Pathfinder is a viable tool for maintaining or creating a GIS database.

GLOBAL POSITIONING SYSTEM

A total of 24 GPS satellites are planned, including 3 in-orbit spares, in 6 orbital planes. The orbital period for all the satellites is approximately 12 hours, with an altitude of about 12,000 miles. Each of the satellites contains a very accurate cesium clock which is synchronized to all the others and to the ground control stations. The satellites radiate spread-spectrum coded signals which are received by the user's GPS receiver. Along with timing information, each satellite transmits information allowing computation of the satellite's exact position. The GPS receiver decodes the timing signals from the satellites in view (4 or more), and knowing their location, computes a latitude, longitude, altitude, and time. This is a continuous process and generally the position is updated on a second-by-second basis on the receiver's display.

CURRENT GPS CONSTELLATION

The current (August 1989) GPS satellite constellation has eight satellites. This constellation provides approximately six hours of 3-D position fixes per day in North America. Coverage in other parts of the world will vary. The daily observation window appears approximately 4 minutes earlier each day. In the summertime in North America, the current constellation of satellites is visible during daylight hours. In the wintertime, the current constellation is visible in North America during the night. As more satellites are launched on the planned 60 to 90 day interval, these coverage windows will expand until a full 24 hour cover is available in 2 years.

OLDER TECHNOLOGIES BEING REPLACED

The Global Positioning System will eventually replace two current navigation systems. These older systems are LORAN and TRANSIT. LORAN is a ground based navigation system providing continuous position fixes accurate to about 500 feet in coastal waters within range of a LORAN chain. The TRANSIT system provides worldwide coverage but only 10 to 30 fixes per day. Sub-meter accuracy is available after 2 days of observation by a stationary user.

SELECTIVE AVAILABILITY AND DIFFERENTIAL GPS

The accuracy of position fixes depends mostly on the actions of the Defense Department and how much they will degrade performance for civilian users. This degradation process is called selective availability (S/A). When S/A is operating, the position fixes may wander up to 100 meters from the true position. To get a good position fix in the presence of S/A, differential GPS is used. With differential GPS, a reference GPS receiver is set up on a known location and any deviations from "truth" are used to correct the locations computed by another GPS receiver at an unknown location. Systems are available to do this differential processing either in real-time or as a post-processing operation. With differential GPS, accuracy will be 3 to 5 meters.

If better accuracy is desired, survey grade receivers are available. These receivers are specified to have an accuracy of 1 centimeter +/- 1 millimeter for each kilometer of baseline. For example, two survey grade receivers separated by

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[1] Presented at the 1989 Council On Forest Engineering Meeting, Coeur d'Alene, Idaho, August 27-30, 1989.

[2] President and Technical Services Manager and VP/Marketing/Sales, respectively, Electronic Data Solutions, Jerome, Idaho. Sales representatives for Trimble Navigation, Ltd., Sunnyvale, CA.

[3] GPS Pathfinder is a trademark of Trimble Navigation, Ltd.

10 km will compute a separation of 10 km +/- 2 cm. Survey grade receivers only work in differential mode.

GPS DATA LOGGING RECEIVER

An example of a GPS receiver designed for GIS and position locating and recording is the GPS Pathfinder which is manufactured by Trimble Navigation, Ltd. The GPS Pathfinder system consists of a GPS receiver, a GPS antenna and a control display unit (CDU) and all weighs less than 5 pounds. All components of the system are battery powered and environmentally sealed. The CDU provides a user friendly interface through a 4-line display and keyboard. CDU functions include receiver control, space vehicle visability status, waypoint navigation and data recording capabilities. Also included with the Pathfinder system is the PC-based post-processing software providing the ability to transfer data to the PC, apply differential corrections, review data, and print or plot data.

GPS PATHFINDER OPERATION

While in the field the user can perform a variety of navigation and logging functions. For example, to map the boundary of a field the user would travel to the starting point, turn on the receiver, verify position fixes were being generated by observing the display, and turn on the data logger to start collecting a data file. Then all that is necessary is to walk, drive or fly around the boundary to be digitized. At the end of the path the data logger is turned off. Upon returning to the office, the data logger is connected to a PC and the files are extracted and the position data is converted to the desired GIS data import format of your choice. It interfaces with a wide variety of GIS software including ARC/INFO[4], GRASS, and INTERGRAPH[5]. The post-processing software also allows reviewing and plotting on 1:24000 (or any other scale) overlays using a HPGL compatible pen plotter.

SUGGESTED GPS FORESTRY RELATED TASKS

The following are some suggested uses or tasks for a GPS data logging receiver:[6]

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[4]ARC/INFO is a trademark of ESRI Inc., Redland, CA

[5]INTERGRAPH is a trademark of Intergraph Co., Huntsville, AL

[6]Information taken from Paper No. 87-1561 presented at the 1987 Winter Meeting of the American Society of Agricultural Engineers by Norman Sears, USDA Forest Service, Washington D.C.; Frederick L. Gerlach, School of Forestry, University of Montana, Missoula, MT; and Richard G. Hallman, Missoula Technology and Development Center, USDA Forest Service, Missoula, MT.

Area Location--Requires two or more positions in order to enclose an area or delineate between areas or establish a line.

- Timber Sale Boundaries
- Timber Plot Boundaries
- Road/Trail/Ski Locations
- Plantation Boundaries
- Easement Boundaries
- Transmission Line Location
- Source Site Location
- Location of Leasable & Non-Leasable Lands
- Archaeological Sites
- Tractor Skid Road Location
- Insect & Disease Areas
- Ownership Boundaries
- Breeding Sites
- Spray Area Boundaries
- Fire Perimeter Boundaries
- Thinning Plot Location
- Cableway Location
- Control Surveys

Point Location--Requires only a single position determination for identification.

- Oil/Gas Well Head Location
- Geotechnical Mapping
- Camera Point Location
- Mine Entrances
- Cabin
- Sunken Objects
- Genetic Trees
- Bird Boxes
- Dens
- Nests
- Culverts/Bridges
- Fire Tower Location
- Helispots
- Section Corners
- Communication Sites
- Fire Location
- Roosting Trees
- Silvicultural Examination

Others

- Aircraft Guidance
- Topographic Mapping
- Search & Rescue
- Emergency Crew Location
- Data Transmission
- Communications

GIS DATA BASE BENEFIT OF GPS

One of the greatest advantages of GPS for GIS applications is that the data is collected quickly and accurately with a common reference system. With data logging GPS receivers the coordinates, time, and other attribute information may be collected and then exported to a GIS data base with no manual digitizing operation. Since GPS provides a common reference system, data from GPS sources and sources rectified with GPS will register with each other and with GPS data collected in the field.

CONCLUSION

GPS is an operational system that offers many benefits to forest managers. This new tool not only saves the forester time in the field completing tasks but also allows him/her to collect more information in a shorter period of time. Plus GPS will benefit the GIS user by collecting accurate geographic coordinates for creating, updating or maintaining the GIS databases.

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OFFTRACKING OF TRUCK AND TRAILER COMBINATIONS USING FOREST ROADS[1]

Thomas W. Erkert and John Sessions[2]

Abstract: A microcomputer program, OFFTRACK, was developed to simulate the offtracking of six different vehicle configurations commonly found on forest roads. The program will predict offtracking through a complex set of road geometrics, including compound and reverse curves. It will analyze the path of a load overhang on a vehicle such as a yarder tower on a lowboy. Test results of the program are presented and compare favorably with several field studies.

Keywords: Forest Roads, Road Design, Logging Trucks, Offtracking

Offtracking of truck and trailer combinations is one of the primary concerns of forest road designers. Offtracking has been defined as the difference in the paths of the inside front wheel and of the inside rear wheel as a vehicle negotiates a curve (Foxworth 1960). Another definition commonly used is the difference in the paths of the centerline of the front and rear axles as shown in Figure 1.

Thousands of miles of forest road are constructed each year. Offtracking of the design vehicle largely determines required travelway widths which affects construction costs, potential site impacts, and safety. For the forest road designer, the situation is complicated by many different types of vehicle configurations and a complex set of road geometrics. Many low volume forest roads have small radius reverse and compound curves or single curves connected by short tangents. The forest road designer must also take into account the path of load overhangs on vehicle configurations.

Many of the available analytical techniques are not capable of analyzing the offtracking of truck and trailer combinations or the path of load overhangs through a set of curves. A microcomputer program, OFFTRACK, was developed to simulate truck and trailer offtracking through a set of curves and tangents up to one mile in length. This paper presents the methods that are currently being used to analyze offtracking, describes the OFFTRACK program, and presents the results of testing the OFFTRACK program with several field studies.

1 Presented at the Annual Council on Forest Engineering Meeting, Coeur D'Alene, Id, August 28 - August 30, 1989.

2 The authors are respectively, Civil/Logging Engineer USDA Forest Service and Professor Department of Forest Engineering, Oregon State University, Corvallis, Or 97331-5706. The mention of trade names of commercial products in this article does not constitute endorsement or recommendation by the authors, Oregon State University, or United States Department of Agriculture.

CURRENT METHODS

There are five methods that are currently being utilized in varying degrees for the determination of offtracking. All of the methods discussed are for use with vehicles that use Ackerman type steering and trailing axles that are fixed perpendicular to the longitudinal axis of the vehicle. The following briefly discusses each method and the advantages and disadvantages of each.

Direct Solution of Maximum Offtracking

The best known method for the direct solution of maximum offtracking is that of the equations in the Society of Automotive Engineers Handbook (SAE Handbook 1964). These equations are commonly known as the "Sum of the Squares of the Wheelbases". The principle behind the equation is shown in Figure 1. The maximum offtracking is developed when a projected line through the centerline of a trailing axle intersects the radius point of the curve.

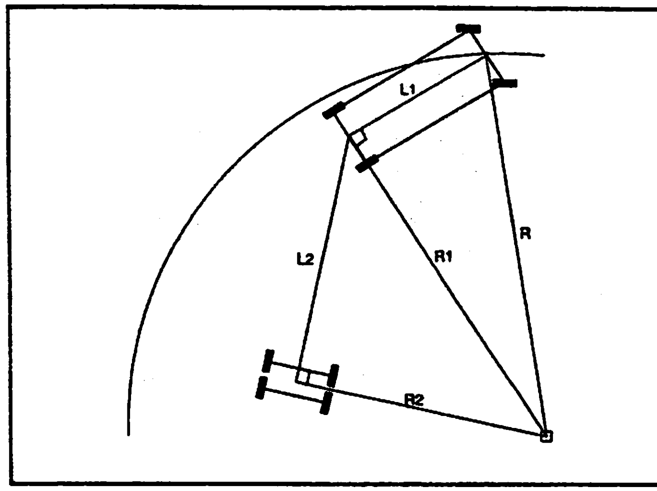


Figure 1. Sum of the Squares of the Wheelbases

The maximum offtracking (OT) relative to the longitudinal centerline of the vehicle can be solved for as:

$$OT = R - \sqrt{R^2 - L_1^2 - L_2^2} \quad (1)$$

The main advantage of this approach is that any vehicle configuration can be analyzed quickly. The disadvantages are that it is only valid for curves that are long enough for maximum offtracking to develop and it can not analyze transitional wheel paths. A transitional wheel path is the path followed from no offtracking to the maximum offtracking.

Empirical Methods

The USDA Forest Service developed a method to predict offtracking as a function of the sum of the squares of the wheelbases, radius of the curve, and the curve central angle (Cain and Langdon 1982). This method uses a regression equation that was developed using variables from differential tractrix equations (Della-Moretta and Cisneros 1976). The regression equation was tested with field tests on a log truck and a scale model simulator for a lowboy vehicle combination (Otte 1972). The equation reported is:

$$C = (R - \sqrt{R^2 - L^2})\left[1 - e^{\left(-.015\Delta\frac{R}{L} + .216\right)}\right] \quad (2)$$

Where: C = Total vehicle offtracking
R = Centerline radius of the road
e = Base for natural logarithms
Δ = Central Angle
$L = \sqrt{\sum_{i=0}^{n} L_i^2}$
L_i = The wheelbase of vehicle unit i

This approach utilizes the principle that regardless of the vehicle configuration, as long as the sum of the squares of the wheelbases and the radius of the turn are identical, the maximum offtracking will be identical (Western Highway Institute 1970). Design charts have been developed that give the required road width for a standard log truck and lowboy for radii of 50 to 300 feet and central angles of 10 to 180 degrees. A two foot steering correction is added to the result of the regression equation within the design charts. The advantages to using this approach are that it is quick, easy to use, and relatively accurate. The disadvantages are that it is not capable of analyzing transitional wheel and load overhang paths.

Scale Models

Because of the deficiencies of the previous methods, scale model simulators have been used to analyze offtracking of vehicle combinations through a set of curves. Three scale models have been developed, U.S. Army Vee-Trans (Foxworth 1960), USDA Forest Service Drafting Vehicle Simulator (DVS) (Kramer 1982), and the CalTrans Tractrix Integrator (TI) (Otte 1972). Each of the scale models are used with the following general procedure:

1. The road traverse is drawn to a large scale. Scales used range from 1 inch = 5 feet for the Vee-Trans to 1 inch = 10 feet for the DVS and TI.
2. The model is adjusted to the dimensions of the vehicle combination and is carefully guided over the traverse drawing. A set of pens trace the path of the rear most wheels.

The scale models have been found to be fairly accurate when compared to field equipment tests (Otte 1972). The DVS is probably the most useful of the scale models for forest road designers. It is capable of analyzing four different vehicle combinations directly. It will also plot the path of a load overhang for a yarder tower lowered for road travel on a rubber tired undercarriage. The disadvantages of the scale models are that they are somewhat cumbersome to use for designing road sections of any length.

Field Simulators

Several vehicle simulators have been designed by the USDA Forest Service for analyzing offtracking of a single unit or a two unit vehicle combination on existing roads in the field. These models are constructed from light weight aluminum tubing and are adjustable in length to simulate different wheelbases. No published results of the accuracy of these models exist. However, these simulators have proven to be quite useful in practice and are felt to be fairly accurate. The disadvantages are that limited vehicle configurations are available and they are only useful for existing roads.

Computer Simulation

Two simulation techniques have been developed that could be useful to the forest road designer. The techniques use different approaches and are summarized as follows:

Tractrix Algorithm

There exists a general mathematical description of the path that the rear of a vehicle follows from a given input steering curve. A steering curve is defined as the set of geometrics that guide the lead unit in a vehicle combination. The path that the trailing axle follows is known as the tractrix of the original steering curve (Jindra 1963). To find a closed form solution, the differential equations must be integrated. This process is extremely complex and not suited for general practice (Sayers 1986). In 1976 a simplified set of the integrated equations for a single unit vehicle were developed and programmed on a computer (Della-Moretta and Cisneros 1976). The program and the algorithm were never fully developed for combination vehicles. The differential tractrix equations are the basis of the OFFTRACK program.

Graphical Algorithm

In this algorithm, a series of geometric relationships were derived to describe the path of the trailing vehicle unit (Sayers 1986). The approach can be done by hand but is too laborious for practical use. The general procedure is to:

1. Extend a line towards the center of the curve along the path of the rear axle of the unit.
2. Extend a line from the centerline of the front axle on the steering curve through the center of rotation of the steering curve. The point of intersection of the lines in step 1 and step 2 is the instantaneous center of rotation of the rear axle.
3. Move the centerline of the front axle along the steering curve a distance of one foot.
4. Strike an arc from the new front axle location across the path of the centerline of the rear axle. The arc has a radius equal to the wheelbase of the vehicle unit.
5. Strike an arc from the center of rotation of the rear axle across the arc from step 3. The arc has a radius equal to the distance from the center of rotation of the rear axle to the centerline of the rear axle in it's previous location. The point of intersection of the arc's in step 3 and step 4 is the new location of the centerline of the rear axle. This completes the cycle of one movement, return to step 1 and continue.

The Sayers program uses a set of equations to accomplish the same set of steps above but for multiple unit vehicles. The main advantages of the program is that it is capable of analyzing any vehicle configuration and will plot the swept path of the outside front wheel and the inside rear wheel. The disadvantages of the program are that it was programmed on hardware that is not commonly used today, is slow to execute, provides no direct numeric output of required road widths, and the analysis is only completed in one direction.

OFFTRACK COMPUTER SIMULATION PROGRAM

The OFFTRACK computer simulation program was developed specifically for forest roads. It does not have the disadvantages of the currently available techniques. The tractrix algorithm is used as the method for describing vehicle movement. The theory behind the program is not presented here but is discussed in an additional article by the authors (Erkert and others 1989). It is programmed for the IBM and compatible family of computers operating under DOS 2.0 or higher.

Program Features

The OFFTRACK program will enable forest road designers to quickly determine required road widths and load overhang paths. The following is a summary of the program capabilities:

1. Analyzes 100 road segments up to one mile in length.
2. Analyzes offtracking both ahead and back automatically.
3. Analyzes load overhang paths.
4. Analyzes road widths left and right of centerline directly.
5. Analyzes most vehicle combinations found on forest roads.
6. Provides a graphical display of the wheel and load paths.

The program features a pull down menu structure and data input editors for ease of use. The main menu structure is shown in Figure 2.

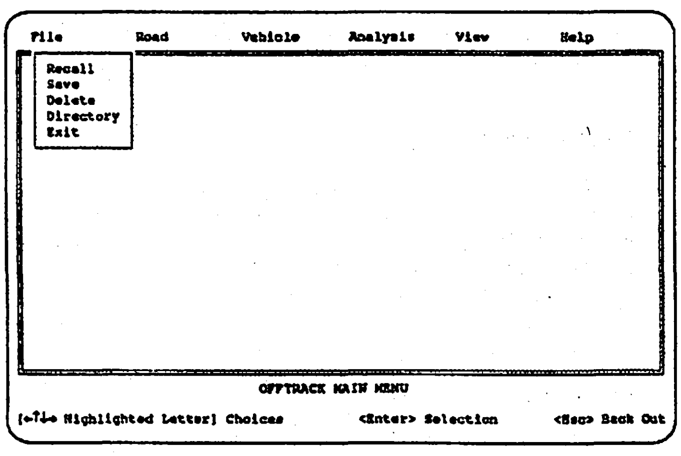


Figure 2. OFFTRACK Main Menu

The data inputs to the program are:

1. Geometry of Road Segments

The geometry of the road segments is input with the use of a spreadsheet type editor and up to 100 road segments can be used. The inputs are the radius, and the beginning and ending distance of the segment. A sign convention is used for the radius to indicate absolute direction. Curves that are clockwise in the ahead station direction are defined as positive and curves that are counter clockwise are negative.

2. Design Parameters and Starting Conditions

Design parameters consist of the minimum travelway width for design, and the minimum steering correction. A two foot minimum steering correction is customary to account for driver error. The starting conditions consist of beginning coordinates and azimuth of the first segment.

3. Definition of Vehicle configuration

The program is capable of analyzing six different vehicle configurations as shown in Figure 3.

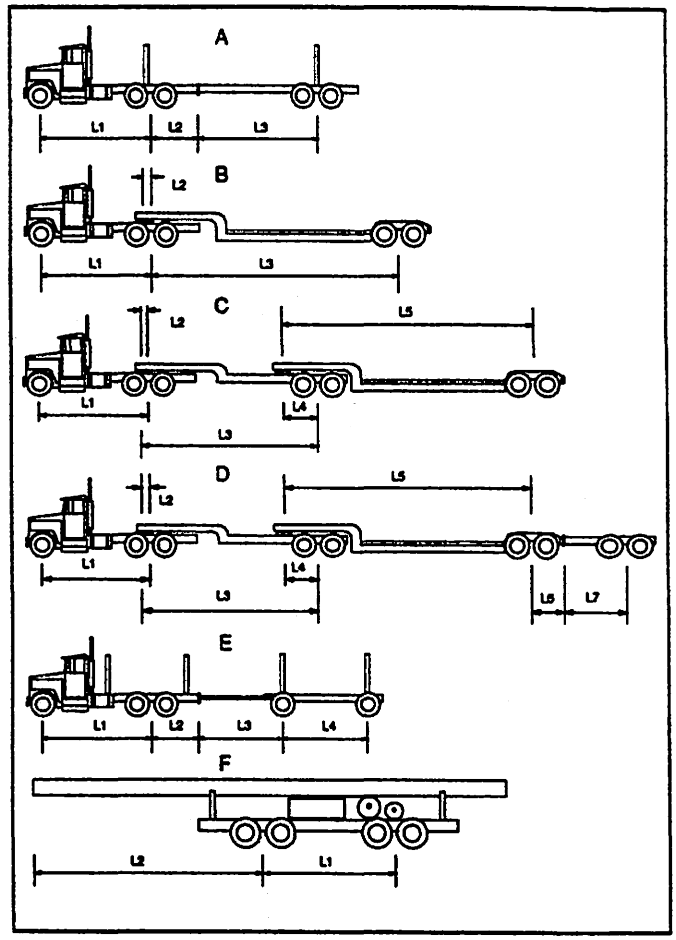
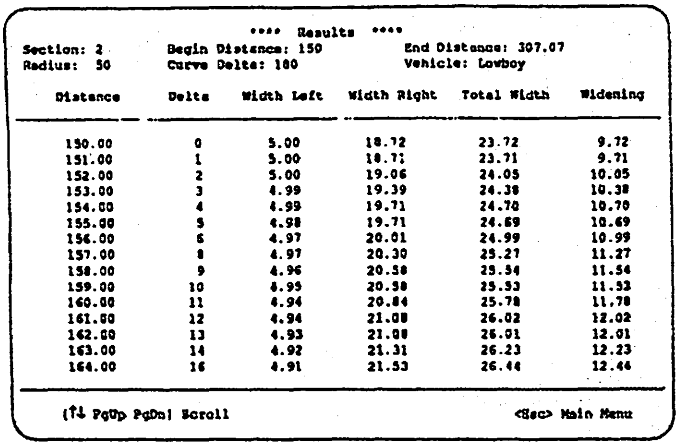


Figure 3. Vehicle Configurations (A) Log Truck, (B) Lowboy, (C) Lowboy with Jeep, (D) Lowboy with Jeep and Pup, (E) Short Logger, (F) Non Hinged

The inputs for any given vehicle are the wheelbases and hinge point offsets for each unit in the combination (Figure 3). Load overhangs can be specified either ahead of the hinge point or behind the rear axle for the lowboy and non-hinged type vehicles or behind the rear axle for the log truck and short logger type vehicles.

The numeric results (Figure 4) are road widths left and right of the centerline of the front axle, total width, and curve widening in one foot increments. It should be noted here that the simulation is done by guiding the centerline of the front axle on the centerline of the road. Therefore, the widths reported are relative to the centerline of the road. All widths reported have a steering correction added in. The curve widening is the total required road width less the minimum travelway width.



Section: 2	Begin Distance: 150		End Distance: 307.07		
Radius: 50	Curve Delta: 180		Vehicle: Lowboy		
Distance	**Delta**	**Width Left**	**Width Right**	**Total Width**	**Widening**
150.00	0	5.00	18.72	23.72	9.72
151.00	1	5.00	18.71	23.71	9.71
152.00	2	5.00	19.06	24.05	10.05
153.00	3	4.99	19.39	24.38	10.38
154.00	4	4.99	19.71	24.70	10.70
155.00	5	4.98	19.71	24.69	10.69
156.00	6	4.97	20.01	24.99	10.99
157.00	8	4.97	20.30	25.27	11.27
158.00	9	4.96	20.38	25.34	11.54
159.00	10	4.95	20.38	25.53	11.53
160.00	11	4.94	20.84	25.78	11.78
161.00	12	4.94	21.08	26.02	12.02
162.00	13	4.93	21.08	26.01	12.01
163.00	14	4.92	21.31	26.23	12.23
164.00	16	4.91	21.53	26.44	12.44

[↑↓ PgUp PgDn] Scroll <Esc> Main Menu

Figure 4. Numeric Results Screen

To promote understanding of the numeric results, a graphical display of the wheel and load paths can be viewed on the screen or sent to a Hewlett-Packard 7580B/7585B or compatible drum plotter and plotted at any scale. This permits the designer to plot the wheel and load paths at the same scale as the road traverse plot. The wheel and load path plot (Figure 5) can then be underlaid under the road traverse plot to evaluate load paths relative to cut slope clearance.

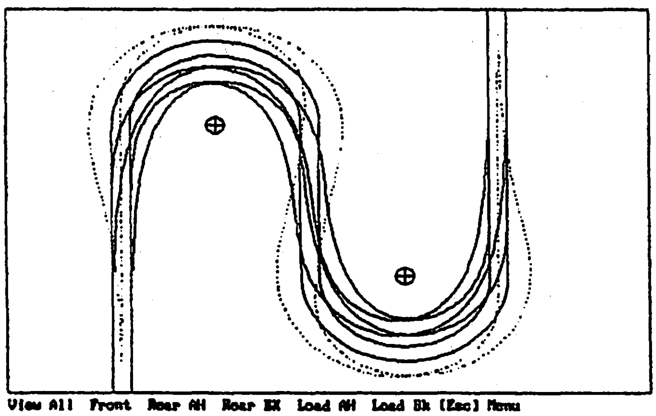


Figure 5. Screen Plot of Wheel and Load Paths

RESULTS

The program was tested with the results of several field studies and the Drafting Vehicle Simulator.

Log Truck Field Test

A test was conducted with a loaded log truck by the USDA Forest Service in cooperation with Champion International at an unpaved yard in Bonner, Montana (Cain and Langdon 1982). Curves with radii of 50 to 125 feet at centerline and central angles of 19 to 180 degrees were marked in the yard. The truck was driven around each curve with the driver doing his best to keep his left front tire on the mark. The path of the rear most trailer tire was noted as the wheel track left in the dirt yard and the offtracking recorded. The authors caution that measurements could be in error by as much as 0.5 feet. The truck used had dimensions of 19.0 foot tractor length, 9.0 foot stinger length, and 18.2 foot trailer length. A comparison of the offtracking from the OFFTRACK program and the field study is given in Table 1.

Table 1. Offtracking Comparison Between USDA Log Truck Field Test and the OFFTRACK Program, 50 Foot Radius.

Source	Delta (deg)	Central Angle Ahead of P.C. (deg) 0	19	30	46	64	90	116	180
		Feet							
Field Test	19	1.8	2.1						
OFFTRACK		2.1	2.3						
Field Test	30	2.2	3.7	3.5					
OFFTRACK		2.3	3.6	3.2					
Field Test	46	2.2	4.6	5.0	3.7				
OFFTRACK		2.4	4.6	4.8	3.9				
Field Test	64	2.2	4.6	5.7	5.7	4.4			
OFFTRACK		2.2	4.5	5.2	5.5	4.4			
Field Test	90	2.2	4.6	5.7	5.8	6.3	4.8		
OFFTRACK		2.2	4.5	5.3	6.0	6.3	4.8		
Field Test	116	2.2	4.6	5.7	5.8	6.4	6.0	4.8	
OFFTRACK		2.2	4.5	5.3	5.9	6.4	6.7	5.0	
Field Test	180	2.2	4.6	5.7	5.8	6.4	6.0	6.8	4.7
OFFTRACK		2.2	4.5	5.3	5.9	6.4	6.7	6.8	5.1

The data in Table 1 indicate a good correlation between the field test and the OFFTRACK program. Most of the measurements agree within several tenths of a foot and the maximum deviation is 0.7 feet.

CalTrans Operational Test

The California Department of Transportation (CalTrans) conducted offtracking tests of a semi tractor trailer, Rocky Mountain Double, Turnpike Double, and Triple combinations (California Department of Transportation 1984). The tests were conducted with Viking Freight Systems, Inc. of Santa Clara California in their paved yard. A line was painted for 60, 80, and 100 foot radius curves over a 180 degree central angle. The driver entered the curve on a tangent, placed the left front tire on the painted line through the curve and then left on a tangent. The path of the right rear most tire was continually marked on the pavement. The OFFTRACK program was used to simulate the semi tractor trailer, Rocky Mountain Doubles, and the Turnpike Doubles. The dimensions of the vehicles tested can be obtained from the authors (Erkert and others 1989). The field test recorded swept width as the difference in radii measured to the left front wheel and the right rear wheel from the center of the curve. Comparisons of the OFFTRACK program versus the field study are given in Tables 2 - 4.

Table 2. Swept Width Comparison Between CalTrans Field Test and the OFFTRACK Program, 60 Foot Radius.

Source	Vehicle	Central Angle Ahead of P.C. (deg) 0	30	60	90	120	150	180
		Feet						
Field Test	48 Foot	12.1	18.4	21.5	23.5	24.4	25.0	21.3
OFFTRACK	Semi	13.0	18.9	21.9	23.5	24.5	24.3	20.2
Field Test	Rocky Mt	15.1	22.5	26.5	28.7	30.1	28.9	23.6
OFFTRACK	Double	16.0	23.0	27.1	29.4	30.6	29.4	24.1
Field Test	TurnPike	17.9	28.2	34.8	38.8	40.3	38.4	31.4
OFFTRACK	Double	20.7	30.3	36.6	40.5	41.8	40.1	33.6

Table 3. Swept Width Comparison Between CalTrans Field Test and the OFFTRACK Program, 80 Foot Radius.

Source	Vehicle	Central Angle Ahead of P.C. (deg) 0	30	60	90	120	150	180
		Feet						
Field Test	48 Foot	10.7	16.1	18.2	19.1	19.6	19.8	16.2
OFFTRACK	Semi	11.5	16.6	18.6	19.4	19.7	19.7	16.3
Field Test	Rocky Mt	12.5	19.1	21.4	22.7	23.4	22.7	16.8
OFFTRACK	Double	13.4	19.6	22.2	23.3	23.8	23.4	18.6
Field Test	TurnPike	14.4	23.0	27.1	29.1	30.4	29.4	20.4
OFFTRACK	Double	16.1	24.4	28.5	30.6	31.1	30.7	24.2

Table 4. Swept Width Comparison Between CalTrans Field Test and the OFFTRACK Program, 100 Foot Radius.

Source	Vehicle	Central Angle Ahead of P.C. (deg) 0	30	60	90	120	150	180
		Feet						
Field Test	48 Foot	11.6	15.6	16.6	17.0	16.9	17.3	13.7
OFFTRACK	Semi	10.7	15.2	16.5	16.9	17.0	17.0	14.3
Field Test	Rocky Mt	12.2	18.0	19.3	19.5	19.7	19.8	16.4
OFFTRACK	Double	12.1	17.7	19.4	19.9	20.1	20.0	16.0
Field Test	TurnPike	14.4	21.5	24.0	24.9	25.4	25.3	19.1
OFFTRACK	Double	14.1	21.5	24.4	25.5	26.0	25.6	19.9

Most of the swept width measurements (Tables 2 - 4) agree within one foot and the maximum deviation is 2.2 feet. The OFFTRACK program usually over predicted the swept width.

The DVS was used to test the program predicted wheel and load overhang paths through a series of curves but are not presented here because of length limitations. In general, the results agreed within 0.5 feet of the DVS.

CONCLUSIONS

The OFFTRACK program simulations provided results within 0.5 feet of the DVS and the log truck field measurements. There was an over estimation of swept widths for the doubles combinations in the CalTrans test. Program results compare favorably except for the shorter radius curves with the turnpike doubles combination where overestimates of swept width of 2.0 feet are made. This disparity is probably due to slip and scrubbing of the tires or misalignment of axles (Morrison 1972). The predicted offtracking for the field test on the log truck in a unpaved yard was very close to measured. This appears to support the influence of tire mechanics because of the lower coefficient of friction associated with the unpaved yard versus the paved yard. The over prediction of swept width in the CalTrans test data is consistent with that reported by several other authors when comparing scale model simulators to actual equipment tests (Cain and Langdon 1982), (Otte 1972). The program appears to predict offtracking with reasonable accuracy for use as a road design tool.

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Tires for Subgrade Support[1]

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Abstract: Used tires accumulate at an alarming annual rate with very few feasible methods of disposal. Roads across marginal subgrades present difficult engineering and construction problems. Using tires to provide subgrade support in these situations seemed to be a possible solution to both problems. Our tests to date have proven very successful in carrying the expected loads over very marginal ground. There seems to be several applications where tires may be a workable solution to subgrade stability.

Keywords: Lightweight fill, floated embankments, settlement, stability, recycling, embankment monitoring, shredded tires

INTRODUCTION

In 1984 legislators across the nation brought the tire disposal problem to the fore-front by initiating legislation to deal with the growing stockpile situation. Every major city throughout the country had tremendous stockpiles of used tires, growing at a rate of about one tire per person, or 225 million tires annually.

The annual tire waste in our country could be used to build a geo-grid 80 feet wide from New York to Seattle one year, and provide a fill three feet deep for a two lane road with 10 foot shoulders from Reno to San Francisco (237 miles) the next year, and so on. The state of Minnesota alone generates 3 million tires or 110,000 cubic yards of rubber shreds annually.

Disposal of tires is an urgent matter for several reasons. The first is the health and welfare of our nation. Stock piles of tires are excellent breeding grounds for various multi disease carrier mosquitos. There is a need to reduce the water holding capacity of these tires or remove them from the environment. Fire is another major concern in the growing stock piles. Although tires are difficult to ignite (unlike wood chips) they are extremely difficult to extinguish. The heavy carbon smoke and residue run off (each tire releases about 2.5 gallons of petroleum products when burned) are major environmental concerns. In most areas of the country burying whole tires in land fills is only a temporary solution since the tires work to the surface in just a few years. The question of how to dispose of this enormous problem remains. The urgency is growing.

RECYCLING/OTHER USES

Many unsuccessful approaches have been suggested to deal with this problem. Grinding tires to 2" X 2" squares to burn as fuel was an early idea. This produced a high particulate count in the smoke and required a 3 to 4 pass shredding operation. The prices paid by the fuel burners did not cover the cost of processing the material for this use. Grinding tires into rubber powder for reuse in new rubber products was another option. The quality control was hard to maintain because of dirt and other materials that get mixed in with the tires. The cost of the grinding could not be paid by the manufacturing operations at the existing market value of their products. Pyrolysis to distill out the oil, carbon black and steel has been proposed but to date no full scale system has been proven. Mass burning of whole tires has had some obstacles in the past but recent developments near Modesto, CA may show some promise for the future.

THE ROAD BUILDING CONCEPT

In 1985 a proposal was made to the Minnesota Pollution Control Agency (PCA) to use waste tires to construct forest roads in Minnesota. This idea originated between a tire recycling firm and a logging contractor. The Department of Natural Resources, Division of Forestry (DNR - Forestry) was asked to explore this proposal and comment on the concept. From the PCA aspect there was no concern about the environmental effects since they felt that the compounds involved were stable under normal conditions and there seemed at least some chance of developing a method of disposal with a low processing cost. DNR - Forestry was interested in the project to provide an economical means for crossing peat and other soft soils which had proven very expensive in the past. The initial idea was to form a type of geo-grid to replace the wooden corduroy which had been the standard in the past but tends to fall apart over time on low standard roads. As the project developed there were some obvious areas to be examined.

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[1]Presented at the Annual Conference on Forest Engineering Meeting, Coeur D'Alene, ID, August 27-August 30, 1989.

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PERCEIVED ADVANTAGES

The waste tire materials seemed to provide a number of advantages that were worthy of consideration. The waste tire material is not effected by ultraviolet radiation like geotextiles are. Rubber is non-biodegradable either in or above the water line. The weight of individual tires was about 20 pounds so they could be easily moved on the job site and as many as 500 could be laced into a truck for delivery to a site. When shredded the tire chip material weighs only about 540 pounds per cubic yard so 100 cubic yards could be hauled to a job in one 40 foot trailer. The cost of processing was within reason since these applications require only a single pass processing to utilize the tires. The porosity of shredded tires is greater than that of washed sewer rock and might provide good cross drainage as well as subgrade drainage in general. The angular shape and friction locks the tire chip pieces together more securely with increasing loadings. With these factors in mind it seemed reasonable to look into testing the idea of using the waste tire materials in roads.

HEDBOM FOREST ROAD - FLOODWOOD, MINNESOTA

An initial proof of concept was initiated on a wet silty soil subgrade. This was a low cost installation designed to demonstrate the concept and was accomplished during spring breakup in 1986. This resulted in a driveable road immediately following the completion of construction despite the unstable conditions of the subsoil.

Based on the knowledge gained from this installation, DNR - Forestry set out to design a series of roadway test sections to determine the feasibility of applying this operationally and in the best configuration to provide the necessary support. The test consists of 8 test sections, each 400 feet long, with a standard geotextile section on each end of the test area as a control section. A 9th test was also installed adjacent to the main road by constructing a turnout using shredded rubber materials. The Hedbom Forest Road near Floodwood, MN was used for the testing. This project consisted of upgrading an existing low standard road across 6 miles of peat swamp, which ranged from 5 to 17 feet deep, to access a large block of state forest land. The original road was too narrow since it was constructed atop the ditch spoil from the construction of a drainage ditch. Some sections were originally constructed with corduroy to reinforce the weak subgrade. Much of the corduroy was breaking up and working out of the subgrade. The new project took advantage of the existing grade as much as possible but doubled the width of the subgrade by expanding the fill out over the peat on the side opposite the drainage ditch (Figure 1).

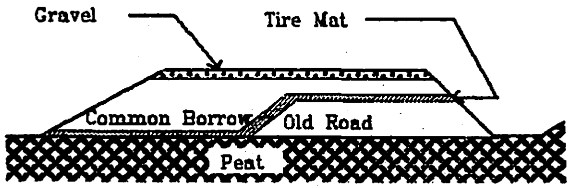

Figure 1 - Cross-section of Hedbom Road tire mat installation.

The tire mats to be tested were placed full width at the base of the embankment which was to be added. To construct the mats the tires were tied together with a nylon toggle strap. The strip was inserted into prepunched holes in the tires. Traffic was maintained through the construction site by folding the mat back on itself until the night before the filling operations were to take place. The sections tested were as follows:

1. A single layer of whole tires tied into a mat.
2. A double layer of whole tires tied into mats with an attempt to offset the top layer 1/2 tire width from the bottom but no ties between layers.
3. A single layer of whole tires tied into a mat topped with 8" of shredded tires.
4. A single layer of half tires (cut through the tread to yield two donuts per tire) tied into a mat with the hollow side (cups) down, topped with 8" of shredded tires.
5. A single layer of half tires tied in a mat with cups up.
6. A single layer of half tires tied in a mat with cups down.
7. A double layer of half tires tied in a mats with cups down on the bottom layer and cups up on the top layer with an attempt to offset the top layer 1/2 tire width from the bottom but no ties between layers.
8. A single layer of half tires tied in a mat with cups down with a non-woven 90 pound geotextile separating fabric over the tires.
9. A chip fill 3 feet deep by 10 feet wide by 120 feet long as a turnout over undisturbed peat adjacent to the road.
10. Test sections on each end using 400 pound woven slit film geotextile.

Work on this project started in November of 1986. All tire mat and tire chip sections were capped with a silty sand common borrow soil. The soil cap was end dumped and dozed with low ground pressure equipment to depth of about 12 inches loose measure. This lift was compacted and a second lift applied to bring the total compacted depth of cap fill to 12 inches above the mats and fabric.

The following summer the contractor placed 6" of 3/4" close-graded aggregate on the surface. Logging followed the same summer. The logging has continued for two years now on a 3 season basis.

Based on settlement plate readings, it appears that no one section has settled more than any other. The truck traffic has not effected the test sections any more than the other parts of the road. No holes have developed in the peat sections but a few soft spots have surfaced in other portions of the road. There is general agreement from all the parties responsible that the project was successful in providing the support that was required.

During the summer of 1989 standard penetration test borings were performed on each of the Hedbom test sections to evaluate settlement and confirm peat depths. The alignment was also test rolled with a truck with an equivalent axle load of about 6 tons per axle. Subgrade deflections were measured during the test roll. The borings showed the widened segment of embankment had settled approximately 12 to 18 inches. In comparison, estimated settlement of a conventional soil embankment would have probably settled an additional 1 to 2 feet. Subgrade deflections at the passing of the 6-ton per axle truck were indiscernible. This observation was rather surprising in that the embankment was "floating" above as much as 17 feet of saturated, very soft organic soil. The appearance of the road suggested it had been performing exceptionally well.

EDEN PRAIRIE, MINNESOTA, ROADWAY

On a municipal wetland fill project to construct a roadway, the earth embankment failed during construction. The alignment was inadvertently overfilled, resulting in nearly 30 feet of soil fill placed over more than 40 feet of soft organic soil. The embankment punched into the soft soils and settled to an elevation that was below the proposed roadway subgrade. After three years, the embankment was still settling at a rate of about 1 foot per year. As development on nearby parcels necessitated completion of the roadway, something had to be done to limit long-term settlement potential. To create an unload, 10 to 14 feet of the existing mineral soil was removed and replaced with shredded tire material. The project used about 30,000 cubic yards of shredded tires. After the shredded tires had been placed and compacted, they were covered with a geotextile fabric and capped with a 4-foot cap of soil (Figure 2). Settlement monitoring plates indicated that the face of the subcut had stopped settling. However, the monitoring device placed on top of the shredded tire material indicated some consolidation of the shredded tires after the mineral cap was in place. A construction delay of three weeks was necessary to allow time for the shredded tire material to compress under the weight of the mineral soil cap. This road will be open to public traffic after it is completed. Settlement monitoring and pavement/subgrade strength determinations will be part of an ongoing study.

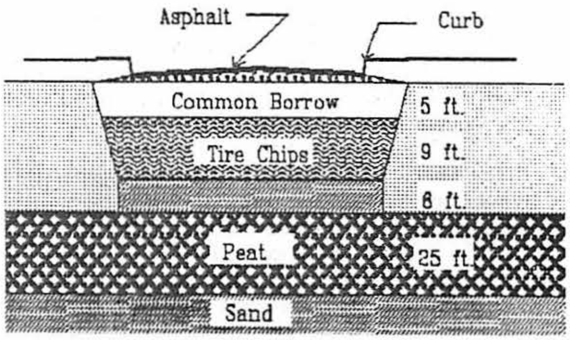

Figure 2 - Eden Prairie lightweight fill.

OTHER COMPLETED PROJECTS

Tires For Wet Spots (TFWS) was founded by Monte Niemi to develop and market these ideas further. In 1986 they installed a mat of whole tires under 18" of common borrow (silty clay) on a county forest road in Carlton county. This project was not instrumented but has proven to be stable up to this point, for the removal of logs and firewood.

In 1987 and 1988 TFWS worked on extending a township road across peat and marginal soils to access a parcel of private ground. Operations have been limited by the funding the owner has available. To date, two sections have been installed (about 600 feet each) and the project is about 40 % finished. The first section is a whole tire mat covered with 12" of shredded tires and the second section is 24" of shredded tires by themselves. The installation of the shredded material was accomplished by backing onto the end of the newly constructed fills and end dumping. During this construction there were no problems with driving on the uncovered shreds or the support which they provided for the trucks. No fabric is anticipated in this application since this is primarily a private driveway for lightweight vehicles. A cap of 12" of granular borrow will be the final topping for the road.

OBSERVATIONS/REACTIONS

From observation of the installation and performance of these sections it is suggested that future geo-grid tire mat configurations use the 1/2 tires with the cups down. The most promising of these configurations for high use roads was the one with the separation fabric. By combining this with a fill of shredded tires we feel that ground with very low strengths could be crossed reasonably cost effectively.

The methods used to tie the mats together for these studies was highly labor intensive on the site. There appear to be methods that could be developed to mechanize the insertion of the ties without prepunching the holes. The mats could also be preassembled in pallet form (16 tires per 8' X 8' layer) to reduce on-site labor substantially.

There seems to be more potential for lightweight fills than for the geo-grid concepts that were originally tested. Our greatest interest now lies in the further study and use of chipped tires as a light weight fill.

The concept of chipped tires as a lightweight fill was not part of the original study plan. It became apparent that the shredded tire material could provide a major source of lightweight fill material. From the limited experience on this project with the shredded tire fill by itself, and the use of wood chip fills in several other locations, DNR - Forestry and Tires For Wet Spots are exploring the use of shredded tires for lightweight fills further.

The advantages of a 5:1 reduction in loading, which is accomplished using the lightweight tire fill, and the load distribution which is possible with larger depths became very apparent with the construction of the turnout. This is best suited to sites where there is enough vegetative cover or surface strength to provide working support, or where enough tire shred material can be brought in to create a working base. By placing a separation fabric below and above the shredded material and leaving the side slopes without fabric it is anticipated that cross road water flows could still be achieved. This would be desirable for wetland crossing. One project of this nature is scheduled for installation and instrumentation on DNR - Forestry lands this summer. One of the additional factors to be examined in this study is the surface stability to determine the feasibility of placing pavements over these materials in high load situations.

Several other projects are now pending to use the lightweight tire fills in private, local, county and state highway projects. One such project has recently been constructed on Division of Forestry lands in central Minnesota. The Esker Trail utilized shredded tire material to cross a finger of peat which was five feet deep (Figure 3).

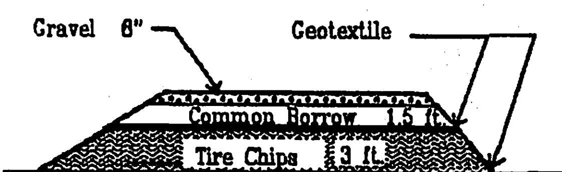

Figure 3 - Esker Trail peat crossing.

It is anticipated that Minnesota's existing stockpiles and annual production of waste tires could be put to good use in subgrade support projects by increasing the use of lightweight tire fills.

REASONS FOR FURTHER STUDY

In 1988, Braun Engineering Testing, Inc. (a geotechnical consultant) worked on about 60 projects where their clients were faced with development problems associated with highly compressible soils typical of wetland environments. On nearly half of those projects, a lightweight fill material could have been incorporated to achieve desired grades and reduce overall embankment settlements.

It seems that every year Braun Engineering Testing, Inc. becomes involved in an ever increasing number of wetland development projects. It is a reality in the Minneapolis/St. Paul metropolitan areas, including the surrounding suburbs, that a majority of the "good" land has been developed, and the land that remains is in need of correction to permit foundation or embankment support. As these areas are developed, the grades of most will have to be raised. So, the market for tire chips appears to be there. For most wetland fill projects in this area, clean sand is commonly used for the initial stages of embankment construction. The clean sand permits a drainage path for excess pore water pressure that develop in the consolidating organic subsoils. A tire chip mat would be a more porous medium to expedite the dissipation of pore water pressures, thus serving the same purpose. Additionally, rather valuable sand and gravel resources could be put to better use (i.e. free draining below grade wall backfills and frost heave resistant subgrades).

For embankments that are to be constructed over highly compressible and very weak organic soils (typical of wetland environments), Braun Engineering Testing, Inc. suggests that the construction begin with placement of a strong geotextile fabric followed by placement of an initial lift of lightweight material (i.e. wood chips or tire chips). This procedure reduces the risk of embankment shear failure into the weak organic subsoils while permitting access to light construction equipment. Embankment settlement estimates are typically made prior to placement of the lightweight fill. If wood chips are used as the lightweight material, the initial thickness of this layer is typically restricted to the amount of settlement expected so that, after embankment settlement is complete, the wood chip layer will be totally submerged thus, slowing the rate of decay.

The advantage of a lightweight fill is that, once it becomes submerged, the effective unit weight is less than 10 to 20 pounds per cubic foot as compared to 60 to 70 pounds per cubic foot for a submerged sand fill. With the use of lightweight fills, the lighter embankment load translates to less embankment settlement. Embankment settlements are a function of the depth of compressible soils and the height of the embankment to be constructed.

The largest advantage tire chips have is that the are likely not biodegradable, and they would not have to be restricted to the lower portions of an embankment like wood chips typically are. Because their submerged weights are similar to wood chips, it is assumed that embankment settlement characteristics where tire chips are utilized would result in similar settlement characteristics as an embankment wherein wood chips are utilized. And, because tire chips could likely be used in above-water applications without fear of decay, embankment loads would be even lighter, and embankment settlements would also be reduced.

Braun Engineering Testing, Inc. was retained to investigate two separate embankment failure projects this past year where grading contractors, while placing fill in wetland areas, placed too much fill to fast and developed embankment loads that exceeded the shear strength of the underlying soils. Massive fill embankment shear failures resulted. On one project, more than 25,000 cubic yards of mineral fill experienced a rotational and sliding failure into a wetland area causing a mud wave that significantly diminished an adjacent pond storage capacity. The contractor spent more than $150,000 to restore the area after the failure. Engineers at Braun Engineering Testing, Inc. analyzed the embankment construction had it been carried out in a staged manner with lightweight fill material such as tire chips and concluded that the embankment failure could have been avoided by virtue of lighter embankment loads and more closely monitored staged construction techniques.

It is very easy for grading contractors to place more fill than is called for, because they commonly try to fill to attain a grade and fail to realize the extremely compressible nature of the swamp deposited soils they are filling over. Lightweight embankment fills would lend to less initial and long-term embankment settlement and the ability to achieve a working platform sooner, thus, lowering the risk of shearing weaker subgrade soils.

Braun Engineering Testing, Inc., based on their experienced with lightweight fills, is of the opinion that use of tire chips as a lightweight fill has merit and warrants further study. They have reason to believe that tire chips are likely a good substitute for other commonly used lightweight embankment materials and that they may possess some advantages over other lightweight materials that are currently in use. Most apparent would be tire chip availability and economics.

Small Tractors for Harvesting Fuelwood in Low-Volume Small-Diameter Hardwood Stands[1]

Neil K. Huyler and Chris B. Ledoux[2]

Abstract: Much of the nonindustrial, private forest land in the Northeast is characterized by small diameter trees with low volume. Conventional harvesting systems used in logging these stands generally result in submarginal economic returns. Often, small-scale harvesting systems have economic advantages in these areas. Time and motion studies were conducted for several small tractors over a range of silvicultural treatments to estimate preliminary cycle times and production rates. Further research is progressing to incorporate this and additional simulation results into a generalized stump-to-mill logging cost, estimating computer package.

Keywords: logging, time studies, production rates

As more and increasing demands are placed on forested lands for timber production, wildlife, esthetics, recreation, hunting, fishing, and other uses, owners of small woodlots are looking for creative ways to harvest or treat the stands to accomplish their objectives. Much nonindustrial, private forest (NIPF) land is characterized by small diameter trees with low volume. Harvests or treatments in these low diameter/volume stands generally result in submarginal economic returns. The increased demands on NIPF owners with small holdings, coupled with small tree diameters and low volumes per acre, present a serious challenge to the logging manager. Often, small-scale harvesting systems have economic applications in these areas.

A series of time and motion studies has been conducted on small-scale logging operations in the Northeast. Several small tractors were studied in a wide range of silvicultural treatments and operating conditions. Specifically, the small tractors included the Pasquali 933, a Holder A60 F, a Forest Ant Forwarder (Skogsmyran), a Massey-Ferguson, and a Same Minitaurus.[3] This paper summarizes the machine attributes, terrain operating conditions, and preliminary cycle time and production results.

MACHINE ATTRIBUTES AND HARVESTING PROCEDURES

The Massey-Ferguson 184-4 farm tractor and the Same tractor were the primary skidding units used in two distinct firewood businesses in northwestern Vermont. The firewood was produced from nonindustrial private forests and was marketed in the local area.

The Holder A60 F, Pasquali 993, and Forest Ant (Skogsmyram) were skidding units selected for testing small tractors harvesting in low-quality small-diameter hardwoods stands in southeastern New York State. This was part of a fuelwood forestry project funded in part by the New York State Energy Research Development Authority (NYSERDA). Firewood and pulpwood were produced from State forest land and marketed in the local area.

The Massey-Ferguson 184-4, a four-wheel drive 60-horsepower diesel farm tractor, was equipped with a JL-456 Farmi winch (fig. 1). The Model 456 Farmi winch, designed for 50- to 120-horsepower, has a line-pull rating of 10,000 pounds with 165 feet of 1/2-inch cable. The tractor was equipped with chains on the rear wheels, extra weights for the front end, and calcium chloride added to both front and rear tires. No roll-over protection was placed on the tractor. To add additional weight and to pile logs at the landing, a bucket loader was attached later in the test.

The Same Minitaurus, a 60-horsepower, four-wheel drive farm tractor manufactured in Italy, was equipped with a JL-30 Farmi winch with a line pulling capacity of 6,600 pounds and a drum capacity of 165 feet of 3/8-inch cable. The tractor was equipped with chains on the rear wheels and calcium chloride loaded in the rear tires. Extra weights were added to the front, along with a bucket loader for added weight and for decking logs at the landing. The tractor had roll-over protection bars, but no safety cage (fig. 2).

The Holder, manufactured in West Germany, was an articulated, 48-horsepower diesel tractor. It was equipped with an Igland 3000 double-drum winch with a rated pulling capacity of 6,600 pounds. The accessory equipment included a dozer blade, a rear butt plate, front-wheel weights, and front tires weighted with calcium chloride. The tractor had a roll-over protection cage and underbody protection pan (fig. 3).

The Pasquali, manufactured in Italy, was an articulated frame, 30-horsepower diesel tractor. It was designed for small acreage farms, hobby farmers, landscapers, nurseries, and a second tractor for a "Big Tractor" farm. The tractor was equipped with a JL-25 single-drum Farmi winch with a pulling capacity of 5,500 pounds (fig. 4). The accessory skidding equipment included a protective roll bar, underbody protection pan, front bucket loader, and weighted front tires.

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[1]Presented at the 1989 Annual Council on Forest Engineering Meeting, Coeur 'D Alene, ID, August 27-30, 1989.

[2]Research Forester and Industrial Engineer, Northeastern Forest Experiment Station, Burlington, VT and Morgantown, WV, respectively.

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

Figure 1--The Massey-Ferguson 184-4 equipped with JL-456 winch.

Figure 2--The Same Minitaurus with JL-30 winch, roll-over protection bars, and bucket loader.

Figure 3--The Holder A60 F equipped with an Igland Jones double-drum winch and roll-over protection.

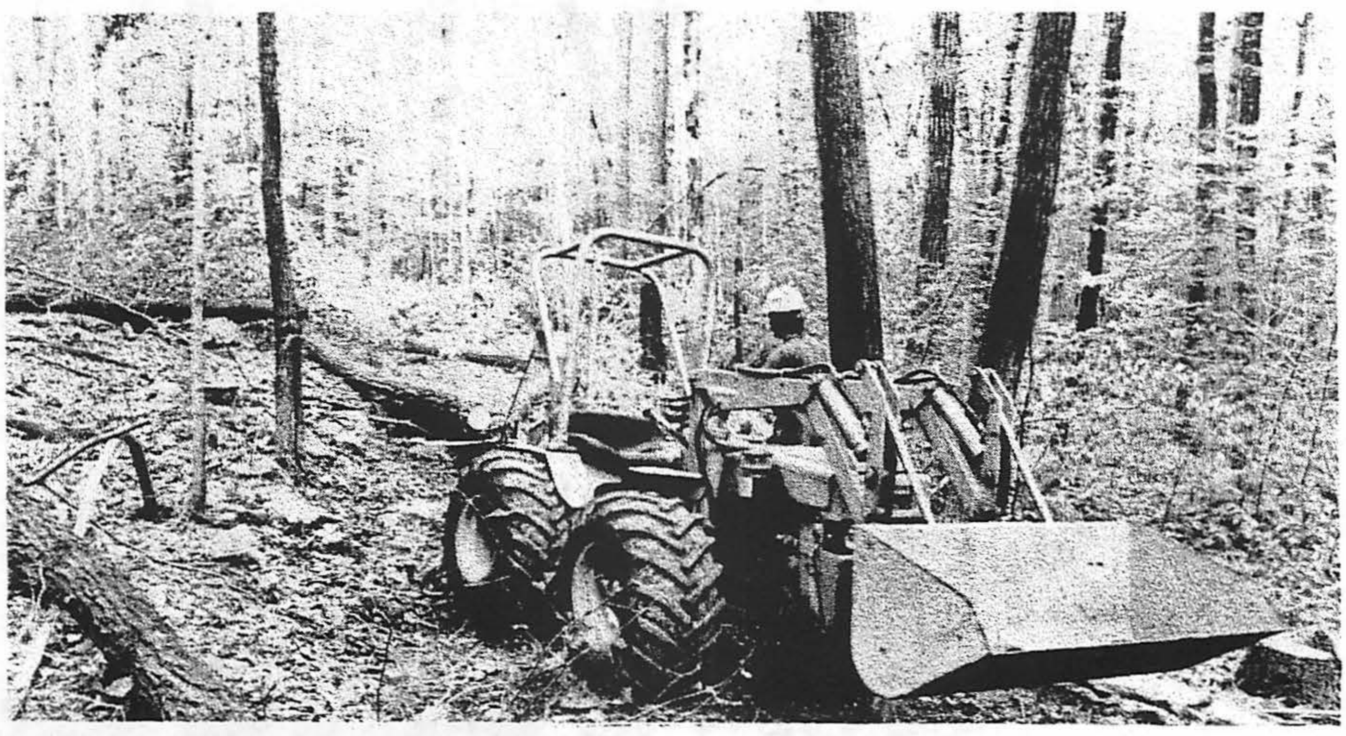

Figure 4--The Pasquali Model 993 with bucket, roll-over protection, and JL-25 single-drum winch.

The Forest Ant, manufactured in Sweden, was designed for gathering and forwarding small softwood loads to the main skid trails. The machine is an articulated tractor with a 12-horsepower, air-cooled engine. It was equipped with a clam bunk and knuckleboom loader with jaw-type grapple. The tractor steering and speed were controlled by a tiller bar in front. The machine had no cab and the operator walked at a comfortable speed with the machine following. There was a "dead man" control on the end of the tiller handle which stopped the machine when the tiller bar was released (fig. 5).

CHARACTERISTICS OF THE STUDY SITES

The study areas for the Massey-Ferguson and Same tractors were on low-quality hardwood stands marked for firewood production. The stand had shallow soils on moderately steep southeast aspect. Skidding ranged from 4 to 6 percent on primary skid trails and 2 to 22 percent on secondary short trails. The stands were predominantly mixed northern hardwoods with small pockets of red spruce. Table 1 shows the characteristics of each study site.

The study area for the Holder, Pasquali and Forest Ant was on the Harvard Black Rock Forest, in Cornwall, New York. The two test sites were similar and locally were called Aleck Meadows and Bugs Bunny. The topography was uneven on slopes of 0 to 14 percent, with scattered outcrops of rock ledges. Table 1 shows the general characteristics of the study sites.

SKIDDING CYCLE TIME AND PRODUCTION RESULTS

The average time per skidding cycle for each turn element is summarized in table 2. The sum of the outhaul, inhaul, hookup, and unhook time is the production time for each tractor. Hookup, unhook, and delay time is the fixed portion of the total time since the tractor is not moving during these elements. Inhaul, outhaul and deck time are the variable time elements, or the travel time. The sum of the productive time and delay time represents the total skid time and can be considered as the scheduled machine time.

The fixed time of hookup, unhook, and delay time for each of the tractors ranged from 63.5 percent to 83.8 percent of the total cycle time, and the variable time of inhaul, outhaul, and deck time accounts for the remaining 16 to 36 percent of total time. The hookup time included maneuvering and winching of stems into position to complete a load. Trees were directionally felled, either away from or toward the assumed tractor position, so that the choker could be set at either the butt or top end of the stem. Since winching angles were not to exceed 30 percent, the tractors were generally positioned in line with the direction of pull. Three to five chokers were used in most cases. The Forest Ant has a different hookup procedure from the other tractors and required more time. Its limited reach required that it be positioned very close to the log to be loaded. Also, the Forest Ant could not deck logs at the landing.

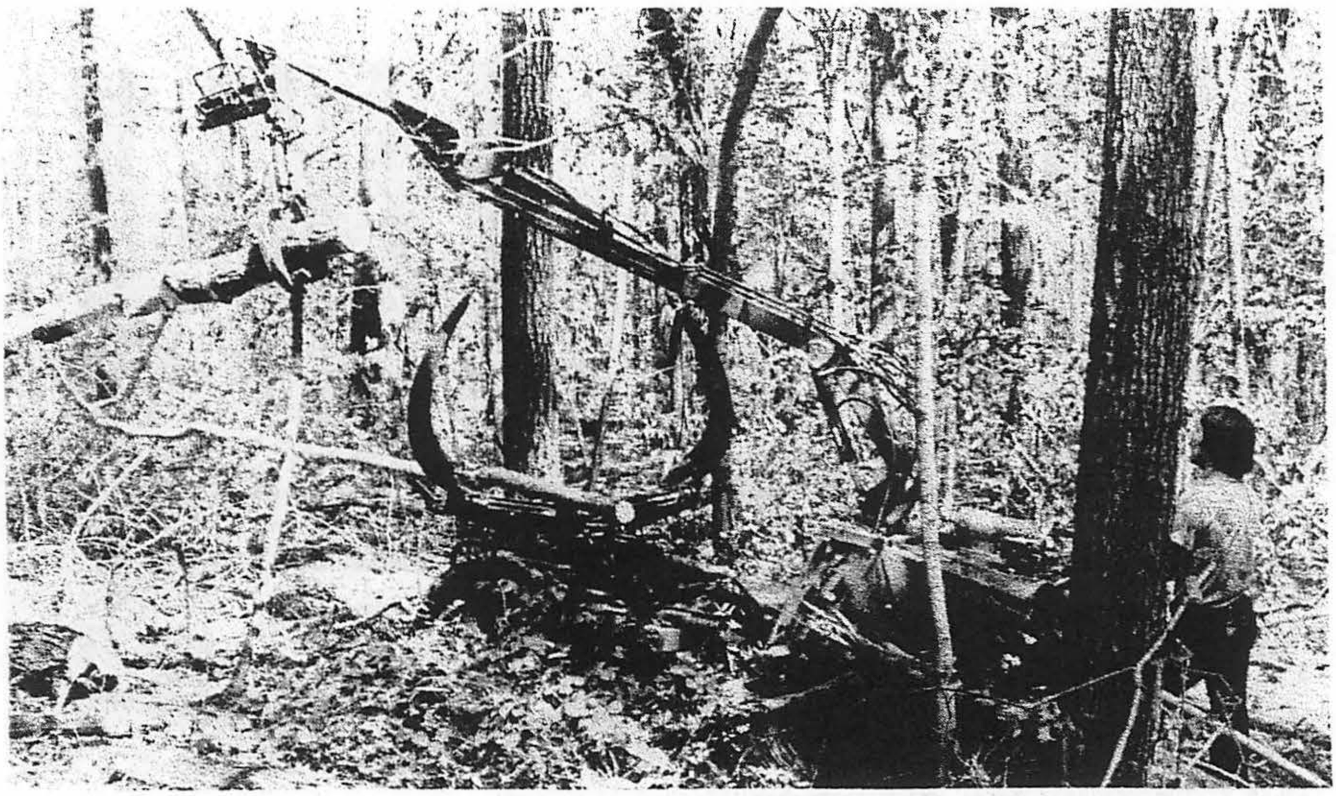

Figure 5--The Forest Ant equipped with clam bunk and knuckleboom loader.

Table 1--Characteristics of the study sites.

Tractor type	Study site No.	Average tree dbh	Basal area		Skidroad slope		Loaded skid direction	Type of cut
			Precut	Postcut	Primary	Secondary		
		Inches	ft^2 per acre		Percent			
Massey-Ferguson	1	9.4	109	80	4	22	Downhill	Selection
Massey-Ferguson	2	10.3	90	0	6	17	Uphill	Regeneration clearcut
Massey-Ferguson	3	10.3	90	0	6	2	Uphill	Regeneration clearcut
Same	4	11.0	110	85	5	15	Downhill	Selection
Pasquali	4	8.6	116	76	0	14	Uphill	Low thinning
Holder	4	8.6	116	76	0	14	Uphill	Low thinning
Forest Ant	5	8.4	96	71	0	12	Uphill	Low thinning

Table 2--Summary of cycle-time elements.

Tractor (Number of observations)	Statistics	Cycle time elements							
		Outhaul	Hookup	Inhaul	Unhook	Deck	Productive time	Delay time	Total time
Massey-Ferguson[a] (119)	Average time (min.)	5.30	11.15	4.68	5.74	--	26.88	7.26	34.14
	Std. dev.	2.02	11.58	2.15	2.81	--	12.86	9.09	15.54
	Percent of total time	13.40	41.60	11.88	14.57	--	78.73[b]	21.27	100.00
Same[a] (32)	Average time (min.)	11.58	13.69	10.73	7.39	--	43.40	17.74	61.14
	Std. dev.	5.63	9.28	4.73	3.33	--	14.58	31.25	31.12
	Percent of total time	18.94	22.39	17.55	12.09	--	70.98[b]	29.02	100.00
Holder[a] (45)	Average time (min.)	2.50	10.30	2.50	4.20	0.30	19.80	3.90	23.60
	Std. dev.	0.57	2.45	0.65	1.20	0.59	--	4.96	5.95
	Percent of total time	10.60	43.60	10.60	17.40	1.30	83.50[b]	16.50	100.00
Pasquali[a] (65)	Average time (min.)	2.70	9.60	2.70	1.70	.20	16.90	8.3	25.20
	Std. dev.	1.08	3.71	.98	.64	.66	--	20.42	21.22
	Percent of total time	10.70	38.20	10.70	6.70	.80	67.10[b]	32.90	100.00
Forest Ant[a] (30)	Average time (min.)	2.50	13.50	2.00	1.00	--	19.00	9.10	28.10
	Std. dev.	1.03	4.24	1.00	.58	--	--	12.27	13.91
	Percent of total time	8.90	48.20	7.10	3.50	--	67.70[b]	32.30	100.00

[a]Mean skid distance of 878, 2,183, 627, 402, and 237 feet, respectively.

[b]Machine utilization rate.

Table 3 shows the mean production data for each tractor studied. For the Massey-Ferguson, each turn produced 3.78 stems with a mean volume of 0.59 cord. Production averaged 1.32 cords per productive hour or 1.04 cords per scheduled hour (without delay time). The machine utilization rate was 78.7 percent.

The Same Minitaurus produced an average of 3.98 stems with a mean volume of 0.83 cord per turn. The daily production averaged 1.12 cords per productive hour or 0.80 cord per scheduled hour (without delay time). The machine utilization rate was 71.0 percent.

The Holder produced an average of 5.67 stems on each turn with a mean volume of 0.61 cord. The production averaged 1.85 cords per productive hour or 1.54 cords per scheduled hour (without delay time). The machine utilization rate was 83.5 percent.

The Pasquali produced an average of 3.94 stems per turn with a mean hitch volume of 0.29 cord. The production averaged 1.01 cords per productive hour or 0.68 cord per scheduled hour (without delay time). The machine utilization rate was 67.1 percent.

The Forest Ant produced an average of 7.10 stems per turn with a mean volume of 0.44 cord. The production rate averaged 1.39 cords per productive hour or 0.94 cord per scheduled hour (without delay time). The machine utilization rate for the Forest Ant was 67.7 percent.

CONSIDERATIONS FOR MANAGERS

The information and results should be valuable to forest managers and planners, and to loggers in evaluating the potential of small tractors operating in low-volume, small-diameter hardwood stands. Although this manuscript only summarizes cycle time and preliminary production results, research is under way to develop detailed comparable cycle time and production estimators for the data set described. Further, research is progressing to incorporate this and additional simulation results into a generalized stump-to-mill logging cost, estimating computer package.

The cycle time and production estimators will be developed so that similar variables such as slope yarding distance, volume per turn, logs per turn, and volume per log are included by machine in each cycle-time estimator. The similarity in production variables eases comparison of machine time and production. Having similar variables in each cycle-time estimator also simplifies the simulation efforts.

The cycle time and production estimators shown by machine, along with a range of stand and forest conditions, would be used as input to select various simulation models. The simulators would be run repeatedly over the range of conditions of interest. The resulting cost or production data points by machine and forest condition would be summarized in mathematical equation form suitable for incorporation into generalized stump-to-mill models. Computerized stump-to-mill methods could be used for estimating costs and production that would help managers, planners, and loggers to determine where specific machines are applicable.

Forest landowners and users are placing increased demands on the forest for a wide variety of uses. Often, the silvicultural treatment needed to bring the woodlot or forest to the desired state will require payment of the associated logging and harvesting costs incurred. Generally, the revenues to offset these costs derive from the value of the wood harvested. It is not intended that the results presented in this paper, or the additional research mentioned, will provide all the answers on the best management of the woodlot or forest. But these results summarized with the results of research in progress should provide managers, planners, loggers, and landowners with detailed and accurate logging cost estimators. The estimators could be used to evaluate and quantify the trade-offs posed by different forest uses and also allow for equipment comparison and selection.

Table 3--Mean production data for each tractor.

Tractor	Number of stems per turn	Volume per turn		Machine utilization rate	Cord volume per production hour[a]	Cord volume per scheduled hour[a]
		ft^3	Cords	Percent		
Massey-Ferguson	3.78	46.9	.59	78.7	1.32	1.04
Same	3.98	66.2	.83	71.0	1.12	.80
Holder	5.67	48.4	.61	83.5	1.85	1.54
Pasquali	3.94	22.8	.29	67.1	1.01	.68
Forest Ant	7.10	34.9	.44	67.7	1.39	.94

[a]Without delay time.

Mechanized Harvesting Research At Oregon State University[1]

Loren Kellogg[2]

ABSTRACT

The mechanized harvesting research project at Oregon State University is providing information to help determine what mechanized logging equipment and new methods of operation are needed and most beneficial in the Pacific Northwest from an economic, long term site productivity, and human resources perspective. A long term planning strategy provides the framework for conducting studies and move from our present level of knowledge and technology toward identified goals. This strategy along with completed projects, current research studies and future directions are highlighted.

Significant changes are occurring in the Pacific Northwest logging environment. One important reason for change in the logging practices is an increase in the proportion of smaller trees from second growth forests. In addition, small tree sizes occur in localized areas from clearcutting of stagnated stands, lodgepole pine, and hardwoods. There is an inherent difference between large old growth and stands with smaller trees. With smaller and more nearly uniform stem sizes, opportunities for logging mechanization have increased significantly. For every step of the logging process, a great number of machines exist or they are being developed. Equipment and system performance in terms of economics, utilization, logging impacts on site productivity, worker safety and training are critical issues in the forest industry today that will affect the future of mechanized harvesting in the Pacific Northwest. The aim of this research project is to provide information that answers questions concerning these critical issues for mechanized harvesting within the Pacific Northwest logging environment.

RESEARCH PLANNING STRATEGY

Our Mechanized Harvesting Research Project is organized to address critical issues beyond the steep slopes of western Oregon. A long term research plan has been designed to help provide organization and clarity toward reaching identified goals. There are three main sections in the research plan: (1) project goals, (2) an assessment of the current situation with an identification of the main driving forces affecting future mechanized logging methods, and (3) the link between sections one and two with a structure of research projects and study topics. The plan is flexible enough to be modified and updated as new information and needs arise. Mechanized harvesting research work integrates with portions of other research projects in the Forest Engineering Department.

Driving Forces Affecting Future Mechanized Logging Methods

In addition to a shift toward harvesting smaller trees, the labor force and safety issues are other important driving forces affecting future mechanized logging methods in the Pacific Northwest region. Skilled workers interested in logging are becoming more scarce. Garland (1989), predicts that new loggers will come from urban areas, be better educated, possess fewer practical skills, and want better work environments than in the past. Logging continues to be one of the nation's most dangerous occupations with many accidents occurring to persons working on the ground performing activities such as manual felling, limbing, bucking and chokersetting. Mechanization will not eliminate safety concerns but it can put a person in a better work environment, and with proper production and safety training, reduce the risk of accidents in the woods. Worker's Compensation insurance rates are a large portion of current logging costs on non mechanized operations. Other states in the southern US have been able to significantly lower Worker's Compensation rates for mechanized logging operations and there are similar opportunities in the Pacific Northwest region.

To help formulate project goals and identify specific study areas, an industry survey (questionnaires, telephone interviews, and on-site visits) on mechanized harvesting operations in the western US was completed in 1985 (Schuh and Kellogg, 1988). The survey located more than 140 timber companies and logging contractors using varying levels of mechanized systems. These were defined to include at least one single or multifunction manufacturing (felling, delimbing, or bucking) machine, or primary transportation with either forwarders or clambunk skidders. The operations ranged from small contractors owning a single feller-buncher to completely mechanized firms operating delimbers, debarkers, chippers and felling machines. One of the survey objectives was to identify problems that might be addressed in our long term research plan. The most frequent problems identified were equipment breakdown, factors contributing to low equipment utilization, and loss of production on steep terrain. In addition, we found that few contractors provide formal training for their equipment operators, a factor that may increase the frequency, duration and severity of equipment downtime.

Research Project Goals

A main research project goal is to provide equipment and system performance information that is useful in forest management decisions, harvest planning, organization of logging operations, and equipment development. The equipment and system performance information focuses on advantages, limitations, economics, influence of stand and site variables, logging methods, impacts on site productivity and system improvements. Data from these studies also provide input for further simulation analysis. In addition, a compendium of summarized information from other relevant mechanized harvesting studies is being compiled. The focus is on information dealing with equipment production, economics, logging systems and identifying data gaps for Pacific Northwest conditions.

1 Presented at the 12th Annual Council on Forest Engineering Meeting, Coeur D' Alene, Idaho, August 27-30, 1989.

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Many of the questions that need to be answered about mechanized logging methods can best be addressed with a simulation analysis approach. Therefore another main research project goal is to develop and validate a tree to mill logging simulation model that is relevant to Pacific Northwest operating conditions. A simulation model, LOGging SIMulator (LOGSIM) for the timber harvesting process has been developed (Wiese et al, 1988) using SLAM, Simulation Language (Pritsker, 1986). The simulation model is programmed for an IBM PC/XT/AT or compatible. Work is currently being planned for model validation and enhancements. Additional simulation analysis has been completed in cooperation with the University of Idaho using SAPLOS - Simulation Applied to Logging Systems (Johnson 1984) and SAPFB - a feller buncher module (Noble, 1987) compatible with SAPLOS.

Research Project Areas and Study Topics

To reach the identified goals, research work is currently organized into eight project areas: Felling and Processing, Ground Based Skidding, Steep Terrain Cable Yarding, Mechanized Harvesting Impacts on Long Term Site Productivity, Wood for Energy, In-Woods Chipping, Equipment Breakdowns, and Human Resources. In each project area, there is a mixture of both operational studies and hypothesis testing studies that are being conducted in cooperation with many different logging contractors and forest landowners. It is not possible to conduct studies simultaneously in all eight project areas because of manpower limitations. The work emphasis therefore varies from year to year. Study topics completed to date with brief highlights are summarized below:

- Red Alder Logging in Coastal Oregon: Two Case Studies

  Cable yarding was cheaper than helicopter yarding, however the helicopter was used in an environmentally sensitive area. The two operations supplied a variety of wood markets ranging from chipping in the woods to delivering sawlogs to the mill. (Schuh and Kellogg, 1989)

- Evaluation of a Grapple Processor

  Two Steyr KP-40 whole tree processors were monitored to determine long term productivity and mechanical availability in Lodgepole pine and mixed coniferous harvesting operations. Mechanical availability was relatively low, however delimbing quality was good and the Steyr's production costs were similar to other whole tree processing equipment. (Kellogg et al. 1987; Pilkerton and Kellogg, 1989)

- Chain-Flail Delimber-Debarkers: Technology for Pulp-Grade Inwoods Chipping Operations

  Three prototype systems were studied and found capable of turning small, low quality stems into marketable pulp quality chips. Chip bark content ranged from 0.5% to 1.5%. Delimber-debarker equipment is changing the cost structure of roundwood harvesting and processing operations thus improving the profitability of some intensive stand management practices. (Schuh et al. 1987; Bassler 1987)

- Cable Landing Organization for Mechanized Processing with a Swing Boom Yarder

  Stroke-boom delimbers were safely used on small cable landings in steep terrain. However, relatively low yarding production rates compared to the delimbers production capability limit utilization and productivity of the delimber and thus the whole system. Also, landing size and equipment arrangement on the landing can affect delimber utilization and productivity. (Schuh and Kellogg, 1988; Kellogg and Robe, 1989)

- Soil Compaction on a Mechanized Timber Harvest Operation in Eastern Oregon

  Soil compaction impacts from tracked feller-bunchers and rubber-tired grapple skidders were measured. In this study, main skid trails were also feller-buncher trails. Regression analysis showed that slash significantly reduced compaction caused by feller-bunchers and skidders. (Zaborske, 1989)

- Intermountain Mechanized Harvesting Operations

  Operating conditions for mechanized harvesting in the Intermountain Region were obtained along with production and cost rates for feller bunchers, whole tree chippers, stroke boom delimbers and wheeled skidders. (Johnson, 1988)

Currently, research studies are being conducted in the following areas:

- Mechanized Harvesting Equipment Downtime and Maintenance Practices Assessment

  Equipment downtime is most frequently cited as a critical problem in mechanized harvesting operations. The goal of this study is to characterize the equipment downtime problem and identify ways to reduce this problem within the structure of the Pacific Northwest contract logging workforce.

- Cable Yarding Log Bunches: A Short Term Evaluation of a Feller-Buncher and Running Skyline System

  Yarding mechanically felled and bunched wood could increase the wood flow to the landing and provide a better production balance with the mechanical processing operation on the landing. Yet the success depends on how well the felled and bunched wood is arranged for cable yarding. This study is examining the critical variables affecting system production with a track mounted swing-boom feller buncher, mobile yarder and stroke boom delimber.

- Cable Landing Organization for Mechanized Processing with a Large Tower

  Much of the steep terrain conditions in the Pacific Northwest requires the use of a large tower for yarding, often long distances and over riparian management leave areas. The goal of this study is to evaluate the feasibility of mechanically processing trees on large tower landing operations. Equipment interactions on the landing, utilization rates and layout requirements will be determined similar to the previous work with swing boom yarders.

In the future, we will continue collecting new mechanized equipment and system performance information within the framework of our long term planning strategy. In addition, we are considering appropriate ways to better integrate logging production studies with harvesting impact studies related to long term site productivity. Answers to questions in both areas are needed to help guide future smallwood resources management decisions. Also we plan to do more work on topics not limited to steep terrain conditions. A current example is the equipment maintenance and downtime study.

CONCLUSIONS

Mechanized harvesting systems are being used to a larger extent in some other regions of the U.S. and different countries compared with the Pacific Northwest. However, certain characteristics of timber stands, site conditions or the logging organizational structure are typically different than the Pacific Northwest. There are definite opportunities in the Pacific Northwest for more productive and safer logging operations with some level of new mechanized logging equipment and methods that are appropriate for smaller tree sizes of the future. Yet there will also continue to be a need for conventional logging systems - especially with big trees and very steep terrain.

The aim of our Mechanized Harvesting Research Project at Oregon State University is to help determine what mechanized logging equipment and new methods of operation are needed and most beneficial from an economic, long term site productivity, and human resources viewpoint. The long term planning framework identifies a general structure, with appropriate flexibility, for conducting studies that fit within the mission of the College of Forestry and that attempts to address the critical future issues in the forest industry.

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Tackling Productivity in Mechanized Logging[1]

Mark Beaulieu, Eldon Olsen, John Garland and Jeff Hino[2]

Abstract: "Tackling Productivity in Mechanized Logging" is a new video-based training package developed by forest engineers at Oregon State University College of Forestry. The package contains a 19- minute video program, Discussion Guide, and ten "Mechanized Harvesting Productivity Cards."

Keywords: Training, video

Audience

This videotape can be used with logging crews involved with mechanized harvesting operations, or with anyone interested in an overview of these operations. Logging crews would view the video with the intent of applying the ideas directly and immediately to their jobs, while others would use it to gain a general impression of the equipment, process and sequence of events in a mechanical logging operation.

Overview

This program demonstrates realistic conditions and shows the physical and mental environment of loggers involved in mechanized operations. It illustrates the complex interactions that occur during a mechanized logging operation, and identifies five major causes of delays: bottlenecks, buffers, breakdowns, and blunders (the 5 B's). It suggests that these "time bandits" can be identified and eliminated by the crew members.

Key concepts in making productivity improvements are teamwork, communication, and cross-training. A football theme is used for continuity and interest. Crews are encouraged to increase a measurable goal: TD's (Truckloads Delivered).

Mechanical harvesting systems are always changing. This dynamic behavior is caused by changing timber types, weather conditions, terrain, equipment performance, operator performance, changing operating procedures, schedules, and new mill demands. Each time a change occurs, the system must be readjusted to get maximum productivity. These adjustments are often best initiated by crew members.

This video restricts itself to changes that lie within the control of the logging crew. Other important factors that influence productivity, such as equipment selection, unit layout, operator training, and scheduling are the main responsibility of supervisors, engineers, and owners, and are not considered in the program. It also avoids discussion of the logging costs; rather it focuses on reducing unproductive delays.

What will it do for you?

Loggers face a new challenge as they switch to mechanized systems. These high investment operations require new skills in making each piece of equipment mesh with the rest of the harvesting system. Using examples from actual logging operations, this training package demonstrates such critical concepts as

- **machine interaction**
- **smooth flow**
- **balanced production**
- **maintenance responsibilities**
- **downtime**
- **cross-training**

When used as part of a planned effort to increase productivity, the package will help:

- **Motivate** employees to use teamwork and communication on the job
- **Train** crews in the skills needed for self-supervision
- **Influence** crews to improve productivity
- **Teach** problem solving on the job.

The video blends real-world logging operations, current trends in mechanized harvesting, and the job environment for logging crews in a lively presentation designed to get **your crew talking productivity.**

The plastic-coated training cards help take the ideas from the video and put them where they count the most: **on the job.**

Who should use it?

- New employees
- Incentive crews
- Contract administrators
- Forest Industry trainers
- Students interested in logging as a career
- Even families and friends will enjoy the opportunity to see a mechanized harvest operation in action!

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1 Presented at the Annual Council on Forest Engineering Meeting, Coeur d'Alene, Idaho.

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Cable Thinning Unit Layout Using Historical Aerial Photography[1]

Stephen E. Reutebuch and Edwin S. Miyata[2]

Abstract: Planning a cable logging thinning unit in steep terrain requires highly accurate profiles of the terrain. In many cases, historical aerial photos are available that were taken shortly after the unit was clearcut and that show the terrain without heavy vegetative cover. In these cases, the historical aerial photographs can provide XYZ coordinate data for planning cable logging corridors. Using a PC-based stereoplotter, skyline deflections, chord slopes, and spans can be easily measured from historical aerial photos. Road grades can be measured, and new roads can be accurately projected onto the photos. Azimuths, slopes, and distances to points of interest can be measured to assist in field layout of the logging plan. Photo overlays can be produced for aerial photos taken at differing scales and times. Map overlays of the logging plan at any desired scale can be automatically generated.

Keywords: cable thinning, logging planning, photogrammetry, aerial photos

For many years it has been recognized that production thinning of young stands in the mountainous western states would be needed to meet projected timber demand (Aulerich 1975 and Lysons 1977). Much of the volume that is projected for commercial thinning production in western states is on steep slopes that are unsuitable for harvest with tracked or rubber-tired vehicles. In these areas, cable logging systems are generally employed. There have been dozens of reports on cable logging systems for commercial thinning. Some systems have worked well while others have not for a multitude of reasons. Most people, however, who have attempted cable thinning operations agree that the level of planning, design, and layout of cable thinning units is much higher than for units that are to be clearcut.

There are several reasons for this. In a cable thinning operation, with the exception of the monocable system (Miyata and others 1986), the cable corridor must be cut through standing timber. The corridor must be along a straight line between the landing and the tailtree to avoid excessive damage to the residual trees. Sufficiently large tailtrees, landings, and any necessary cable anchor trees must be located in a dense stand prior to felling any trees. The corridor must be surveyed and marked carefully on the ground. In areas of limited deflection, the profile of corridors must be plotted and checked for adequate payload capacity. If there is not sufficient lift, corridors must be changed or intermediate supports must be located and marked in the field for a multispan operation. The area to be yarded to each corridor must be carefully marked on the ground so that the felling crew can see which direction to fell the trees for ease of yarding and to minimize damage to the residual stand during yarding.

In most areas to be thinned, the existing road system was designed and built when the area was originally clearcut with large cable systems. These large cable systems generally had tall spar trees (100+ feet), large cables, and powerful, large-capacity winches to handle the old-growth timber size. Distances between truck roads were often 1000 - 2000 feet or more. Smaller cable thinning systems have shorter towers (20 - 50 feet), smaller cables, and lower horsepower winches. In difficult terrain with limited deflection, these shorter towers and smaller winches cannot be rigged in a single span to reach the full distances between widely spaced roads. In these situations, either additional roads must be built or a multispan cable system with intermediate supports must be rigged to thin the entire area. In many areas, the cost of additional roading exceeds the value of the timber recovered from the thinning, making the operation uneconomical. Multispan operations require even more careful planning than single span thinning units (Winniger 1983).

As stated above, when the monocable system is used, the corridor along which the cable will be rigged need not be marked or surveyed in the field prior to felling. There is, however, a considerable amount of planning that must take place for the thinning operation to work efficiently. Although the monocable system can be rigged over large distances and is not limited by deflection, there are limits on how much weight can be loaded onto the system at a given time and limits on the piece size the choker setters can manually move and hook to the cable. The planner must determine how many landing sites are needed and where there are suitable sites for landings as well as the expected amount of cable and blocks that will be needed to reach the entire area. The planner must also estimate the range of the piece sizes that are expected and check to see if they exceed the weight limit that choker setters can manually handle.

FIELD SURVEY METHODS FOR CABLE THINNING LAYOUT

Although many authors point out the need for intensive design and layout of cable thinning operations, few authors give more than a cursory description of the process of preparing a thinning unit. Bruno (1979), however, gives a comprehensive description of design and field layout techniques used for cable thinning units. He recommends that cable corridors be surveyed with a staff compass, clinometer, and cloth tape. For each corridor, the tailtree and landing must be

[1]Presented at the 12th Annual Council on Forest Engineering Meeting, Coeur d'Alene, ID, August 27-30, 1989.

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selected prior to surveying the final corridor. To do this, Bruno suggests that the layout crew identify a wide area along which the landing can be located. The crew then runs a straight compass line from the middle of the suitable landing area out toward the edge of the thinning unit. The compass line should be approximately perpendicular to the contour of the land. When the edge of the unit is reached, the crew searches the area for the nearest suitable tailtree. The crew then adjusts the compass bearing to take into account the distance the tailtree is offset from their initial line. They then survey and mark a corridor profile line back to the selected landing site. With care, the return survey line should intersect the suitable landing area. When corridors are widely spaced or there is heavy brush, a line halfway between each corridor should also be flagged to help fallers determine the correct direction to fell trees. Using this method, Bruno states that "two or three 800-ft roads [cable corridors] per day can be surveyed with an experienced two-man crew, providing potential tailholds have been identified."

The requirement to have tailtrees and anchor trees marked before thinning and the need to have straight corridor lines marked on the ground results in much more field survey work than that required for clearcut operations. After corridor profiles have been surveyed, the planner must plot the profiles and compute the payload capacity of the cable system. If the corridor proves inoperable, the survey crew must return to the field and find new landings, tailtrees, or intermediate supports.

HISTORICAL AERIAL PHOTOS

In most forested areas of the country, aerial photos have been taken every few years for the last 4 to 5 decades. These historical aerial photos provide a visual image of the condition of the forest estate at different points in time. Photos that were taken shortly after an area was clearcut provide a view of the shape of the ground unobscured by heavy vegetative cover. Such photos can be very helpful in the design and layout of cable thinning units where the shape of the ground controls the type and size of cable system needed to harvest the area.

If the stand to be thinned was planted or naturally regenerated in a clearcut that was harvested in the last 40 years, there are most likely historical aerial photos that were taken within a few years of the clearcutting. Although photos may not be available for the exact year of the clearcutting, photos taken 5 to 10 years later still provide good views of the underlying ground shape.

There are many sources for historical aerial photos. The first place to look is in the files of the office that administers the forested land. Often old photos are stored with current photo coverage or archived with other old maps and documents. If old photos are not available locally, there are three national libraries of aerial photography that can provide historical photos.

The libraries are:

U.S. Department of Agriculture
Agricultural Stabilization and
Conservation Service
Aerial Photography Field Office
2222 West, 2300 South
P.O. Box 30010
Salt Lake City, Utah 84130 - 0010
Phone: (801) 524-5856

U.S. Department of Interior
Geological Survey
EROS Data Center
Sioux Falls, South Dakota 57198
Phone: (605) 594-6151

National Archives - NNSC
Washington, DC 20408
Phone: (703) 756-6700

The Aerial Photography Field Office (APFO) maintains a library of all U.S. Department of Agriculture standard aerial photography. This includes most of the aerial photos taken after 1950 for the Agricultural Stabilization and Conservation Service, the Soil Conservation Service, and the Forest Service. APFO also has some NASA photography that was taken specifically for the U.S. Department of Agriculture. USDA photos taken prior to 1950 have been deposited with the National Archives.

EROS Data Center maintains a library of photos from all federal agencies except the U.S. Department of Agriculture. EROS services about 20 different agencies including the U.S. Geological Survey, the Department of Defense, the Bureau of Land Management, Fish and Wildlife Service, the Bureau of Indian Affairs, the Environmental Protection Agency, NASA, and the Army Corp of Engineers. The EROS library includes photos back to the early 1940's.

The National Archives maintains a library of aerial photos that includes older USDA and Defense Department photos back to 1936.

To find out what photography is available for a given area, the planner can outline the area of interest on a USGS 7.5' or 15' quadrangle map and send the map to each of the addresses listed above. In about a month, each photo library will send a list of all available photos that cover the area of interest. The list will include the date, scale, and film type (black and white, natural color, or color infrared) of the available photos. The planner can then select and order copies of photos with the scales and dates that best fit planning needs.

In addition to these federal sources, many state and local agencies maintain libraries of aerial photos, as do most private timber companies. If photos of an appropriate scale and date are not available from federal sources, the planner can contact state land management agencies and local county planning offices. Many aerial photo contractors have extensive libraries of aerial photos from which copies can be purchased.

When ordering copies of aerial photos, a copy of the camera calibration report for the camera that was used to take the photos should be requested. Modern aerial mapping cameras are calibrated by the U.S. Geological Survey to determine the exact focal length of the camera lens. This calibrated focal length (CFL) is used in determining the scale of aerial photos taken with the camera. For most photos taken in the last 25 years, the calibration report or at least the calibrated focal length of the camera used to take the photos is available. Many older photos were taken with cameras that were not calibrated and therefore only nominal lens focal lengths are available. For the type of relative distance measurements used in thinning layout, the nominal focal length can be used for orienting the photos in a stereoplotter when the calibrated focal length is unavailable. The nominal focal length of an aerial mapping camera is usually within 1 percent of the calibrated focal length.

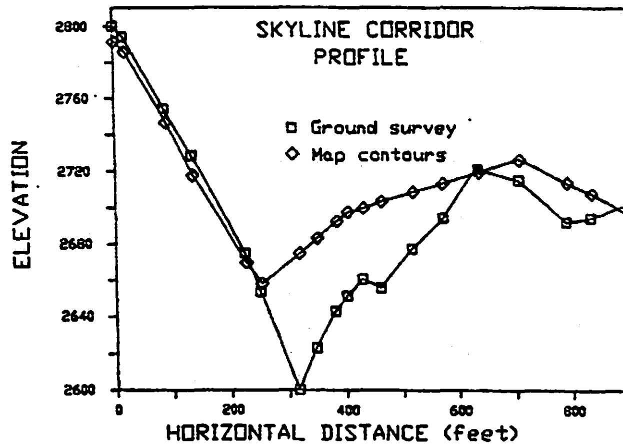

Figure 1--Map versus ground surveyed profile in heavy, old growth timber.

PHOTOGRAMMETRIC SURVEY METHODS

Aerial photos have been used in instruments called stereoplotters to accurately measure terrain for the last 50 years (Loving 1980). Stereoplotters allow the user to accurately measure the XYZ coordinates of any image seen within the overlapping area of a stereo pair of photos. Traditionally, stereoplotters have been used to produce topographic maps that provide a 2-dimensional representation of the 3-dimensional images viewed in the stereoplotter. Nearly all modern topographic maps are made in this way. These topographic maps are often used as a starting point for the design of harvest units (Twito and others 1987); however, it is widely recognized that these maps may have large errors in elevation in areas that were covered with heavy timber at the time of mapping. If heavy timber obscures the ground surface on the photos used to make the map, the stereoplotter operator cannot see the ground and therefore can only estimate where the ground surface would most likely be under the tree canopy. Often errors in elevation of 50 or even 100 feet occur in closed canopy, old-growth forests in mountainous terrain (fig. 1). Because of these elevation errors, planners cannot rely on profiles digitized from topographic maps for thinning layout. In addition, topographic maps generally have contour intervals of 20, 40, or even 80 feet. For thinning layout and design, elevation changes of 5 or 10 feet can be critical.

It is important to recognize that the aerial survey method itself is not the source of error in the contour data. Indeed, if the ground is clearly visible, the ground elevation can be measured to within a few feet with photo scales of 1:12,000 to 1:30,000. Topographic maps with 10- or even 5-foot contours can be generated using modern stereoplotters and 1:12,000 photos with bare ground conditions. The expense, however, of producing such detailed maps is usually prohibitively high for large areas.

By using old photos taken shortly after clearcutting, the problem of heavy canopy is overcome. The stereoplotter operator can clearly see the ground surface on the photos. However, rather than producing a highly detailed contour map of the area and then measuring the thinning corridor profiles from the map, it is much more efficient to measure the profiles directly from the photos.

Valentine (1986) used a highly accurate and expensive analytical stereoplotter for measuring skyline profiles from aerial photos. Mann and Reutebuch (1988) proposed using a simpler, less expensive PC-based analytical stereoplotter to aid harvest planners. PC-based stereoplotters can be located in local forestry offices and used by local harvest planners. Reutebuch (1987) states that local staff can be trained to operate a PC-based stereoplotter in approximately 1 week.

CONTROLLING AERIAL PHOTOS

Before ground measurements can be made from photos using a stereoplotter, the photos must first be fitted to some ground coordinate system. This process requires that several points that have known XYZ ground coordinates be identifiable on the photos. Often such ground control is not available and the photos must be controlled using existing maps. This "map control" process involves finding control points, such as road intersections, buildings, peak tops, etc., that are clearly indentifiable on both the photos and a map or orthophoto of the area. XY coordinates are obtained by placing the map on a 2-axis graphics tablet and digitizing each control point. If a Z coordinate for a control point is not listed on the map, an elevation for the point is interpolated from the map contour lines. After carrying out this map control process, quite accurate 3-dimensional distance measurements between points can be made. Reutebuch and Shea (1988) found that distances between stumps in clearcuts could be measured to within 2 feet of the true ground distance from 1:12,000 aerial photos that were controlled with XYZ coordinates digitized from 1:24,000 USGS quadrangle maps. It is important to note that this 2-foot error is independent of the distance between the stumps. In other words, one would expect to be within 2 feet of the true distance between two stumps that were 10 feet apart and two stumps that were 10,000 feet apart!

The map control process is somewhat complex and is best left to trained photogrammetrists. Fortunately, in many areas data for controlling aerial photos are becoming more available, eliminating the need to do map control locally (Mann and Reutebuch 1988). Control data are routinely produced by aerial triangulation programs when mapping organizations produce topographic maps and orthophotos. These data can be read into some PC-based stereoplotters, greatly increasing the ease and efficiency of local stereoplotter use. Once one set of photos is controlled for an area, control can easily be passed or "bridged" to other sets of photos that cover the same area--XYZ coordinates of easily identifiable image points are digitized from the controlled set of photos and then assigned to the same image points on the uncontrolled set of photos.

PROFILE MEASUREMENTS FROM HISTORICAL AERIAL PHOTOS WITH A PC-BASED STEREOPLOTTER

When planning a cable thinning unit, the planner uses current aerial photos in conjunction with older historical aerial photos to survey proposed cable corridors. The current photos provide the planner with a view of the present conditions in the area to be thinned--the size and distribution of trees, the location and condition of roads, and the condition of adjacent stands. The historical photos, taken shortly after clearcutting, provide a view of the terrain shape beneath the present tree canopy.

The current photos are mounted in the stereoplotter and controlled. The planner examines the photos and delineates the area that is to be thinned. Using the stereoplotter, sample tree heights can be made where openings occur in the stand. The thinning unit boundary is digitized from the photos in terms of the XYZ coordinate system used to control the photos. The planner also digitizes likely landing and tailtree locations, noting the presence or lack of suitably sized trees for anchors. Any new roads that do not appear on the older photos are also digitized so that their location can later be plotted on the older photos.

Before removing the current photos from the stereoplotter, the planner locates several points on the current photos that are identifiable on the older, historical photos. These points are marked on the older photos and their XYZ coordinates are digitized from the current photos. These points are used later as control points for the older photos.

The current photos are then removed from the stereoplotter and the older photos are set up and controlled using the control points digitized from the newer photos. Overlays that fit the older photos are then plotted from the boundary, landing, tailtree, and road data digitized from the newer photos. These overlays are placed over the older photos so that the thinning corridors can be easily identified.

Once the corridors are located on the old photos, the planner can digitize the ground profile along each corridor. The stereoplotter displays the azimuth, distance, and grade between points as lines are digitized. As each profile is digitized, the planner should take note of the azimuth, slope, and length of the line between the landing and the tailtree and the azimuths, slopes, and distances between adjacent corridors. These azimuths, slopes, and distances can later be used to aid with field layout of the corridor. The PC-based stereoplotter also can simulate the cable yarder and directly measure the amount of deflection along a proposed corridor (Mann and Reutebuch 1988).

If additional roads must be built to connect landings, the ground profile and azimuths, slopes, and distances along the proposed road can also be measured. In areas where the planner noted a lack of suitable trees for anchors on the newer photos, the planner can use the stereoplotter to look on the old photos for any large stumps that may still be intact and usable for anchors.

After corridor ground profiles have been digitized, a skyline analysis program, such as LOGGERPC (available from the Department of Forest Engineering at Oregon State University, Corvallis), can be used to analyze their operability. Corridors that appear inoperable should be modified and their new location digitized.

Before the older photos are removed from the stereoplotter, the planner should carefully examine the entire area to be thinned and digitize any good landing sites or difficult terrain breaks that may not have been apparent on the newer photos. When such features are found, the planner can measure the azimuth and distance from each feature to some other point that is easily located in the field. When the unit is laid out in the field, these azimuths and distances can be used to locate the features, even though they are hidden under the tree canopy on the newer photos.

After a set of workable corridors has been located and verified on the old photos, overlays that fit the current photos are plotted to aid in field layout. The planner also has the distance, slope, and azimuth from one landing to the next and from the landing to the tailtree of each corridor. A map of the unit can also be plotted at any scale from the digitized data. Field layout is much simplified with this information and the overlays for the old and new photos.

PHOTO MEASUREMENTS FOR THE MONOCABLE SYSTEM

As stated above, the monocable or zigzag system does not require long, straight corridors to operate in a thinning unit. Instead, the cable system is laid out in a zigzag pattern with blocks

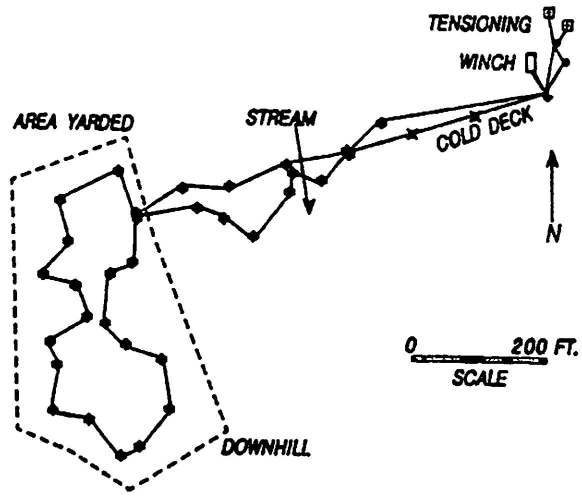

Figure 2--Plan view of typical zigzag cable thinning operation (Miyata and others 1986).

hung from trees in the residual stand (fig. 2). The process of planning for a monocable operation is similar to planning for a traditional cable system. The main difference is that the ground profiles of straight line corridors are not required. Instead, the planner selects likely landing sites on the current photos and then uses the old photos to measure the distance, direction, and slope of the path along which the monocable will be rigged. Logs are manually rolled and attached to the cableway with the zigzag system. The planner must take care to locate the cableway on the downhill side of logs so that they do not need to be carried uphill by the choker setters. The old photos provide the planner with a view of the micro-topography through which the cable system will be routed. The slope and depth of small gullies and ridges are measured, and routes for rigging the cable through or around them are selected and digitized. The overall length of a cable path for a landing is measured and an estimate is made of the number of blocks needed to suspend the cable.

After photo planning is complete, photo and map overlays showing the approximate location of the cable paths are produced to aid with field layout.

CONCLUSIONS

When planning a cable thinning operation in stands planted during the last 40 years, historical aerial photos can sometimes be used to get a view of the ground surface that is obscured by the tree canopy in newer photos. In most areas, aerial photos going back into the late 1930's or early 1940's are available from 3 federal libraries and from state and county agencies. Old photos are often available in archive files in local forestry offices. If photos are not available locally, the planner should allow several weeks for copies of photos to be made and delivered. Using these old photos in conjunction with more recent photos, cable corridors can be located and ground profiles can be measured to within a few feet of the true ground distances with modern stereoplotters. By viewing the ground surface on the old photos and the present tree crop on the current photos, the planner can save a considerable amount of time in the field layout of cable corridors.

Using traditional ground survey methods, 2 or 3 corridors can be surveyed per day with a 2-person crew, whereas 20 - 30 corridors can be measured in a day with a stereoplotter from old photos in which the ground surface is visible. Profiles can then be quickly analyzed to determine in which areas the cable system will or will not function well. The planner does not waste field time surveying profiles in areas that later prove to be inoperable, and azimuths, slopes, and distances measured from photos increase the efficiency of subsequent field layout.

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Low Water Fords: An Alternative to Culverts on Forest Roads[1]

Terry Warhol and Marvin R. Pyles[2]

Abstract: Low-water fords are a cost effective way of providing stream crossings for many forest roads. It is expected that low-water fords will require less maintenance, and are less likely to experience wash-out failure than a culvert installation. A list of design considerations is presented, along with the results of a survey of low-water ford installations from the Cascade mountains of Oregon. Fords have recently been constructed on watersheds from a few acres to over 4 square miles in area throughout an elevation range that includes both rainfall and snowmelt dominated runoff regimes. About 30 percent of the surveyed fords had experienced some erosion damage, but most damage appeared related to poor construction or inadequate design.

Keywords: stream-crossing, low volume road, watershed

INTRODUCTION

The Pacific Northwest Region (Oregon and Washington) of the U.S.D.A. Forest Service manages over 91,000 miles of road. These roads provide access to an array of resources including range, recreation, watershed, wildlife, and timber. Forest Service roads cross thousands of streams utilizing a number of types of stream crossings. These include bridges, culverts, and low-water fords; culverts are the most common type of stream crossing.

Stream crossing maintenance represents a large share of the Forest Service road budget every year. In the last few years, a steady decline in maintenance budgets coupled with increasing miles of road to maintain has created the need for structures that are more reliable in passing peak flows while requiring less maintenance. In an effort to reduce the cost of selected stream crossings, some national forests in the Pacific Northwest region are constructing low-water fords as an alternative to culverts. Low-water fords are designed to pass water over the road either continually or only during peak flow periods, depending on the structure. This type of structure is not usually passable during high flows.

Low-water fords are an attractive stream crossing alternative because they can usually be constructed of readily available materials that are often part of required excavation along the road route, making their initial installation cost very competitive with conventional structures. Further, a properly designed and constructed low-water ford usually results in little required maintenance, and the physical service life of the structure is limited only be the durability of the material used in construction.

This paper will present a description of the types of low-water fords, a review of design considerations for low-water fords, and present the results of a survey of existing low-water fords in the Mt. Hood, Willamette, and Umpqua National Forests.

TYPES OF LOW-WATER FORDS

A low-water ford, also called a low-water stream crossing (LWSC), dip, or drainage dip is defined as a structure that passes low flows under the road, or over the road at shallow depths, and is designed to be overtopped at impassable depths during periodic high flows (Coghlan and Davis, 1979). A low-water ford has a design discharge, above which damage to the ford should be expected, but the damage will be in the form of erosion of the ford material which is often the same as the stream bed material, making the environmental impact of even complete failure modest. In contrast, conventional structures such as bridges and culverts are designed to pass even periodic high flows up to the design discharge without the water reaching the road surface. At flows above the design discharge, culverts or bridges may be expected to experience significant damage or even complete wash-out failure. Complete wash-out of a bridge or culvert usually results in adverse impact to the stream for some distance down channel. Further, we should expect that most visitors to the forest will view washed-out bridge and culvert sections scattered downstream from a repaired crossing as visually undesirable.

There are three basic types of low-water fords in use. They are unvented fords, vented fords, and low-water bridges. This paper deals strictly with unvented and vented fords - no low-water bridges were found in the survey.

Unvented fords, also commonly known as dips or fords, are structures that pass all water over the ford surface. The surface of the ford is at or near the level of the stream bed. Unvented fords are commonly used on intermittent streams, or perennial streams with low flows. The standard design geometry of an unvented ford does not allow for fish passage therefore only streams for which fish passage is not a consideration are good candidates for an unvented ford crossing.

An unvented ford may have a number of design provisions (Figure 1a) depending on the local requirements, but many unvented fords are nothing more than non-engineered stream crossings (Berger et al., 1987). The unvented fords found in the survey have four main components. These are: 1) a core or subgrade reinforcement, 2) base or surface course, 3) splash apron (foreslope), and 4) geotextile or filter medium. Cutoff walls upstream and/or downstream may also be appropriate in some circumstances. Upstream cutoff walls are used to control under-seepage in cases where that is important, and downstream cutoff walls serve to protect the base of the splash apron from erosion.

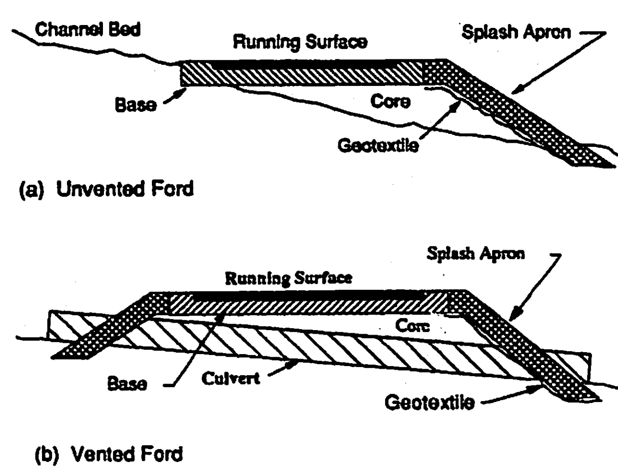

Figure 1. Typical sections, unvented and vented low-water fords.

1 Presented at the 12th Annual Council on Forest Engineering Meeting, Coeur d'Alene, ID. August 27-30, 1989.

2 The authors are Transportation Engineer, Umatilla National Forest, and Associate Professor of Forest Engineering, Oregon State University.

Table 1. Low-Water Ford Design Considerations -- In addition to standard culvert considerations	
Consideration	Item
Base flow level	1. Length of ford along the road. 2. Venting requirement. 3. Required passability (headwater that can safely be negotiated by the design vehicle, and the time during which the ford must be passable).
Peak flow events	1. Length of ford along the road. 2. Capacity of vent if included. 3. Allowable headwater level (local flooding) 4. Road and foreslope surfacing.
Fish Migration	1. Generally, low-water fords are not the best alternative for streams where fish migration is a consideration.
Maintenance	1. Road passability during low flows (debris may be deposited during high flows; road grade may become too rough for lower clearance vehicles).
Economics	1. Life of the installation. a. Vented fords (The physical service life of the vent pipe can be interpreted as the life of the crossing). b. Unvented fords (Physical service life will be limited only be degradation of the road surface and splash apron material). 2. Original installation and annual maintenance cost (these are important when comparing vented and unvented fords, or when comparing a ford with a standard culvert installation).
Legal Requirements	1. Peak flow capacity (often mandated by Forest Practice Regulations). 2. Signing of roads open to the public may be necessary.

Vented fords are constructed with single or multiple culverts that pass low flows. Flood flows are intended to overtop the structure. They are commonly used in low to moderate flow perennial streams, or where the normal flow would exceed a fordable depth. A vented ford provides an economical alternative to a regular culvert installation in cases where large approach fills would otherwise be required. Vented fords have the same design provisions as unvented fords except for the inclusion of a pipe (or pipes) (Figure 1b). By proper sizing and placement of the pipe, a vented ford may be designed to provide for fish passage.

DESIGN CONSIDERATIONS AND CRITERIA

Currently there are no hard and fast criteria for the design of low-water fords. Each installation is a custom structure requiring it be fit to the site. The bulk of the design considerations for a low-water ford crossing are the same as those listed for a stream crossing culvert installation presented in a companion paper by Pyles et al. (1989). The design considerations for low-water fords that are significantly different than for culverts are detailed below.

The single most important factor in designing a low-water ford is protection against erosion during high flows. Careful consideration of flood size and frequency, site selection, material selection, ford geometry and construction control is essential to eliminating potential problems. Table 1 details a list of general design considerations and criteria. The discussion that follows will expand on some of the factors.

The design base flow is the maximum flow at which the ford is to be passable by the design vehicle (usually a medium clearance vehicle such as a pick-up truck). For some roads this may be a summer season flow, while in other cases, it may be a wintertime base flow. Depth of flow can be controlled by length of the vertical curve, grades, length of ford, fill height, and the number and size of vents. Any or all of these factors may be adjusted to match the base flow depth with the design vehicle

Design Procedure

There are a number of approaches that can be taken in designing a low-water ford. We will detail one such procedure here that should be sufficient to illustrate the process. The procedure is adapted from Ring (1987), and Sheladia Associates (1982a, 1982b). A number of options are available for surfacing a ford, but the procedure given below will focus on the use of riprap surfacing because it is the most common, and is likely to be the least expensive in most cases.

1. Select design vehicle and estimate design base flow --

   The difficult aspect of this step is the hydrologic analysis required to estimate the design base flow. First, the period of the year during which the ford should be passable must be selected, and second, the likely stream flows during that period must be estimated. One approach for estimating stream flows is to analyze a scaled stream gauge record from a nearby watershed of similar size. The scaling should be done on the basis of watershed area.

2. Select the design flood return interval and estimate peak flow --

   The design flood return interval defines the peak stream flow above which the ford will begin to fail by erosion. On the average, the longer the return interval used for design, the longer will be the useful life of the structure. Design flood return interval is a largely a matter of choice, but legal requirements do establish a minimum value (e.g. Oregon Forest Practice Rules require passage of the 25 year peak flow, Washington requires passage of the 50 year peak flow).

3. Select a trial apron riprap material --

   Riprap is generally described by an average size and size distribution or some criteria about the maximum and minimum rock size (e.g. Federal Highway Administration, 1967). This procedure will deal only with the average rock size. From a cost perspective, the most attractive choice for a riprap material is rock that can be obtained from required excavation along the road right-of-way near the ford.

4. Select ford surface and apron geometry and determine flow conditions --

   The width and depth of the ford must be sufficient to pass the base flow at the design depth and keep the design peak flow within the limits of the ford. Depending on whether the ford surface is at stream bed level or elevated, an open channel flow equation (e.g. Manning's equation) or a wier equation should be used to determine the ford surface geometry required to pass the design peak flow. The apron geometry required to pass the peak flow should be determined using an open channel flow equation.

5. Check the velocity of flow against the allowable velocity of flow for the trial riprap size --

   This may be done using the allowable velocity graphs available from Sheladia Associates (1982b) or the Federal Highway Administration (1967). If the flow velocity is greater than the allowable velocity, either larger riprap to accommodate the velocity, or a geometry change to reduce the velocity will be required.

The forth and fifth steps listed above require some additional discussion. Since the splash apron will usually be much steeper than the ford surface, we should expect that the controlling water velocity will be on the splash apron. Within an open channel flow equation, Manning's equation for example, the apron material, apron geometry, and apron slope all influence the computed velocity. Estimates of Manning's "n" or roughness for the riprap material will have a profound effect on the computed velocity, yet these estimates are very uncertain. Tables of Manning's "n" values typically give a range of from 0.05 to 0.09 for bed conditions that correspond to riprap material. Further, Manning's equation applies to channels of relatively flat slope (less than 10%) making the application of the equation to the apron doubtful. The net result is that very high (but erroneous) flow velocities can be computed that would indicate that even large riprap material (24-36 in.) would not be stable, when in fact this large riprap would be stable. Further, the riprap stability charts that give allowable flow velocities are for full submergence of the riprap material. This may not be the case for large riprap material on rather small streams.

If open channel flow computations made with conservative estimates of bed roughness give velocities that are less that the allowable velocity for the riprap material, then a successful design is virtually insured. If computed velocities are not less than the allowable velocity, then the best alternative may be to adopt an observational construction plan that allows for repair of damage with larger riprap material if erosional damage to the splash apron occurs.

Vented versus Unvented Fords

The choice of using an unvented ford versus a vented ford is not always obvious. Many land managers simply do not want traffic driving through streams. Some transient increase in turbidity should be expected when vehicles drive through a stream. The extent of this as a problem will be a function of the period and frequency of use of the ford. Depth of flow across an unvented ford may prohibit some or all traffic. Whether a stream is intermittent or perennial and the intended season of use are often used as the determining factors in selecting between vented and unvented fords.

The vent in a ford (simply a culvert pipe) can become plugged with debris, therefore a vented ford requires routine maintenance similar to a standard culvert installation. Failure to maintain a fully open vent may bring about excessive flow across the ford surface resulting in damage to the ford, and even to the stream channel. Culverts usually require a maintenance inspection annually, so vented fords should be expected to require the same. An unvented ford can be designed with the intent of requiring no maintenance, but the ford survey detailed below indicates that damage does occur periodically. A statistically sound estimate of the frequency of maintenance for an unvented ford cannot be made at present, but maintenance will undoubtedly be less frequent that for culverts.

Cost

A comparative cost analysis of a standard culvert stream crossing and a ford stream crossing should be done prior to selecting the ford alternative. As more information on the performance of fords becomes available, such cost comparisons will be fairly straightforward, but for the present, without uncertain estimates of maintenance cost and service life, it is difficult to compare more that the capital cost. However, by determining the total discounted expected cost for the culvert alternative, and deducting from this, the capital cost of the low-water ford the break-even discounted cost of maintenance and expected failure is obtained. It should be possible to judge if the actual discounted cost of maintenance and expected failure will be less than this amount for many cases.

Safety

Traffic control in the form of warning signs, or barriers may be necessary on some low-water fords (Carstens and Woo, 1981). Restricting traffic or closing the road during periods of high runoff is another alternative. On the type of logging roads found in this study, work would normally be discontinued during peak flows large enough to make the fords impassable.

LOW-WATER FORD SURVEY

A survey of existing low-water fords was conducted to determine (1) the range of watersheds and stream conditions where they have been used, (2) the range in types of fords and materials that have been used and, (3) what design provisions result in a successful low-water ford. The study area selected (Figure 2) included the Mt. Hood, Willamette, and Umpqua National Forests in Western Oregon. These forests generally follow the Cascade Mountain range which extends in a north-south direction through Oregon. Average annual precipitation in the study area ranges from 40 to 110 inches per year with heavy snow packs above 4000 ft.

Within the Mt. Hood and Willamette National Forests, relatively few low-water fords have been developed, so all known low-water fords were evaluated. In contrast, numerous low-water fords have been constructed within the Umpqua National Forest. Since many of these are located either on very small watersheds, or are actually cross drains, a

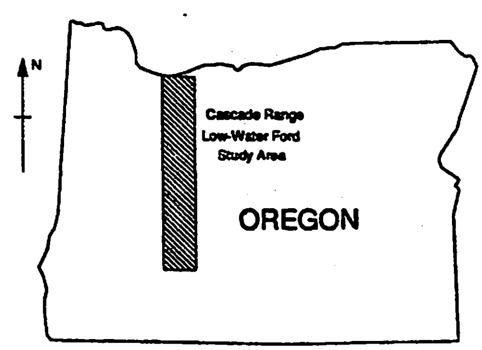

Figure 2. Low-water Ford Study Area.

set of fords on larger watersheds was selected for evaluated. A listing of the entire population of fords on the Umpqua National Forest was not available, so it was not possible to randomly select the fords for the survey. 51 low-water fords were surveyed to determine design type, materials used, and the current condition as an indication of performance. In addition, a subset of 13 low-water fords were surveyed, plotted and their peak discharge capacity was calculated.

The distribution of watershed areas on which low-water fords were found is shown in Figure 3a. Small watersheds dominated the distribution, but about 15% of the ford were found on watersheds larger than 1 square mile, indicating that fords can be an important component of the forest road network drainage system even for the larger more costly stream crossings. To some extent, watershed area will correlate with whether a stream is perennial or intermittent. We did not attempt to do an exacting classification of the streams as perennial or intermittent, but by conducting the survey in August of a very dry year (1988), it is reasonable to expect that streams flowing water at the time of the survey can be classified perennial. The fords were about evenly distributed between perennial (55 percent) and intermittent (45 percent) streams.

Fords were found at elevations ranging from 1680 to 5560 feet (Figure 3b). In the Cascade mountains, this elevation range spans three stream runoff regimes. Up to about 2500 feet, peak stream flow is driven by rainfall from large frontal system storms that come in from the Pacific Ocean. From 2500 to about 3500 feet in the transient snow zone, many stream flow peaks are rainfall driven, but the largest peak flows are often the result of rain on snow storm sequences. Above about 3500 feet, spring snow melt probably dominates the stream flow regime. Of course, the elevations that divide these zones vary locally and from north to south through the Cascade Range, but the fact that low-water fords have been constructed at elevations that span all the zones indicates their broad applicability.

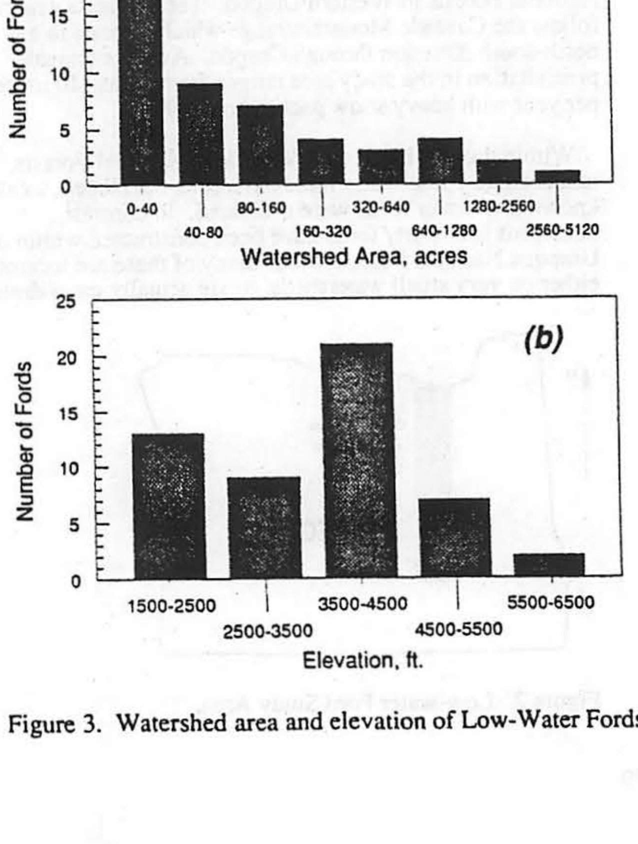

Figure 3. Watershed area and elevation of Low-Water Fords.

Ford Type, Geometry, and Materials

Only 7 of the 51 low-water fords surveyed were vented fords. This percentage is reasonable given that vented fords will have maintenance requirements similar to a culvert stream crossing, eliminating one of the advantages of a low-water ford. The remaining advantage of a ford is generally a lower construction cost. An excellent example of this was found in a case where a large stream with a broad flood plane was crossed using a multiple pipe-arch vented ford. If a standard culvert stream crossing had been used, much larger pipes would have been required, and thousands of cubic yards of fill would have been required for the approach fills.

As indicated above, part of the objective in using a low-water ford is to keep the fill height to a minimum. This saves on road and structure materials necessary to build the ford whether the ford is vented or unvented. One of the simplest methods of reducing fill heights is to steepen the grades into and out of the ford. Gradeability of the road then becomes a concern.

Road grade changes can drastically affect the ability of equipment to use the road. Grade changes are measured in terms of the algebraic difference between the grade into and out of the vertical curve that defines the ford. Low-water fords should have a definite grade break (achieved with the vertical curve), centered over the top of the structure. This grade break serves to define the overflow channel, thereby confining the water that overtops the structure. A wide range of grade changes are being used (Figure 5). All of the fords were navigable by a standard logging truck. One extreme example had a grade change of 37 percent (18 percent into the ford and 19 percent out of the ford) through a 60 foot radius vertical curve on a 50 foot radius horizontal curve.

The core of a low-water ford (Figure 1) is protected by the base, filter, and splash apron, therefore common excavated material from along the road alignment can be used in the core. However, the core of a majority of the low-water fords surveyed (75 percent) consisted of riprap material the same as that used for the base and splash apron. If common material was used for the core, then a base and surface of riprap or asphalt concrete (AC) was used to protect the core. In two exceptions, Portland cement concrete (PCC) was use for the core material.

Riprap was the most widely used base material. In addition, 82 percent of the fords were surfaced with rock, usually a 1.5 or 3 inch minus crushed aggregate. 12 percent of the fords were surfaced with AC, and the remaining 6 percent were covered with PCC. Crushed aggregate is usually readily available and least expensive. One concern with unvented fords is truck traffic carrying sediment from along

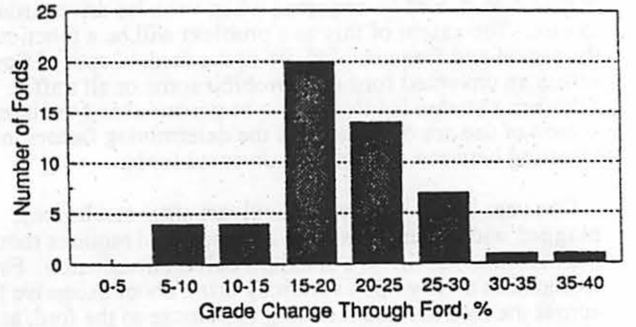

Figure 4. Grade change through low-water fords.

the road into the water, causing an increase in turbidity. Surfacing the ford and some length of road on either side of the ford with PCC or AC helps minimize this.

Riprap as also the most common material used for the splash apron. 90 percent of the fords had riprap splash aprons, 8 percent were PCC, and the remaining 2 percent (1 ford) was AC. An important capability of riprap splash apron material is its ability to respond to minor local erosion by movement of the individual stones as water flows over the ford. This is particularly true where the splash apron meets the natural stream bed at the downstream end. PCC and AC do not have this capability, hence greater care must be taken to terminate the apron into stable stream bed material. A cutoff wall can serve this purpose.

Performance

Approximately 30 percent of the fords surveyed showed erosion damage, the principle form of damage that a low-water ford can experience. The damage consisted primarily of splash apron erosion which in some cases led to base course erosion. We believe that the splash apron failure in these cases is directly attributable to poor matching of the base and splash apron, and to undersized riprap. It is extremely important that the base and splash apron match properly and there are no voids for the base or surfacing to be eroded through (Figure 5) Poor matching of base and splash apron is easily observed, but judging the riprap to be undersized is a more subjective judgement since, as noted above, hydraulic calculations can be questionable. Our judgement was based on the performance of similar fords in the survey that had larger riprap than those that showed damage.

The cross section data obtained for the 13 fords that were measured in greater detail allowed us to estimate the maximum flow that the ford could pass. These flows were then compared to estimates of the 25, 50, and 100 year peak flows for those ford obtained from peak flow equations presented by Campbell et al. (1982). All the fords would pass the 25 year peak flow, and 10 of the 13 would pass the 100 year peak flow. These estimates are clouded by the same hydraulic calculation uncertainty discussed above, but they are most likely reliable enough to reflect design that exceeds the requirement of the Oregon Forest Practice Rules (25 year peak flow).

SUMMARY

Stream crossings often present a challenge to the forest road manager. The capital cost and annual maintenance requirements of culvert installations on small watersheds will likely be significantly higher than a low-water stream crossing (ford). Fords, by no means a new type of structure, are re-emerging as an important component of the forest road system. Design of these types of structures will often require an observational approach, but with local experience, can be done with reasonable certainty. Vented and unvented fords offer options that should accomodate a wide array local stream crossing requirements.

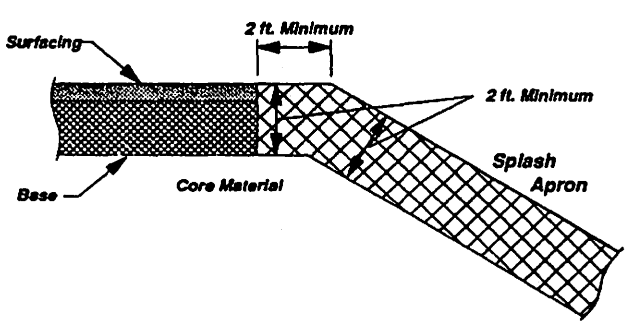

Figure 5. Detail cross section of joint between surface, base, and splash apron.

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Culvert Design and Performance on Forest Roads[1]

Marvin R. Pyles, Arne E. Skaugset, and Terry Warhol[2]

Abstract: Culvert design requires consideration of hydraulics, hydrology, fisheries, economics, and legal requirements. Surveys of culvert installations in the Coast and Cascade Ranges of Oregon show that a majority of culvert installations have adequate capacity to meet legal and reasonable design standards. However, no common design standard was apparent, and 15 to 25 percent of the culvert installations surveyed appeared unable to meet Oregon Forest Practice Regulations as they were designed. Further, reduced capacity due to inlet damage or partial plugging affected about half of the culverts surveyed. Care in design should be taken in the future to insure that culverts remain an available alternative for stream crossings.

Keywords: stream-crossing, low volume road, watershed

The recent increase in focus on riparian values on forest land is resulting in significant modifications of management practices and harvesting techniques in and around riparian zones. Forest road construction and maintenance in riparian zones must be viewed as an integral part of the health and prudent management of these zones. Stream crossings on forest roads, which number in the tens of thousands in the Pacific Northwest and hundreds of thousands nationwide, are a necessary component of forest road systems. They also possess the potential to damage riparian zones if they are poorly designed and/or maintained. Inadequate design and maintenance of stream crossing culvert installations is also costly to landowners which makes sound culvert design and maintenance a prudent management practice for economic as well as environmental reasons.

This paper will present a review of design considerations for stream crossing culvert installations and the results of two recent culvert installation surveys. Also included is an assessment of the peak flow capacity of the surveyed culverts and comments on culvert design methods.

DESIGN CONSIDERATION AND DESIGN CRITERIA

Design criteria for a culvert installation is unique to a given installation. Therefore, it is pointless to write a universal set of design criteria for stream crossing culverts. However, under the rubric of "Design Considerations", a list of items that should be considered for a culvert installation can be developed realizing that some of the items will not pertain to every installation. The list in Table 1 is written in general terms to give the flavor of design considerations for stream crossing culverts. Depending on local conditions or requirements, greater detail or additional items may be warranted.

For each of the design considerations that is appropriate to a given culvert installation, there are design criteria which are the standards against which trial designs are judged. Some standards may pertain to a single condition such as a peak flow which may occur only once during the physical service life of the culvert. Other standards may pertain to the day to day or year to year performance of the installation such as fish passage or annual maintenance cost.

The selection of design criteria for a particular culvert installation is a function of many interacting factors:

(1) The flow capacity and characteristics of a culvert installation which are controlled by culvert hydraulics.

(2) The hydraulic demand placed on the culvert which is a function of the watershed hydrology above the culvert.

(3) The forest practice rules which set some minimum design criteria, particularly with respect to peak flows.

(4) Land management objectives which determine those aspects of design criteria that vary with road design standard (e.g. temporary versus permanent roads).

(5) Business risk objectives which determine the degree to which design criteria will consider the probability of culvert installation failure resulting in replacement costs and off-site damage.

Design criteria derived from the first three factors listed above should be approximately equal regardless of the land owner or organization doing culvert installation design. The forth factor will result in different design criteria because land management objectives are not the same. The fifth factor will result in different design criteria and therefore different designs between land owners depending on business objectives and the local potential for off-site damage.

CULVERT INSTALLATION SURVEY

The actual performance of existing culvert installations relative to design considerations will be assessed using data from two culvert surveys. The surveys were conducted in the central Coast Range of Oregon in 1984 and 1985 (Piehl, Pyles, and Beschta, 1988) and the Oregon Cascades in 1988 (Warhol, 1989) (Figure 1). In the Coast Range, culvert installations were surveyed on forest land managed by the Forest Service, Bureau of Land Management, State of Oregon, and Private Industry, while in the Cascades, culverts were surveyed only on Forest Service land

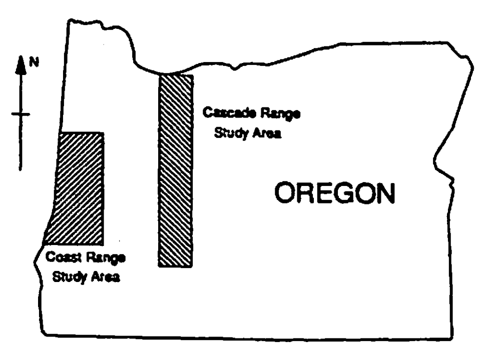

Figure 1. Coast Range and Cascade Range culvert surveys.

1 Presented at the 12th Annual Council on Forest Engineering Meeting, Cocur d'Alene, ID. August 27-30, 1989.

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Table 1. Stream Crossing Culvert Design Considerations.	
Category	Item
Peak flow events	1. Pipe size, slope, and entrance type 2. Freeboard 3. Allowable headwater level (local flooding)
Fish migration	1. Migration period (range of flows during the migration period). 2. Water velocity and depth (a function of pipe size, and placement). 3. Pipe outlet geometry (jump required for fish to enter pipe).
Maintenance	1. Floatable and non-floatable large (relative to the pipe) organic debris carried by the stream (effects pipe size decision). 2. Stability of outlet pool (effects fish migration) 3. Bed load of stream (extreme bed load transport can require culvert cleaning). 4. Maintenance funding. 5. Current maintenance cycle being used.
Economics	1. Life of the installation. a. Permanent or temporary installation. b. Physical service life of pipe. 2. Original installation cost. 3. Annual maintenance cost. 4. Replacement cost and potential cost of damage from failure.
Legal requirements	1. Peak flow capacity (often mandated by forest practice regulations). 2. Construction timing and practices (environmental sensitivity, and physical feasibility).

(the Mount Hood, Willamette, and Umpqua National Forests). The culvert survey results reported in this paper focus on the design of stream crossing culvert installations for peak flow capacity. Peak flow capacity is embodied in the first three factors listed above and is a primary design consideration for stream crossing culvert installations. The performance of culvert installations for design requirements to accommodate fish passage at low to moderate flows are not considered in this paper primarily because these requirements were beyond the scope of the culvert surveys. The culvert surveys did not consider moderate to low flow design requirements for two reasons. First of all, there is an overriding interest in the peak flow capacity issue and secondly, the geographically based random selection of culvert installations used in the surveys results in a large percentage of the installations being on small streams for which fish passage is not a consideration. A separate study of the fish passage issue is needed, but a carefully stratified sample is required to obtain a representative sample of the pertinent culvert installations.

During the culvert surveys, information was recorded regarding the current condition of the culvert installations that was not specific to peak flow capacity. This information was used to give some impression about the quality of the construction and maintenance of the culvert installations as well as the physical service life of the culverts. The surveys included a record of culvert diameter, length, material, inlet type, slope, cover, and freeboard (freeboard may be less than pipe cover if the culvert installation is on a grade).

Flow Capacity of Existing Culvert Installations

The actual performance of existing culvert installations is difficult to determine because the ability of a culvert to pass a given peak flow is only tested when that peak flow occurs. Without a continuous recording of flow through a culvert there is no way of knowing what flows the culvert has successfully passed. Further, given the probabilistic nature of streamflow, it is possible for a given culvert installation designed for a particular peak flow to never experience that design peak flow or to experience it a number of times during the life of the installation. In any case, the only characteristics of a culvert installation that can be easily observed are its physical dimensions and the fact that it exists which implies that the currently installed culvert has not experienced a complete washout failure since installation.

The physical dimensions of an installed culvert provide some information that allows the culvert installation to be compared with design standards. Comparing existing installations with design standards is not equivalent to assessing actual field performance, however, it is a reasonable surrogate and will indicate whether existing stream crossing culverts were designed with adequate and consistent design standards.

The culvert installations in the surveys were randomly selected on a geographic basis. The culvert installations for the Coast Range survey were selected without regard for contributing watershed area which resulted in contributing watersheds as small as two acres being included. The culvert installations selected for the Cascade survey were selected from those culvert installations with a contributing watershed area that was identifiable on a USGS 15 minute quadrangle which resulted in a distribution of larger watersheds. Summary data for the culvert installations from both surveys are shown in Figures 2 and 3. Although pipe arches are increasingly being used on forest roads, they did not show up as a significant percentage of the randomly selected culvert installations and, for this reason, they are not included in these results.

The two major factors that effect the peak flow capacity of a culvert installation are the slope and inlet type of the installed culvert. The summary data for culvert slope and inlet type from the culvert surveys are shown in Figures 4 and 5. Culvert slopes reflected the stream gradients of headwater streams in the Coast and Cascade ranges which are generally quite steep. A projecting inlet, in which the pipe projects out from the road fill, was the most common inlet type. In the larger culvert sizes, there was a trend toward mitered inlets in which the culvert inlet is mitered to the slope of the road fill (Figure 5) thus improving its hydraulic performance.

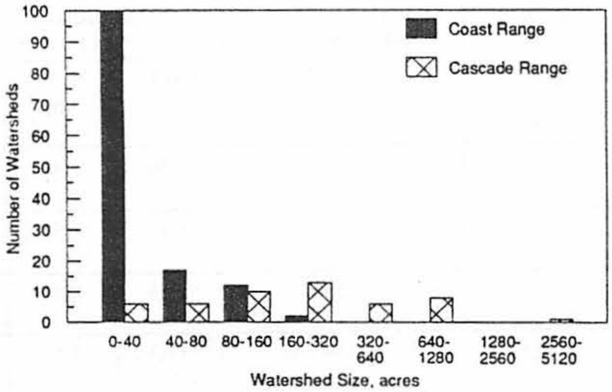

Figure 2. Size distribution of watersheds.

Hydrology of Small Forested Watersheds

The streamflow that a culvert installation experiences is a function of the watershed above the installation and its precipitation regime. There are a number of methods used to estimate the expected streamflow at a culvert installation site (Campbell, et.al., 1982; Fedora, 1988). A complete discussion of all available methods is beyond the scope of this paper. The most easily applied method is the use of regional peak flow equations developed from statistical analysis of stream gauge records for small forest watersheds (e.g. for Oregon, Campbell, et.al., 1982).

The peak flow equations give an estimate of the instantaneous maximum discharge for a given return interval in terms of watershed area and other variables found to be statistically correlated with the peak flows in that region. For example, equations presented by Campbell et.al (1982) for the Oregon Coast Region are given in Table 2.

Depending on design criteria, these equations may be sufficient to estimate design peak flows for a culvert installation. For example, the Oregon State Forest Practice Regulations require culvert installations to pass the 25 year return interval peak flow. Given other design criteria, different peak flow return intervals or even entire peak flow distributions may be desired. Peak flows for return intervals not given directly by the equations can be obtained by linear interpolation between the equations. The function is non-linear, but using linear interpolation will introduce only a small error.

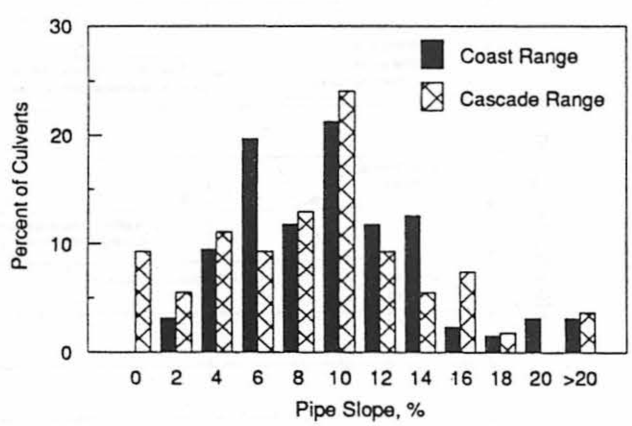

Figure 4. Culvert slope distribution.

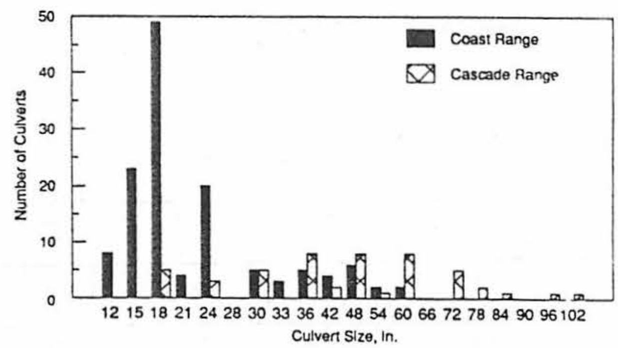

Figure 3. Culvert size distribution.

The simplicity of the peak flow equations does not come without a price. As indicated in Table 2, the standard deviation of the ratio of the estimated to actual peak flows for the streams from which the peak flow equations were developed is quite large. This means that actual peak flows for a given return interval may be significantly larger than the estimated values. For example, to be 95 percent confident that an estimated design peak flow will not be less than the actual peak flow for a 25 year return interval, the estimated peak flow from the equation would have to be increased by approximately 50 percent. Peak flow ratios for 90 percent, 95 percent, and 99 percent confidence levels are given in Table 2.

The large variability in peak flow data, that is evident by the standard deviations listed in Table 2, is the result of both natural variability and the fact that the peak flow equations are based on a small data set of short duration. Other peak flow estimation methods include the same natural variability and therefore are not superior to the peak flow equations obtained by Campbell et. al. (1982). For this reason, the performance of culvert installations for both the Coast and Cascade surveys was assessed using peak flow estimates obtained from Campbell's equations. The culvert surveys included watersheds from the Oregon Coast, Willamette, Cascade, and Rogue-Umpqua Regions.

Culvert Hydraulics

Water flowing through a culvert must overcome resistance from three components; (1) flow restriction at the culvert inlet, (2) pipe barrel friction, and (3) backwater from the tailwater pool. To overcome this resistance, the water level

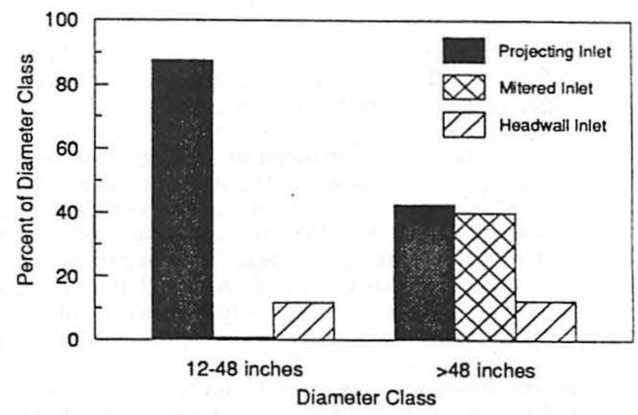

Figure 5. Culvert inlet type distribution.

Table 2. Campbell's Equations for Peak Flow in the Coast Region of Oregon								
Return Interval	Estimating Equation	R^2	Sample "n"[a]	Mean Peak Flow Ratio,[a] $\frac{Q_{est.}}{Q_{station}}$	Std. Dev. of Peak Flow Ratio[a]	Upper one-tailed limits of Peak Flow Ratio[a, b]		
						90% limit[c]	95% limit	99% limit
10	$Q_{10} = 5.87\,A^{1.04}E^{.49}$	.83	20	≈ 1.0	0.28	1.36	1.46	1.65
25	$Q_{25} = 6.31\,A^{1.01}E^{.51}$	.79	20	≈ 1.0	0.31	1.40	1.51	1.72
50	$Q_{50} = 7.77\,A^{1.01}E^{.50}$	.79	20	≈ 1.0	0.33	1.43	1.54	1.77
100	$Q_{100} = 8.40\,A^{1.00}E^{.50}$	.78	20	≈ 1.0	0.34	1.43	1.55	1.78

[a] Interpreted from Campbell's data by the authors.

[b] The use of prediction limits on the discharge ratio is not the standard way of representing the likely variability in a population described by a regression equation, but it is far simpler to understand and use, and it is as rigorous as prediction limits transformed from logarithmic space where the regression was done.

[c] In other words, 90%, 95%, and 99% respectively of the peak flows for a given return interval will have a discharge ratio less than or equal to the given values.

at the culvert inlet (headwater) must rise, increasing the water pressure at the inlet which, in turn, forces the water through the culvert. Since the gradient of headwater streams is usually steep, and the stream crossing culverts installed in these streams are usually placed on fairly steep slopes (greater than 3 percent, see Figure 4), only the first of the three resistance factors is important in determining culvert installation capacity. The performance of a culvert installation should be expressed as the headwater depth needed to pass a design discharge because, typically, culvert installations have an operational limit on headwater depth.

This can be illustrated by examining the performance of a hypothetical culvert installation (Figure 6). For a headwater depth that goes from zero up to the level of the road surface, the discharge through the culvert is controlled by the hydraulic properties of the inlet. As the water level rises above the road surface, the discharge includes flow over the road. If the culvert installation has not been designed and constructed to withstand water flowing over the road, when the water level is even with the road surface the maximum capacity of the culvert installation is attained (Figure 6). The headwater level at the road surface represents an extreme limiting case of culvert installation capacity because for a headwater level above the road surface a washout failure of the installation is likely.

However, the capacity of a culvert installation can be defined in different ways. An alternative is to define the capacity of a culvert installation as the instantaneous discharge at a lower headwater level. This is often the case for culverts installed on forest roads where there is a high likelihood that debris will partially block culvert inlets during high flows. The definition of culvert capacity at a headwater level lower than the road surface provides a buffer allowing the desired peak flows to pass even though the culvert is partially blocked. Although this principle is commonly suggested, it is largely a matter of judgement since no formal data on the probability of culvert blockages during high flows exists. Culvert capacity from the two culvert surveys was examined with respect to two definitions; (1) the extreme limiting case of the headwater level at the road surface, and (2) the more common case of the headwater level at the crown of the culvert inlet.

The capacity of a culvert installation has little meaning expressed in terms of discharge alone. It is the hydraulic capacity, based on culvert hydraulics, compared to the hydraulic demand, based on watershed hydrology, that is meaningful. When the demand placed on a culvert installation is considered, the capacity of the installation is often stated in terms of the return interval of the flow that the installation was designed to pass. For the culvert installations in the surveys, peak flow return intervals were obtained by interpolating between the values estimated by the peak flow equations.

When the return interval was outside the range of the equations (from 10 years to 100 years), a return interval was extrapolated. The extrapolation was limited to return intervals not less than two years or not more than 250 years. These limits are arbitrary, but they do identify the points that are well outside the 10 to 100 year range estimated by the equations.

The estimated peak flow return intervals for the two headwater cases for all the culvert installations surveyed are

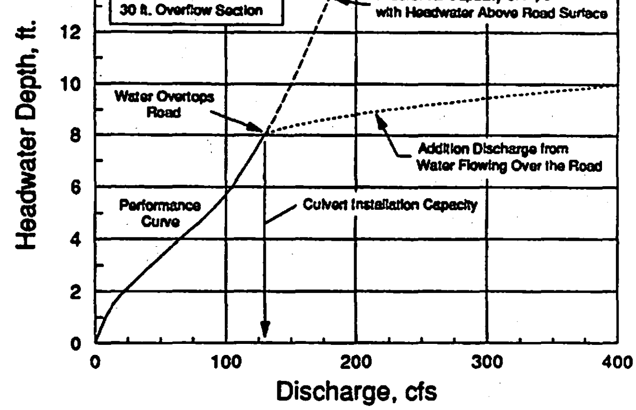

Figure 6. Example culvert installation performance curve.

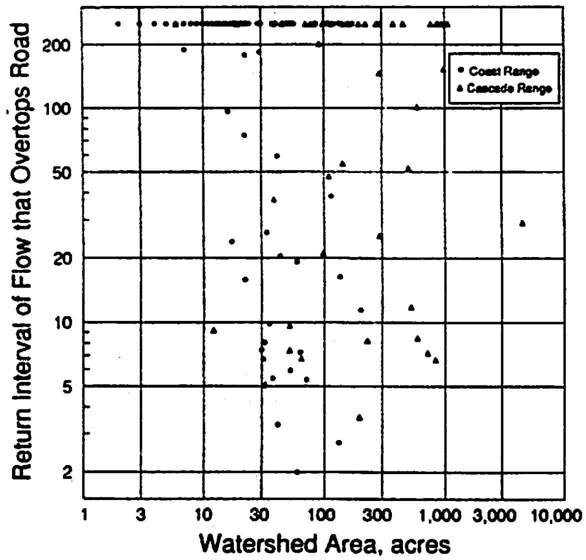

Figure 7. Peak flow return interval for the condition of headwater at the road surface (Maximum allowable headwater).

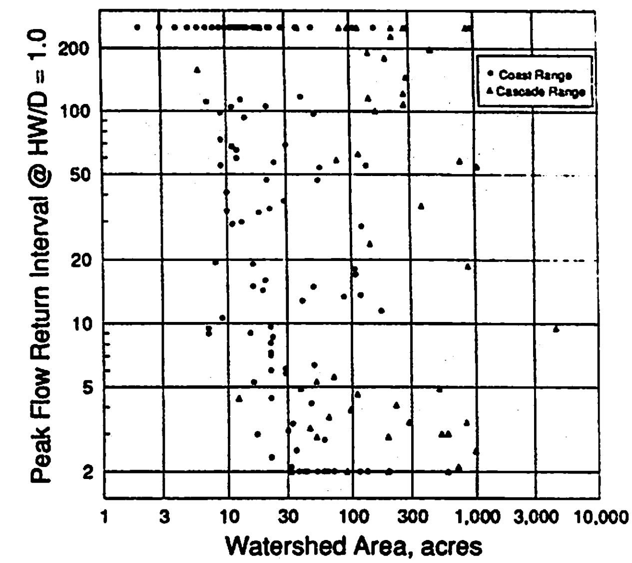

Figure 8. Peak flow return intervals for the condition of headwater at the crown of the pipe (Headwater to diameter ratio equal to 1).

plotted against watershed area in Figures 7 and 8. Both Figures show a wide scattering of peak flow return intervals throughout the range of watershed areas. The scattering of return intervals should be expected for two reasons. First of all, different designers will use different peak flow estimation methods which will result in a scattering of design peak flows for similar installations. When these installations are compared using a common peak flow estimation method, the differences in design appear as differences in peak flow return interval. Secondly, even if all designers used a common peak flow estimation method, the presence of local factors, such as large quantities of debris, downstream property values, mainline versus spur road installation, and other factors, would result in a scattering of peak flow return intervals because some installations would have larger culverts to accommodate the varying local conditions. However, the scattering of estimated peak flow return intervals is expected to be above some minimum standard value. This is not the case for either the Coast Range or Cascade Range culvert survey. Therefore, the conclusion must be made that a common peak flow design standard was not used for the surveyed culvert installations.

This conclusion, by itself, is not particularly alarming, but what is alarming is that so many culvert installations do not even meet the minimum return interval standard required by Oregon Forest Practice Rules (Figure 9). Furthermore, these installations do not appear to be designed with a very high probability of even surviving the physical service life of the culverts. The physical service life of a culvert can vary depending on local corrosion rates, but it is rare that a culvert does not last at least 25 years and special treatment, such as asphalt coating, can increase culvert life well beyond this.

Before solidifying this conclusion, an appropriate question to ask is, if a different method of peak flow estimation had been used would an appropriate minimum design standard have been indicated by the estimated peak flow return intervals? The two most likely alternative peak flow estimation methods are the Rational Formula and Talbot's equation. Comparisons of the Rational Formula with stream flow records show that it over-predicts peak flows (Heimstra and Reich, 1972). If this result holds for the Coast and Cascade streams, then using the Rational Formula would result in even lower estimated peak flow return intervals than Campbell's equations generate. Furthermore, both methods require runoff coefficients calibrated to local forest watershed conditions. Published coefficients for the Rational Formula or Talbot's equations are not generally available meaning that there is room for doubt that either method would produce more consistent results for the surveyed culvert installations than those reported in this paper. However, to check this, peak flow return intervals for all the culvert installations from the surveys were estimated using Talbot's equation with locally calibrated runoff coefficients for a headwater to diameter ratio of 1.0 (e.g. Beschta, 1984) and varying return intervals. These equations are similar to Campbell's equations for the Willamette region except they have an exponent for watershed area of 0.5 instead of the value obtained from regression. Most of the peak flow return intervals estimated by Talbot's equations were different from those obtained using Campbell's equations, but there was no less scatter in the peak flow return intervals and there was no minimum standard evident.

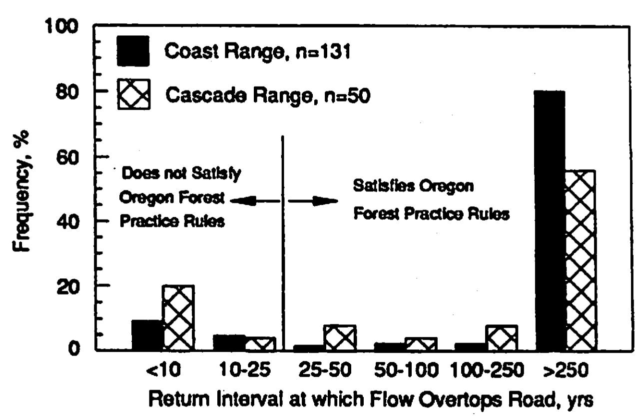

Figure 9. Histogram - return interval at which flow overtops road.

The results of the culvert surveys certainly indicate, to some degree, the results of past practices and they should not be considered a true reflection of current practices. However, the results do indicate a need to review culvert installation design standards so that the continued installation of cost effective stream crossings is insured. This is particularly important as older culverts are replaced either because they wear out or fail at sometime in the future.

Current Conditions of Culvert Installations

The current condition of culvert installations is of interest from the perspective of the physical service life of the culverts and the degree to which the installations retain the hydraulic provisions that allow for fish passage. These factors were beyond the scope of the two surveys reported here, however current culvert condition is of interest because it affects peak flow capacity. The peak flow capacity analysis presented in this paper used the original geometry of the culvert installations. The culvert installation surveys indicated that many of the culverts have reduced capacities due to inlet damage or partial blackage of the culvert inlet and/or barrel.

Approximately 50 percent of the culverts from both the Coast and Cascade surveys had the cross sectional area of the culvert inlet or barrels reduced (Figure 10). These reductions were primarily due to inlet denting, organic debris at the inlet, or sediment at the inlet and in the culvert barrel. If these conditions persist throughout the life of the culvert, then a design allowance must be made to account for the lost culvert capacity.

Without unusual maintenance, a dented inlet will most likely stay dented. However, organic debris should be removed through normal maintenance activities taking care not to dent the culvert inlet during maintenance thus creating one problem in the solution of the other. Sediment accumulations in culvert barrels present an uncertain situation. If the sediment is fine, then high flows may wash it from the pipe and restore some of the lost capacity of the culvert. However, this should be viewed as a rather tenuous process, at best. Sediment transport out of a culvert barrel requires time, yet peak flows sufficient to transport sediment are a transient phenomena. If high flows prior to a peak flow are of too short a duration to completely flush the sediment from the culvert, then a partially plugged condition will persist. In any case it seems prudent to consider reductions in effective pipe size during design. The culvert surveys indicate that the majority of the culverts with reduced inlet or barrel cross sectional area have between 80 percent and 100 percent of their original cross sectional area. One pipe size would seem sufficient to accommodate the majority of the reduction concerns. Design standards could be adopted that would require one culvert size larger than nominally required.

SUMMARY

In this paper, design considerations for stream crossing culvert installations on forest roads have been presented along with analysis of the performance of culvert installations with regard to peak flow capacity. Design considerations for a culvert installation are based on criteria that are unique for each particular installation site. But, in general, design standards should be set for peak flow capacity, moderate to low flow characteristics for fish passage, maintenance, and potential for off-site damage in the event of a failure. Design standards between similar culvert installations should vary depending on the land management objectives of the land owner and their business risk philosophy.

The performance of culvert installations were assessed with regard to only peak flow capacity. The assessment is the result of two recent culvert installation surveys in the Oregon Coast Range and the Cascade Range. The peak flow capacity of culvert installations was reported in terms of the peak flow return interval of the installation with the headwater level at first, the road surface and then, the crown of the pipe. The hydraulic capacity of the culvert installations was computed using culvert hydraulics and the geometry of the existing installations. Peak flow return interval was estimated by linking hydraulic capacity with hydraulic demand by interpolating or extrapolating from Campbell's equations. The results show that there appears to be no minimum acceptable standard for peak flow capacity in terms of return interval for existing culvert installations. This result was verified using Talbot's equations as alternative peak flow return interval estimators with no noticeable change in the outcome. These results indicate that the design standards for peak flow capacity in terms of return interval need to be reviewed to insure the continued installation of cost effective stream crossing culverts on forest roads.

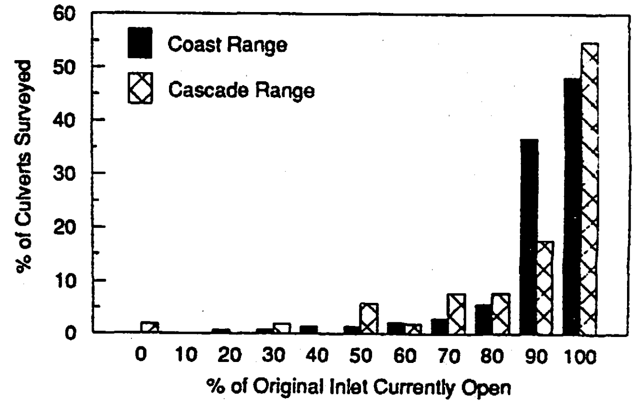

Figure 10. Current culvert condition - cross sectional area.

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Log Trucks Pulling Mud onto Public Roads: Possible Solutions to the Problem[1]

Robert M. Shaffer and James M. Keesee[2]

Abstract: The transfer of mud from soil-based logging roads to paved public roads by log trucks operating during muddy conditions is a major problem for southern logging contractors. Safety, liability, fines, and loss of production are major concerns resulting from this problem. Possible solutions include ceasing operations during muddy conditions, logging road construction and surfacing techniques to minimize mud, and methods of removing the mud from the log truck prior to entering the highway. Four potential devices for removing mud from log truck tires are described.

Mud is a problem much of the year for loggers operating in the South. Extended periods of rainfall typically occur from December through April, followed by frequent heavy afternoon thunderstorms during the summer months. This abundant moisture, combined with the clay soils found over much of the region, creates muddy logging conditions that cause numerous operating problems for logging contractors. Perhaps the most serious problems is the transfer of mud from soil-based logging roads to paved public roads by log trucks operating during muddy conditions.

Sticky clay-based mud tends to pack into the space between the dual tires and stick to the tire tread as log trucks move slowly along unsurfaced haul roads. As they exit the woods and pull onto the paved road, they typically pull large volumes of mud onto the highway.

This mud often accumulates in large amounts at the logging road entrance point and can sometimes be seen for up to a mile down the paved road as the truck gets "up to speed" and slings the mud out of the dual tires.

Mud transfer causes several problems for the southern logger. It poses a serious safety hazard for motorists, who may lose control of their vehicle when they suddenly encounter an unexpected "mud slick" on the highway. Several civil lawsuits have resulted from accidents caused by mud from a logging operation. Pulling mud on the highway is a direct violation of the law in some jurisdictions. Many county supervisors or road commissioners will quickly obtain court injunctions to stop logging if they become aware of log trucks pulling mud on the roads or receive complaints from citizens. Expensive fines are commonly assessed to violators in several southern states.

Mud transfer can be eliminated in a number of ways. Perhaps the most obvious is to simply stop logging during muddy conditions. However, given the production-based payment system commonly used by the forest industry in the South and the high fixed expenses of most logging contractors, few could afford to cease operating 2-3 months out of the year.

Improved logging road location and construction could eliminate much of the mud transfer problem. If loggers would always construct well-drained haul roads on stable soils and use crushed rock, wooden or metal mats, and/or geotextile for surface stabilization where needed, log trucks would not encounter much mud from the woods landing to the highway. Unfortunately, economics often makes this solution unrealistic. Much of the timber logged in the South comes from small private landholdings of less than 100 acres. Typically, a logging contractor will complete a job and move to a new tract every 2 to 4 weeks. Logging roads are usually temporary and are "retired" immediately after logging is completed. Thus, it is often difficult to economically justify extensive road-building costs for each tract. The operating strategy used by many independent logging contractors in the South is to simply "brush out" enough branch road with a small dozer to get the timber removed. These branch roads typically are not much more than single-lane trails with the surface organic material scraped off and a few water turn-outs installed at key points. Sometimes a few loads of crushed rock may be spread at obvious "soft" spots in the road, or at the last 50 to 100 feet where the logging road enters the highway. As you may expect, rain quickly turns the top 2 to 3 inches of many of these soil branch roads into mud, and some of that mud often ends up on the highway.

Most loggers operating in the mud will take time to try to clean the highway to some extent at the end of the day using hand shovels or the skidder blade. A few even lease portable high-pressure water systems to periodically wash the mud off the road at the entrance point.

Assuming that, for economic as well as operational reasons, southern loggers will continue to drive log trucks over muddy haul roads, members of the Industrial Forestry Operations Research Cooperative at Virginia Tech challenged Graduate Student Jim Keesee and Associate Professor Bob Shaffer to design a device that, when attached to a log truck or trailer, would effectively clean the mud from the dual tires, leaving it in the woods rather than transferring it onto the highway. Cooperative members Randy Starling (Procter and Gamble Cellulose), John Ramage (Bowater, Inc.), Richard Green (Inland-Rome, Inc.), and Jim Willis (Chesapeake Corp.) determined that for such a device to be successfully adopted by logging contractors, it must work well, be simple in design, be inexpensive to construct and mount, be something that a logger can build in his shop, and be easy to use.

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[1]Presented at the 12th Annual Council on Forest Engineering Meeting, Coeur d'Alene, ID, August 27-30, 1989.

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Working within these constraints, the study team conducted a literature review, made several trips to the field to examine and evaluate possible techniques, and hit the drawing board. After much deliberation and trial and error, four devices were determined to have the most potential. In order from the simplest to the most complex, these were:

1. A heavy nylon rope connected around the spacers between the dual tires on the trailer tandem (Figure 1). As the wheels turn, it was believed that the rope would force the mud out from between the duals, keeping them from filling up. This was the simplest, least expensive and easiest to use device, since it could remain in place at all times. A nylon rope was chosen over a steel cable since it was believed the rope would present less risk of damage to the tires' inner sidewalls.

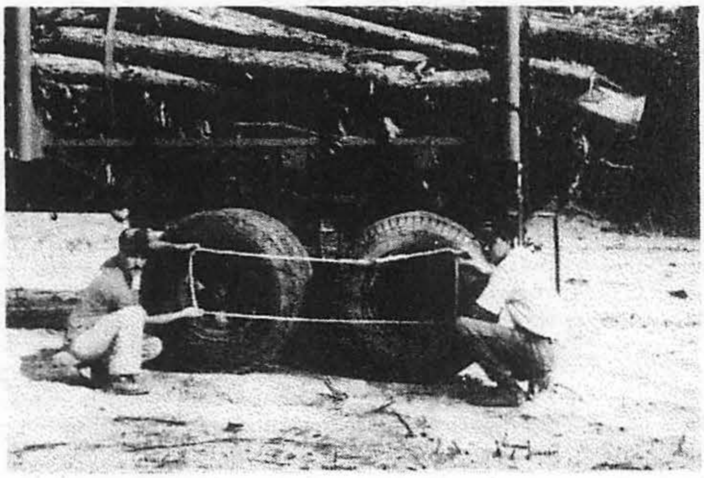

Figure 1. The rope.

2. A round steel bar or pipe, mounted vertically from the trailer frame, that extends the depth of a tire into the space between the dual tires (Figure 2). The bar, positioned just behind the spacers, should force the mud out from between the duals as the wheels turn. The bar is mounted on a hinge pin, so that is can be raised away from the tires during highway travel. The diameter of the bar or pipe is approximately 0.5 inches less than the width of the space between the dual tires.

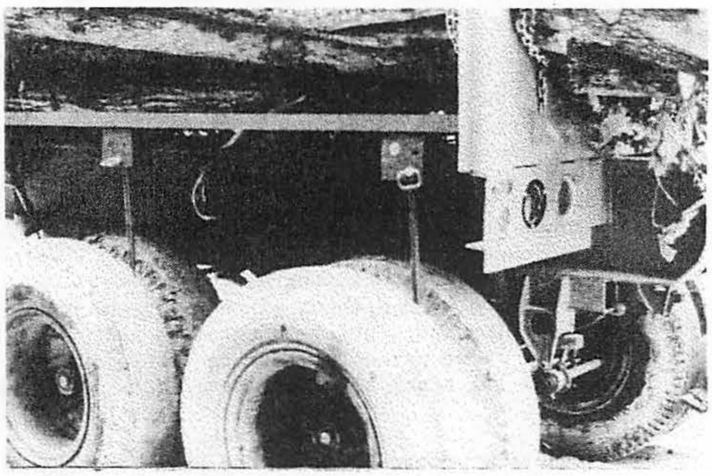

Figure 2. The bar.

3. A steel bar similar to (2), with a heavy-duty rubber scraper blade mounted on an adjustable steel sleeve (Figure 3). With the bar properly positioned between the dual tires, the rubber scraper is lowered into position until it rests firmly against the tire tread, then locked into place with thumbscrews. As the wheels turn, the bar forces the mud out from between the duals and the scraper "peels" that mud as well as the mud sticking to the tire tread away from the tires. As with (2), this "bar and scraper" is mounted on a hinge pin that allows it to be easily swung up and out of the way for highway travel. The rubber scraper for the prototype device is made from 1-inch-thick heavy rubber "cow mat," commonly used as a durable floor covering in the stalls of dairy barns.

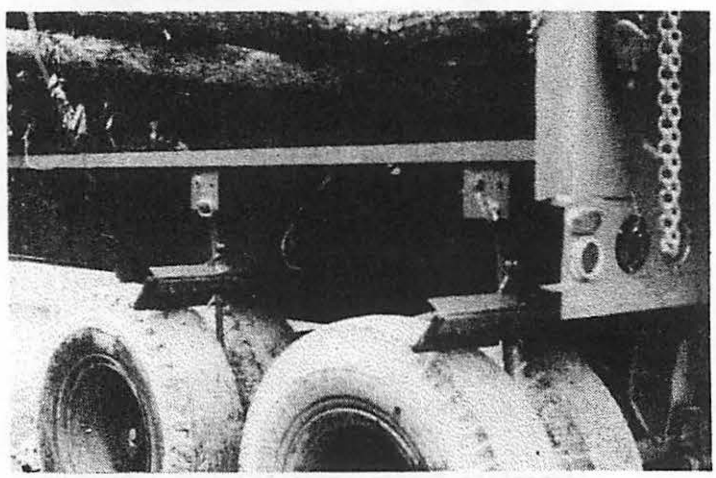

Figure 3. The bar and scraper.

4. A pneumatically operated steel "mud flap" (for the rear set of dual tires) linked with a "bar and scraper" (same as #3, for the front set of duals) (Figure 4). The mud flap is constructed from a sheet of 0.25-inch steel, is approximately the same width as a normal highway mud flap, and is about 6 inches longer. A triangular shaped piece of 1.0-inch-thick heavy gauge fiberglass plate is attached vertically and perpendicular to the mud flap. A rubber scraper is attached horizontally and perpendicular to the mud flap at the base of the fiberglass plate. When the mud flap is pulled into position by a pneumatic cylinder, the fiberglass plate extends into the space between the duals and the rubber scraper fits snugly against the tire treads. A steel rod links the mud flap with a "bar and scraper" mounted at the front set of duals, while a second linkage rod connects both devices to a pneumatic cylinder mounted on the trailer frame. The pneumatic cylinder is connected to the tractor/trailer's air supply and can be operated from the cab. When reversed, the pneumatic cylinder pushes the devices away from the tires for highway travel.

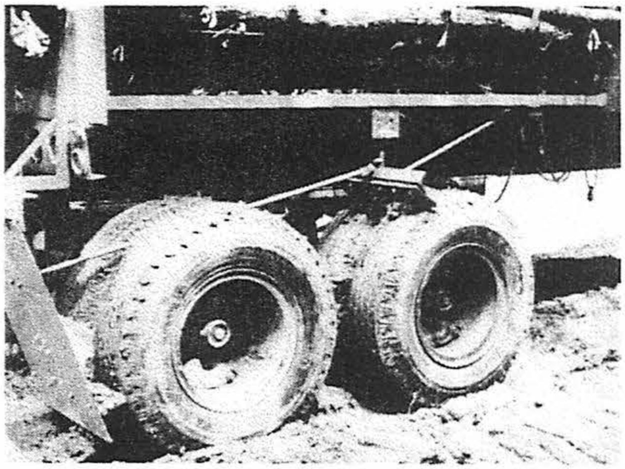

Figure 4. The mud flap assembly.

In March 1989, these devices were temporarily attached to a University-owned dump truck and underwent brief preliminary testing at Virginia Tech. It was observed that the rope (1) did not appear to work very well, that the bar (2) removed a substantial portion of mud, and the bar and scraper (3) and mud flap assembly (4) appeared to be highly effective. In June, the study team acquired a double-bunk, rigid frame, 40-foot log trailer for the project. Thorough field testing of the devices is planned that will allow vigorous statistical analysis of the differences in mean transferred mud weights between a control (no device) and the four devices. The results of these tests will be published in a future report.

DOES NETWORK ANALYSIS PAY?[1]

Jack Cullen and John Sessions[2]

Abstract: The Washington State Department of Natural Resources (DNR) in carrying out its mandate to efficiently manage trust lands under its jurisdiction is implementing network analysis techniques as part of an overall harvest planning system. Results of completed projects indicate high potential savings. In moving toward field implementation, DNR has adopted a four part training process which takes personnel from theory to practical problem solving. A central part of the training is demonstrating the importance of generating alternatives.

Key words: Harvest planning, network analysis

DEPARTMENT OF NATURAL RESOURCES

The Washington State Department of Natural Resources (DNR) is developing an integrated harvest planning system. No system has been found that integrates all necessary tools together into one package. However, many of these tools are currently available as separate components. One of these tools is network analysis. The DNR is beginning to put network analysis to work as a harvest planning tool. This paper reviews the process DNR is using to introduce network analysis techniques into its organization including hardware, software, training requirements, and an evaluation of its cost effectiveness.

DNR Forest Management

DNR manages 1.7 million acres of state land as commercial forest land. About 900 million board feet is harvested from this land annually. Sale of this timber yields 130 to 170 million dollars a year. This revenue supports several public trust beneficiaries including school construction and DNR forest management operations. To manage this forest land, DNR annually adds 130 to 160 miles of road to its existing 12,000 mile system at a cost of 7 to 9 million dollars.

DNR's central goal in forest land management is to "conserve and enhance the natural resources of state forest lands while attaining the highest long-term income from these lands." (Wash. St. Dept. Nat. Res. 1988)

This revenue oriented goal and the complexity of the DNR road system suggested the use of network analysis for both enhancing revenue and reducing long-term system construction and maintenance costs. The DNR has chosen to use the network analysis program, NETWORK, (Sessions 1985) because it is readily available and relatively user friendly. NETWORK is not a complete integrated harvest planning system. It accepts the harvest schedule as given and is concerned with choosing between harvesting systems, road locations, road standards, and mill or market destinations over multiple time periods. The use of NETWORK in the short run is expected to improve management decision making over current methods. In the long run, fully integrated harvest planning is anticipated to significantly improve the DNR revenue and cost picture.

DNR Operations

DNR is organized in seven administrative Regions with a central support staff in Olympia. Each of the seven Regions covers a defined geographic area with five to the west of the Cascades and two to the east. Each Region is subdivided into "local units". There are about 60 local units statewide. Typical local units administer 10,000-40,000 acres of state land. Each Regional headquarters has a staff that supports field operations. Nearly all actual field work is done by local unit staff, who literally work out of their pickup trucks. A small engineering staff of one to seven forest engineers is included in each Regional headquarters staff. The Regional engineering staffs provide technical engineering consulting services to Local Unit Foresters in areas of forest roads, logging systems and sale unit layout. Nearly all computer assisted harvest planning analysis is done by these engineering staffs as a service to the field.

NETWORK IN DNR

Harvest Planning

Harvest planning tools that are available include computer programs developed by the Forest Service such as SKYLINE for predicting cable yarding payloads (Nickerson 1980) and PLANS for predicting logging costs as well as payload feasibility (Twito et al. 1987). Others, such as the DNR geographic information system (DNRGIS) provide environmental and inventory data. Economic feasibility and investment strategies are currently evaluated using in-house developed programs and spreadsheet templates.

For transportation analysis, several programs are available including NETWORK, SNAP (Sessions 1988) and IRPM (Kirby et al. 1980). NETWORK and SNAP are network-based. IRPM is a mixed integer linear programming model developed by the Forest Service. NETWORK is the simplest and least comprehensive model, IRPM allows full integration of harvest scheduling and transportation, and SNAP falls somewhere in between.

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[1] Presented at the 12th Annual Council on Forest Engineering Meeting, Coeur D'Alene, Idaho, August 27-30, 1989.

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IRPM and SNAP require considerable training and experience to use. They also have specialized hardware requirements that cannot be met with equipment presently available to DNR. While NETWORK has limitations in solving the forest harvest problem that may be overcome with the more complex models, it also has the advantage of being relatively easy to use. And, it can be run IBM-PC compatible microcomputers. DNR has several hundred of these machines throughout its operations.

History of NETWORK in DNR

From 1984 to 1986 DNR purchased Hewlett-Packard HP9836 computer systems for six of their Regional engineering operations. A seventh system was installed in Olympia for system support. An early Forest Service version of NETWORK was converted for these systems. No NETWORK training was provided on these systems. Individual DNR engineers were left to discover what they could about it on their own. It should come as no surprise that NETWORK on the HP9836 was used only a few times with spotty success.

During this period, much of DNR's contact with NETWORK came through annual University of Washington Forest Engineering Senior Field Studies on DNR forest lands. These studies produced logging plans that included several large network analyses. It became evident from the benefit of these analyses that DNR should implement NETWORK in its operations. In 1987 DNR management decided to provide NETWORK training to all 25 of their forest engineers.

NETWORK Training

The first NETWORK training was an 8 hour session in 1987 that included both network analysis theory and hands-on time. A small scale, IBM compatible version of NETWORK was distributed to each Region at that training session.

There was an implicit assumption that if potential users understood the theory of network construction, had some hands-on practice with the program and were given some simple examples that they would begin to discover applications for it in the field. This assumption proved to be incorrect. Only one Region extensively used the program. A few others had limited success with it. Engineers in Olympic Region, after a year of experimentation, had the greatest degree of success. They also developed some spreadsheets which allowed relatively straight forward collection and calculation of road construction, road maintenance, haul and harvest costs for use in NETWORK. These achievements were discussed at DNR's annual engineering training in Spring, 1988.

In spite of this apparent lack of implementation success, at this point benefits of limited NETWORK application significantly outweighed training and experimentation costs.

To achieve an acceptable level of implementION, a more intensive training program was instituted in Spring, 1989. This program is currently underway.

Three people from each Region were selected for training. Two came from the engineering staff and would become NETWORK technical experts. The third was a field manager who would help relate the benefits of NETWORK analysis to other field managers and thus serve as an advocate or NETWORK "champion". Volunteers are sought who were risk takers, innovators, and interested in use of analytical planning tools.

The training was organized in four parts:

1) NETWORK theory with exercises, 8 hours.
2) Data collection on real field problems, 2-5 days over 3-5 weeks.
3) Debugging, analysis and solution of field problem, 8 hours.
4) Evaluation and follow-up. Publication of successes.

Part one was a group session with all 21 trainees. Parameters were defined for the field problem at this session. The exercise would not be effective if the area under analysis was either too complex or too simple. The suggested problem was to have about 100 links (representing harvesting choices or road segments) and 10-15 sales. Each Region was to bring one real problem. An objective was that the cost saving generated by the problems solved in the training cover the cost of the training itself.

Part three was accomplished through three small group sessions. The groups were scheduled so that Regions with more NETWORK experience were with less experienced Regional groups. These classes were taught by Dr. Peter Schiess of the University of Washington.

DNR is now in the evaluation and followup stage. Several of the analyses started in class are still in progress. In some cases additional data was needed to correctly complete an analysis. At this writing the value of cost reductions from completed exercises are estimated to exceed the cost of the training by over $100,000.

Once the initial core group of trainees has successfully implemented NETWORK, it is likely DNR will train more people. In addition to the explicit benefits of NETWORK analyses, NETWORK use will pave the way for a broader understanding and acceptance of analytical planning techniques.

DOES NETWORK ANALYSIS PAY?

NETWORK use in the Olympic Region has had a high return on time invested. Results of several of Olympic's analyses are shown in Table 1. The majority of the cost for these analyses was in labor time. The projects involve either planning of single sales or comprehensive logging plans involving several sales.

TABLE 1. A comparison of planning cost to project savings using NETWORK for six projects in the Olympic Region. All costs and savings are discounted.

PROJECT	PROJECT TYPE	SIZE ACRES	SIZE LINKS	PLANNING COST	SELECTED SAVINGS	B/C RATIO
Shuwah	Logging Plan	1800	150	$2,200	$116,000	52.7
Cut Off	Single Sale	80	35	$800	$15,000	18.8
Murphy	Logging Plan	340	104	$1,850	$120,000	64.9
Ridge	Single Sale	120	40	$1,100	$16,000	14.5
Matheny	Single Sale	40	23	$80	$17,600	220.0
Canyon	Single Sale	242	56	$400	$26,000	65.0
	Total			$6,430	$310,600	48.3

In each of the cases shown, routing and sale sequencing decisions had been made prior to the NETWORK analysis by typical current practice (generally "seat-of-the-pants") taking into account as many factors possible by manual methods. This established a base line to compute analysis benefits or costs. In some cases the "selected savings" shown were not the maximum savings calculated by NETWORK because the maximum savings option was precluded by other management considerations. In those cases the cost of applying those considerations was known because a NETWORK analysis had been done.

Typical cost savings or revenue enhancements run from 5 to 10 percent of total project values. In all cases potential gains far exceeded the cost of the analyses.

The term potential is used because DNR timber sales are bid in public auction. The cost savings calculated using NETWORK will be realized if purchasers factor reduce operating costs into their bids. Although it is recognized that many demand and supply factors affect bid price, an hypothesis is that rational bidders consider harvest and transport costs. DNR will attempt to devise a method to test this assumption. Cost reductions can also accrue directly, if analysis shows that an excessive amount of capital is being tied up in long term structures such as road systems.

NETWORK Use: Lessons Learned

During implementation, DNR engineers learned a number of things about NETWORK. Perhaps the most important thing was how to draw the picture of the network. In other words, how are alternatives generated? If no alternatives are defined, there is no potential for improvement. Create as many physically possible road locations or harvesting choices (links) when drawing the network. These should be drawn without regard to cost. With some experience an analyst can second guess infeasible routes somewhat but generally our experience has shown that attempting to shortcut by second guessing or anticipating the results of analysis should be avoided. Including too few alternatives in the initial network was a common error observed in program use. There was a tendency to reject link options by using "intuition" and use road locations that one would have used in developing a plan manually, especially if the link cost is high. This second guessing can result in expensive errors. In one case such an assumption would have cost over $50,000 and was not obvious by simple inspection.

Second, harvest planning always involves a lot of data. Results from NETWORK should always be checked carefully to see if data entry has been clean. This is a task with few shortcuts. Although NETWORK provides sorting options and statistics on the input data, some hard work is involved. A good check is to eyeball the haul routes from each sale. Often data entry errors tend to produce strange looking haul routes. Currently this has to be done manually, since the IBM version does not have plotting capability.

And finally, since NETWORK is a heuristic, that is, a set of rules to provide good, feasible solutions, the optimal solution (lowest cost or highest net value) is not guarenteed. Each solution is feasible and computationally correct. Sensitivity analysis should always be done. This is where intuition is useful. You should ask "why is timber going this way?". If upon cutting the link to prevent NETWORK from using the route yields a better solution, then you have found a better solution!

ACKNOWLEDGEMENTS

We would like to thank Doug Ferris, Olympic Regional Engineer, Department of Natural Resources, and his staff for contributing data.

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The Northeast Region Report

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Keywords: Exports, Land Sales, Environment, Legislation, Production

Exports: This is a timely and exciting addition to the northeast. The export market is in the early stages of growth and shows signs of continued growth if fostered properly. Presently, the export log market is helping to stabilize log production and log values. A partial list of the export products are: Sugar maple (Acer saccharum) logs, Spruce (Picea rubens, Picea glauca) logs, Hemlock(Tsuga canadensis) logs, and mixed hard wood chips. Presently, the Pacific rim is the most active export market.

Land sales: Major tracts of land (1,000 - 200,000 acres) have been sold, traded, and some broken into small fragments. At this time, there has been little effect on timber accessibility due to sales. Land sales have given the law makers an added subject to deal with. This is particularly true in areas around ponds, lakes, and watersheds. The problem has escalated due to large tracts being broken up into 40-acre lots. An example of this is an 8,400-acre tract completely divided into 40-acre lots for development. This could have a future impact on timber supply.

Environment: Through the cooperation of State Government, local towns, foresters, and logging contractors, many watersheds have been harvested with exceptionally good results. This demonstrates that with good engineering, the proper equipment, and the right people, we can change the public perception regarding harvesting of sensitive areas. The Army Corp of Engineers has begun to take an active role in all matters concerning wetlands and waterways. We have begun to feel their impact regarding roads in some areas.

Legislation: There is a considerable amount of diverse legislative activity in the northeast. The hottest topic regarding forestry is in Maine. A forestry practices act was recently passed. The law is not completely formulated, and is subject to many changes at this time. The biggest impact could be related to what kind of equipment can be used on a given piece of land. There could be a limit on mechanized harvesting, such as I have seen on the last three State of Maine public lot bids. All three bids noted no mechanical harvesters could be used. All of the bids could be harvested mechanically and still produce a high-quality job.

Production: Pulpwood demand is good and appears to be stable for the near future. Dimensional lumber demand has slowed this year. The one bright spot in the dimensional market has been hemlock logs. The hemlock studwood market has helped considerably in balancing production. Chipwood, particularly for fuel, has shown a slow but steady increase in production.

Southern Regional Report[1]

Bob Rummer[2]

This has been a year of progress and development for the forest industry in the Southern United States. There is a good demand for forest products, mill capacity is expanding, and new opportunities for more efficient forest operations are being explored.

Market Demand

Pulp and paper and hardwood chip markets have been strong this year, leading to industrial expansion around the South. New mills and additions are under construction and in the planning stages. The dimension lumber market is slower, reflecting the drop in general construction.

Increasing demand for hardwood pulpwood is both a driving force and a product of industrial expansion. Competition for hardwood pulpwood is increasing due to growing demand in domestic and export markets. A relatively sudden shift in export markets has occurred as Pacific Rim countries began purchasing hardwood chips from the Southern region. Chip exports are increasing at both Gulf and Atlantic ports. The chip export market is promoting industrial development along the Tennessee-Tombigbee Waterway in the Miss-Ala region with the construction of chipyards and chip-handling facilities. The development of the hardwood chip export market is occurring at the same time as rising domestic demand fueled by an increasing use of hardwood in the pulp mix. There is also an increasing demand for hardwood grade logs on the Atlantic coast for the export market. Again, most of the consumption is in the Pacific Rim.

As hardwood demand increases, pressures mount for environmentally sound, cost-efficient harvesting systems for wetlands and upland hardwood sites. Pine management is also changing in response to the hardwood demand, with the objective of developing multi-product pine stands rather than just pulpwood. This is creating more interest in thinning systems and merchandising during the final harvest. Increasing competition for the hardwood resource is leading to longer hauls. Forest engineering is faced with the challenge of developing new systems for the changing utilization of pine as well as improved systems for harvesting and transporting hardwood.

The southern United States is currently enjoying its position in the international hardwood market, but it is important to recognize and address international competition Cost-effective harvesting and transportation will be necessary to maintain our market position

Harvesting Systems

The most recent Pulpwood Logging Contractor Survey shows a trend toward more productive mechanized operations in the South. Over 45 percent of the contractors surveyed produce more than 100 cds/week. These highly productive operations account for 90 percent of the volume produced. Feller/bunchers are used by 30 percent of the contractors and grapple skidders now outnumber cable skidders. Average crew size has almost doubled since 1980. As crews are shifting to higher output levels, transporation systems have changed. The majority of the wood produced is now hauled by tractor-trailer rigs. Most of this change is occurring through the attrition of smaller, less-efficient and less-productive producers.

New interest is developing in forwarder/processor systems that enhance sorting and merchandising wood to tighter specifications. The need to obtain maximum value from the raw material is also generating interest in improved in-woods chipping systems. Flail delimber/debarkers are increasing across the South to provide quality, clean chips for the pulp and paper industry One new pulp mill has announced plans to purchase 60 percent of its input volume in chip form. Currently there are approximately 20 flail debarkers operating in the South. This number should at least double in the next year. The use of sawheads is still on the rise in the South, although product development seems to have stabilized. The challenges for forest engineering are to develop and improve more productive harvesting systems for southern conditions as well as to innovate new methods of extracting more value from each tree.

Safety

Logging in the South, as in other regions, is a dangerous occupation which is reflected in the Workmen's Compensation Insurance (WCI) rates for the region. The average manual rate for pulpwood logging is about $50/$100 of payroll. In Mississippi, the manual rate for general pulpwood logging is $97.82. Some progress, however, is being made in addressing WCI costs. Mississippi has initiated a new WCI classification for mechanized logging operations. Logging systems with mechanized felling qualify for the new rates which are 15 percent below the standard manual rates. The development of this new WCI class was a product of legislative effort initiated by Mississippi loggers. The measure was passed with the support of the State Insurance Commissioner and state legislators. Florida and South Carolina are also working on logging WCI bills to reduce insurance costs. A similar national effort to define a mechanized logging classification is underway, sponsored by the American Pulpwood Association. As WCI rates begin to reflect the inherent safety of

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[1] Presented at the 12th Annual Council on Forest Engineering Meeting, Coeur d'Alene, ID, August 27-29, 1989.

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mechanized systems, there will be a greater effort to mechanize.

On another legislative front, the new OSHA logging safety standard was issued for public comment this spring. The primary modifications in the standard are: (1) extended coverage to all logging operations, (2) required safety equipment for chainsaw operations, and (3) mandatory operations, safety, and first aid training. While the impact on southern logging will be determined by the final form of the standard and its enforcement, the logging industry is taking note. The American Pulpwood Association is supporting the draft standard. Hopefully, successful implementation will improve the safety record of logging. The challenge for industry, however, is to develop effective training programs for loggers.

Concern about trucking safety has fueled interest in truck driver training workshops. As many as 5,000 logging truck drivers may have completed the combined safety and maintenance course that is being offered across the South by state associations and the American Pulpwood Association.

Environmental Concerns

The spotted owl problem has come to the South in the guise of the red-cockaded woodpecker. Environmentalist litigation in Texas has resulted in court-ordered forest management for the woodpecker on Forest Service lands in Texas. The court decision requires an 1100-acre area around each colony tree to be managed for the bird. At the present time, the Forest Service is drafting management guidelines to implement the judicial edict in most of the southern region. Although the details are not known at this time, the management guidelines will probably dictate longer rotations and some form of selective cutting in woodpecker management areas to generate the older stands the bird prefers. This issue will not stop at the Forest Service boundary. Already, actions are being brought for woodpecker management on a military reservation in Georgia. State land management agencies are keeping an eye on these developments. In addition to woodpecker areas, pressure is being brought on the Forest Service in the South to stop clearcutting. This is creating interest in single-tree and group selection harvesting. Restrictive harvesting guidelines will present forest engineering challenges to develop cost-effective, environmentally sound harvesting systems for these special areas.

Environmental interests are also evident in the development of regulations for timber harvesting at the state and county levels. Of particular concern are guidelines for harvesting sensitive sites such as wetlands. Most of the southern states have voluntary Best Management Practices (BMPs), but Virginia now requires a compliance inspection of all logging operations. If the logging industry fails to meet environmental guidelines based on a review of the compliance inspections, regulatory BMP's will be instituted. Florida is at a similar point, with 2-year audits of BMP compliance. The Chesapeake Bay area is an example of even more stringent local regulations. To minimize sedimentation of the Bay, areas which are in the Chesapeake watershed have strict timber harvesting guidelines which specify requirements such as buffer strips. The environmental impacts of timber harvesting in the South are being scrutinized and the possibility of enforced logging practices is on the horizon. The challenge for forest engineering in the South is the development of environmentally sound, cost-efficient harvesting systems for sensitive sites.

Southern Regional COFE

Another significant development in the southern region this year was the formation of a Southern Regional COFE group. A meeting was held in Auburn, Alabama in May The one-and-a-half day meeting consisted of three technical sessions with papers from industry, government researchers, and academia. Over 90 people attended the conference. The Southern Regional COFE was formally organized at a business meeting following the technical sessions.

1989--a year of success and growth as well as a year of new challenges for forest engineering in the South.

Pacific Northwest Regional Update[1]

Stephen P. Aulerich, P.E.[2]

TIMBER SUPPLY

Owls

The U.S. Fish and Wildlife Service (FWS) published in the Federal Register June 23, 1989 a proposal to list the northern spotted owl as "threatened" under the Endangered Species Act (USDA Forest Service 1989a). Until September 21, 1989 the FWS is asking for scientific information and public comments regarding the listing. The FWS will review and analyze the information and determine whether to list the owl as threatened by June 23, 1990. A six-month extension is also allowed.

When a species is proposed for listing, federal agencies must check with the FWS on any activities that may affect the continued existence of the species. The FWS has to review all timber sales that might affect owl habitat and provide recommendations.

On March 17, 1989 Seattle District Court Judge Dwyer granted a temporary restraining order on 140 Forest Service timber sales in spotted owl habitat (USDA Forest Service 1989b). On March 23, 1989 the court enjoined 140 sales, pending a hearing scheduled for June 13, 1989. The injunction effectively halted the sale of over half of Forest Service 1989 timber sales, or 2.5 billion board feet (Northwest Forest Resource Council 1989). On May 26, 1989 Judge Dwyer granted a Forest Service motion to stay all proceedings in the case, leaving the March 23rd injunction in place.

On March 29, 1989 Portland District Court Judge Frye granted a preliminary injunction halting old-growth timber sales within 2.1 miles of known spotted owl habitat sites on Bureau of Land Management lands (Corn 1989). A hearing is scheduled for August 17, 1989 (USDA Forest Service 1989b). The injunction remains in effect at the time of this writing (Renthal 1989)[3]. It effectively ties up 0.5 billion board feet (Northwest Forest Resource Council 1989).

Timber Summit

A timber summit called by Oregon Governor Neil Goldschmidt was held June 24 in Salem, Oregon. Industry representatives, federal agency officials, and preservationists met with Oregon's legislative delegation to discuss the complex issues relating to the current timber supply problem. A compromise proposal was introduced by the Oregon/Washington congressional delegation and was reluctantly accepted by industry, but rejected by the preservationists. The two-year compromise would have opened up some sales blocked by federal court injunctions and also would have exempted agreed-upon timber sales from lawsuits or administrative appeals.

Log Exports

The log export market continues to be strong. The Bush Administration has proposed lifting the ban on exporting logs from federal timberlands in order to increase federal revenues. Republican Senator Bob Packwood of Oregon has introduced legislation making the ban on exporting logs on federal timberlands permanent.

Log exports from state owned timberlands are presently allowed. Current legislation before Congress would permit states to restrict exports from state-owned lands. In June, Oregon passed Measure 2, which called for the ban of raw log exports from state-owned lands, but only if Congress permits.

Bid Prices

For the first three months of 1989 bid prices are exceeding the value of finished products, as mills are competing for available timber sales (Northwest Forest Resource Council 1989). The current supply situation has sent some sales above $600/MBF (Shelton 1989)[4].

Yellow Ribbons

Yellow ribbons are flying across the northwest to show support for the timber industry. Numerous rallies and log truck parades have been held to make the public and elected officials aware of the concerns of timber-dependent communities.

Tongass

On July 13, 1989 the U.S. House of Representatives passed legislation which would reduce the allowable sale quantity of the Tongass National Forest to less than half of its current management plan of 4.5 billion board feet per

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[1]Presented at the 12th Annual Council On Forest Engineering Meeting, Coeur d'Alene, ID, August 27-30, 1989.

[2]Vice-President, Forest Engineering Incorporated, Corvallis, OR.

[3]Personal communication from Jim Renthal, Bureau of Land Management, Medford, OR, August 11, 1989.

[4]Personal communication from Pam Shelton, USDA Forest Service, Willamette National Forest, Eugene, OR, August 14, 1989.

decade (Alaska Loggers Association 1989). The legislation mandates a 100-foot "no harvest zone" on all salmon streams and their tributaries; designates an additional 1.8 million acres of wilderness; and amends the Alaska National Interest Lands Conservation Act, which provided for an intensive management program on submarginal timber stands. The legislation also cancels the two existing long-term timber sale contracts established by Congress in the Tongass Timber Act of 1947.

NEW EQUIPMENT

Harvesting

Kootenay Manufacturing (Nelson, B.C.) has acquired the North American rights to manufacture and market the FMC models FT180 and 220 class tracked skidders.

Ross Corporation (Eugene, OR) introduced their Thunderbird hydraulic log loaders designed for loading logs or shovel logging at the 1989 Oregon Logging Conference.

Christy Manufacturing (Orofino, ID) recently introduced a radio-controlled clamping carriage. Eagle Truck & Machine (La Grande, OR) has added the "Golden Eagle" skycar to their line of motorized slack-pulling carriages (Baker 1989)[5]. Raven Carriage Corp. has developed a radio-controlled slack-pulling carriage, which is powered by two 12-volt batteries (Davis 1989)[6].

Chipping

Peterson Pacific Corp. (Pleasant Hill, OR) introduced their Model DDC 5000, which combines four functions in one machine (Peterson Pacific Corp. 1989). The machine loads itself, debarks, delimbs, and then chips whole trees.

Site Prep

Prescribed burning of slash continues to get public attention. With the ever-increasing pressures to reduce slash burns, D & M Machine Division (Montesano, WA) has introduced the "slashbuster," a brush-clearing attachment for excavators. It is currently clearing slash mechanically for planting sites on terrain negotiable with an hydraulic excavator (Marshall 1989)[7].

[5]Personal communication from Scotty Baker, Eagle Truck & Machine Co., La Grande, OR, July 6, 1989.

[6]Personal communication from Tom Davis, Raven Carriage Corp., Philomath, OR, February 2, 1989.

[7]Personal communication from William Marshall, D & M Machinery Inc., Montesano, WA, August 9, 1989.

WESTERN REGIONAL COFE

"Soil Compaction and Mechanized Harvesting" was the topic of a two-day meeting held June 22-23, 1989 in Redmond, Oregon, by the Western Regional subdivision of COFE. Approximately 80 people attended from federal, state, and private organizations.

Talks presented on the first day included the scientific basis for concern about compaction, the characteristics of soil types found in central Oregon, techniques and machines currently being used in mechanized harvesting, and concerns from timber sale purchasers on harvesting restrictions related to soil compaction.

The field trip on the second day visited areas to be logged as well as ones in the process of being logged. The field trip focused on specific problems and proposed solutions.

Bill Atkinson[8] summarizes the meeting as follows: "This session sparked a number of dialogues and debates among participants and indicated that we have a long way to go before everyone is happy about response to the compaction problem. Different timber-selling organizations respond to potential compaction in different ways, and even within organizations there is great variation. A good deal of confusion and misinformation exists on all sides. All in all, the sessions served to highlight areas of common concern and made an excellent start on the process of communication."

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[8]Personal communication from Bill Atkinson, Oregon State University, Corvallis, OR, August 14, 1989.

Sierra Cascade Regional Report[1]

Bruce R. Hartsough[2]

Abstract: California's forest industry is undergoing several transitions. Urban influences and smaller trees present difficult challenges, while an increasing number of biomass-fueled electric plants and interest in hardwoods and short rotation plantations for pulp provide new opportunities.

In spite of tales of it's imminent demise, the forest products industry is very much alive in California. The state still produces more lumber than any other except Oregon. Although the number of mills declined by 40 percent between 1976 and 1985, the remaining plants are larger and total employment is almost the same as it was a decade ago (Howard and Ward 1988).

Changes are taking place, and the industry does face several challenges, many of which engineers can help address.

THE URBAN-FORESTRY INTERFACE

California has the toughest Forest Practices Act in the country. In 1977, very few California timber harvest plans were protested by the public. In 1984, 5 percent of the plans on private land were appealed and this percentage appears to be increasing (Anon. 1988). Most of the protests are not from environmental groups, but from owners of lands adjacent to the proposed harvest units (Fortmann et al. 1986). Many of these landowners have migrated to the rural forested areas from urban settings.

Loggers in Santa Cruz County, close to the San Francisco Bay area, have successfully employed smaller equipment in carefully managed operations which appear to be more accepted at the urban interface. Similar operations or new, more acceptable methods will probably have to be adopted for harvesting in other parts of California.

Tighter restrictions on the use of herbicides and pesticides are in part related to the urban influence. The recently passed Proposition 65 will reduce the number of chemicals which can be applied, and public pressure is likely to limit when, where and how they can be used. To provide an alternative to chemical vegetation management, John Miles at U.C. Davis is studying mechanical methods to uproot brush in young plantations.

SMALL TREES

California has enjoyed the luxury of an abundance of old growth; until 1985 more than half of the volume of logs consumed in the state was cut from trees older than 100 years (Howard and Ward 1988). Now, however, the industry is feeling the effects of the transition to small logs. A survey a few years ago found almost no mechanized harvesting in the state. Today, 20 to 30 contractors employ feller/bunchers, delimbers and/or mechanical debarkers, and the number is growing. Much of the state's "flat" ground is relatively rugged, so steep terrain feller/bunchers are popular. In second-growth redwood, the close spacing of the coppice regeneration and extreme height of the trees has made feller/bunchers impractical. Some loggers are felling and bucking with chainsaws, then prebunching for grapple skidders with small loaders on crawler chassis.

On cable ground, more mobile yarders with two or three guylines are in use and anchor stumps are smaller, resulting in a high incidence of yarder overturns. A guyline tension monitor developed at U.C. Davis in cooperation with Oregon State University has been demonstrated in the woods, and several loggers have requested tests on their equipment. A non-contact tension sensor for running lines is also under development at Davis.

WOOD-FUELED POWER PLANTS

The number of wood-fueled electric generation facilities has increased drastically over the last decade, and total generation capacity may double to 400 MW between now and 1991, then level off (Anon. 1988; Edwards and Heinz 1985). The increases are results of the Public Utilities Regulatory Policy Act of 1978, as implemented in California. Prices for wood fuels are on the rise due to the expanding number of plants competing

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[1]Presented at the 12th Annual Council on Forest Engineering Meeting, Coeur d'Alene, ID, August 27-30, 1989.

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for the material. Delivered prices range as high as $30 to $50 per bone dry ton. Even with these figures, most forest residues are still too expensive to recover, but some materials are being chipped at roadside. Approximately fifteen woods contractors produced fuel chips during the past year (Hartsough 1989). Most operations use feller/bunchers, rubber-tired skidders and chippers. Chipping of whole trees is most common. Some integrated sawlog-fuel chip operations are at work, as are a few second-pass systems. One contractor, using a Llamma helicopter in combination with a chipper, has been removing 20 tons per acre in a second pass operation on a fire salvage sale.

Although several contractors have attempted to process tops and limbs, most have abandoned these efforts due to high costs. John Miles and others at U.C. Davis are developing a device to produce modules (large bales) of tops and limbs left by mechanical delimbers at log landings. Modules would be dried at the landing, then transported to the electric plant. The machine will be tested later this year.

Because of the artificially high prices for electricity, the demand for wood fuel in California will increase and remain high for the next decade. As a result, several new contractors are expected to enter the forest residue business this year. Fuel facilities are having difficulty meeting their needs at reasonable costs from sources within the State. One company has shipped mill residues by rail from Washington to Northern California, and another plans to barge material down the Pacific Coast to plants in Central California.

One company is considering hauling whole trees to their mill and using the tops, limbs and bark in their existing cogeneration plant. Although partly driven by fuel value, this policy would also avoid the increasing costs and restrictions placed on slash burning in the woods.

PULP, HARDWOODS AND SHORT ROTATION PLANTATIONS

Paper mills have never been major players in the California forest products industry, and essentially all their supply has come from sawmill softwood residues. Some mills are adding hardwood to their furnish, and more harvesting of the underutilized native hardwood resource is underway. Several fixed woodroom installations incorporating drum debarkers are installed or planned.

Eucalyptus, a fast-growing exotic, produces high quality fiber, so one company is planting 10,000 acres of drip-irrigated, fertilized stands on low site agricultural pasturelands. Other major companies have expressed interest. These plantations present challenges in establishment, cultural operations and harvesting.

Many small landowners have also planted eucalyptus, but their primary objective is firewood production. They may also be interested in producing pulp chips and/or selling residues to energy plants, but small tract size results in high move-in costs for conventional harvesting equipment. Lower cost methods are needed.

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